In an embodiment, the pixel circuit applies a voltage difference across the optically sensitive layer. The optically sensitive layer has a photoconductive gain when the voltage difference is applied and the optically sensitive layer is exposed to the light. The optically sensitive layer comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V). The responsivity is achieved when a bias is applied across the optically sensitive layer, wherein the bias is approximately in a range of 1 volt to 5 volts. The optically sensitive layer comprises monodisperse nanocrystals. The optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the common electrode. The nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores. The plurality of nanocrystal cores are fused. A physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles. The physical proximity includes a separation distance of less than approximately 0.5 nm. The electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles. The plurality of nanocrystal cores are electrically interconnected with linker molecules. The optically sensitive layer comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

Embodiments are directed to a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the substrate, the optically sensitive layer positioned to receive light; and a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a switching element between the charge store and the optically sensitive layer for the respective pixel region, the charge store and the switching element one or more of integrated on and integrated in the semiconductor substrate below the plurality of pixel regions. The switching element controls an integration period simultaneously for the plurality of pixel regions. Conductive material is positioned between the charge store of the respective pixel region and the optically sensitive layer of the corresponding pixel region such that the respective charge store is shielded from the light incident on the optically sensitive layer, wherein the light is in a wavelength band, wherein at least a portion of the conductive material is a metal layer in electrical communication with the optically sensitive layer. The switching element is a transistor, or a diode, or a parasitic diode.

In an embodiment, the photodetector comprises an opaque material between each pixel circuit and the corresponding pixel region, the opaque material shielding the charge store and the switching element from the light received by the optically sensitive layer. It comprises circuitry configured to simultaneously switch the switching element of each of the pixel regions. Each pixel region comprises a respective first electrode and a respective second electrode, wherein the optically sensitive layer of the respective pixel region is positioned between the respective first electrode and the respective second electrode of the respective pixel region. The pixel circuit transfers a voltage from the first electrode to the charge store when the switching element of the respective pixel region is in a first state and to block the transfer of the voltage from the first electrode to the charge store when the switching element of the respective pixel region is in a second state. It comprises circuitry to switch the switching element of each of the pixel circuits from a first state to a second state at the same time for each of the pixel circuits. It comprises circuitry to switch the switching element of each of the pixel circuits after an integration period of time.

In an embodiment, the photodetector comprises reset circuitry to reset a voltage difference across the optically sensitive layer while the switching element is in the second state. It comprises reset circuitry to initiate another integration period of time while the switching element is in the second state. The reset circuitry comprising at least one of a transistor, a diode, and a parasitic diode. The reset circuitry is configured to vary the voltage of the second electrode of each pixel region to reset the voltage difference across the optically sensitive layer. The reset circuitry resets the voltage difference across the optically sensitive layer after the end of a respective integration period and before all of the voltages transferred to the charge store for the respective integration period have been selected to be read out by the read out circuitry. The reset circuitry initiates a next subsequent integration period before all of the voltages transferred to the charge store for the prior integration period have been selected to be read out by the read out circuitry. It has a reset circuit having a first state to reset the voltage difference across the optically sensitive layer, a second state to integrate charge based on the flow of current across the optically sensitive layer, and a third state to transfer a voltage from the first electrode to the charge store. It has a first reset circuit to reset a voltage difference across the optically sensitive layer after the end of a respective integration period and a second reset circuit configured to reset the voltage of the charge store. The first reset circuit resets the voltage difference while the switching element is in the second state. The second reset circuit resets the charge store independently of the reset circuitry for the voltage difference across the optically sensitive layer. It has read out circuitry to read out a signal from the charge store for each pixel circuit corresponding to a selected row of pixel regions.

The photodetector has a read out circuit is one or more of integrated on and integrated in the semiconductor substrate below the plurality of pixel regions. The read out circuitry reads out sequential rows of the pixel regions.

The optically sensitive layer of each pixel region is positioned between a respective first electrode and a respective second electrode. A distance between the first electrode and the second electrode of each pixel region is less than approximately 3 micrometers, or less than approximately 2 micrometers, or less than approximately 1.5 micrometers. In an embodiment, the optically sensitive layer for each pixel region has a top surface area of less than approximately 6 square micrometers, or 5 square micrometers, or 4 square micrometers. The pixel circuit applies a voltage difference across the optically sensitive layer. The optically sensitive layer has a photoconductive gain when the voltage difference is applied and the optically sensitive layer is exposed to the light. The optically sensitive layer comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V). The responsivity is achieved when a bias is applied across the optically sensitive layer, wherein the bias is approximately in a range of 1 volt to 5 volts.

In an embodiment of the photodetector, the optically sensitive layer comprises monodisperse nanocrystals. The optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the common electrode. The nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores. The plurality of nanocrystal cores are fused. A physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles. The physical proximity includes a separation distance of less than approximately 0.5 nm. The electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles. The plurality of nanocrystal cores are electrically interconnected with linker molecules. The optically sensitive layer comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions over the semiconductor substrate, each pixel region comprising a respective first electrode, a respective second electrode and an optically sensitive layer between the first electrode and the second electrode; a pixel circuit for each pixel region, each pixel circuit comprising a charge store, a switching element between the charge store and the optically sensitive layer for the respective pixel region, and a read out circuit to sample a voltage from the charge store, the pixel circuit formed on the semiconductor substrate below the plurality of pixel regions; circuitry to switch the switching element for all of the pixel circuits at substantially the same time; wherein the distance between the respective first electrode and the respective second electrode for each respective pixel region is less than approximately 2 micrometers, and a top surface area of each pixel region is less than approximately 4 square micrometers; and wherein each pixel circuit is formed on a region of the semiconductor substrate below the plurality of pixel regions having an area less than or equal to the top surface area of the corresponding pixel region. It has a via between each respective pixel circuit and the corresponding pixel region. Each pixel region has a corresponding pixel circuit with dedicated read out circuit, wherein the dedicated read out circuit is separate from the read out circuit of the other pixel circuits. The area of the semiconductor substrate for each respective pixel circuit is positioned under a portion of the corresponding pixel region and a portion of an other pixel region that is not in electrical communication the respective pixel circuit.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions over the substrate, each pixel region comprising a respective first electrode, a respective second electrode and an optically sensitive layer between the first electrode and the second electrode; a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a switching element between the charge store and the first electrode for the respective pixel region; global shutter circuitry to switch the switching element for all of the pixel circuits at substantially the same time; and bias circuitry configured to change the voltage of the second electrode for each of the pixel regions at substantially the same time. The plurality of pixel regions includes pixel regions for a plurality of rows and a plurality of columns. Each pixel region includes a vertical stacked pixel, the vertical stacked pixel comprising at least two optically sensitive layers, the two optically sensitive layers comprising the optically sensitive layer and a second optically sensitive layer, the optically sensitive layer over at least a portion of the semiconductor substrate and the second optically sensitive layer over the optically sensitive layer. The global shutter circuitry switches the switching element for the two optically sensitive layers for all of the pixel circuits at substantially the same time. The global shutter circuitry controls an integration period simultaneously for the plurality of pixel regions. It has conductive material positioned between the charge store of the respective pixel region and the optically sensitive layer of the corresponding pixel region such that the respective charge store is shielded from the light incident on the optically sensitive layer, wherein the light is in a wavelength band, wherein at least a portion of the conductive material is a metal layer in electrical communication with the optically sensitive layer.

In an embodiment, the switching element is a transistor, a diode, or a parasitic diode. An opaque material between each pixel circuit and the corresponding pixel region, the opaque material shielding the charge store and the switching element from the light received by the optically sensitive layer. The pixel circuit transfers a voltage from the first electrode to the charge store when the switching element of the respective pixel region is in a first state and blocks the transfer of the voltage from the first electrode to the charge store when the switching element of the respective pixel region is in a second state. The global shutter circuitry controls switching of the switching element of each of the pixel circuits from a first state to a second state at the same time for each of the pixel circuits. The global shutter circuitry controls switching of the switching element of each of the pixel circuits after an integration period of time. It has reset circuitry to reset a voltage difference across the optically sensitive layer while the switching element is in the second state. It has reset circuitry to initiate another integration period of time while the switching element is in the second state. The reset circuitry comprising at least one of a transistor, a diode, and a parasitic diode. The reset circuitry is configured to vary the voltage of the second electrode of each pixel region to reset the voltage difference across the optically sensitive layer. The reset circuitry resets the voltage difference across the optically sensitive layer after the end of a respective integration period and before all of the voltages transferred to the charge store for the respective integration period have been selected to be read out by the read out circuitry. The reset circuitry initiates a next subsequent integration period before all of the voltages transferred to the charge store for the prior integration period have been selected to be read out by the read out circuitry.

In one embodiment, a photodetector has a reset circuit having a first state to reset the voltage difference across the optically sensitive layer, a second state to integrate charge based on the flow of current across the optically sensitive layer, and a third state to transfer a voltage from the first electrode to the charge store. It has a first reset circuit to reset a voltage difference across the optically sensitive layer after the end of a respective integration period and a second reset circuit configured to reset the voltage of the charge store. The first reset circuit resets the voltage difference while the switching element is in the second state. The second reset circuit resets the charge store independently of the reset circuitry for the voltage difference across the optically sensitive layer.

In one embodiment, a photodetector comprises read out circuitry to read out a signal from the charge store for each pixel circuit corresponding to a selected row of pixel regions. The read out circuit is one or more of integrated on and integrated in the semiconductor substrate below the plurality of pixel regions. The read out circuitry reads out sequential rows of the pixel regions. A distance between the first electrode and the second electrode of each pixel region is less than approximately 3 micrometers, or 2 micrometers, or 1.5 micrometers.

In an embodiment, the optically sensitive layer for each pixel region has a top surface area of less than approximately 6 square micrometers. The optically sensitive layer for each pixel region has a top surface area of less than approximately 5 square micrometers. The optically sensitive layer for each pixel region has a top surface area of less than approximately 4 square micrometers. The pixel circuit applies a voltage difference across the optically sensitive layer. The optically sensitive layer has a photoconductive gain when the voltage difference is applied and the optically sensitive layer is exposed to the light. The optically sensitive layer comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V). The responsivity is achieved when a bias is applied across the optically sensitive layer, wherein the bias is approximately in a range of 1 volt to 5 volts. The optically sensitive layer comprises monodisperse nanocrystals. The optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the common electrode. The nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores. The plurality of nanocrystal cores are fused. A physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles. The physical proximity includes a separation distance of less than approximately 0.5 nm. The electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles. The plurality of nanocrystal cores are electrically interconnected with linker molecules. The optically sensitive layer comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions over the substrate, each pixel region comprising a plurality of optically sensitive layers over the semiconductor substrate, each optically sensitive layer being positioned between a respective first electrode and a respective second electrode; a pixel circuit for each pixel region, each pixel circuit comprising a charge capture circuit for each optically sensitive layer of the corresponding pixel region, the charge capture circuit comprising a charge store and a switching element between the charge store and the first electrode for the respective optically sensitive layer of the corresponding pixel region; and global shutter circuitry to control the switching element of the charge capture circuit for each optically sensitive layer of each of the pixel regions at substantially the same time. Each pixel circuit is formed on the semiconductor substrate below the plurality of pixel regions. Each pixel circuit applies a voltage difference across the respective optically sensitive layer. The respective optically sensitive layer has a photoconductive gain when the voltage difference is applied and the optically sensitive layer is exposed to the light. The circuitry to control the switching element of the charge capture circuit for each optically sensitive layer of each of the pixel regions is global shutter circuitry. The global shutter circuitry controls an integration period simultaneously for the plurality of pixel regions. Conductive material positioned between the charge store of the respective pixel region and an optically sensitive layer of a corresponding pixel region such that the respective charge store is shielded from the light incident on the optically sensitive layer, wherein the light is in a wavelength band, wherein at least a portion of the conductive material is a metal layer in electrical communication with the optically sensitive layer.

In an embodiment, the photodetector comprises an opaque material between each pixel circuit and the corresponding pixel region, the opaque material shielding the charge store and the switching element from the light received by the optically sensitive layer. The pixel circuit transfers a voltage from the respective first electrode to the respective charge store when the switching element is in a first state and blocks the transfer of the voltage from the respective first electrode to the respective charge store when the switching element is in a second state. The global shutter circuitry controls switching of the switching element of each of the pixel circuits from a first state to a second state at the same time for each of the pixel circuits. The global shutter circuitry controls switching of the switching element of each of the pixel circuits after an integration period of time.

In one embodiment, a photodetector has reset circuitry to reset a voltage difference across each optically sensitive layer while the switching element is in the second state. It has reset circuitry to initiate another integration period of time while the switching element is in the second state. It has reset circuitry comprising at least one of a transistor, a diode, and a parasitic diode. The reset circuitry configured to vary the voltage of the respective second electrode of each corresponding pixel region to reset the voltage difference across the corresponding optically sensitive layer. The reset circuitry resets the voltage difference across the corresponding optically sensitive layer after the end of an integration period and before all of the voltages transferred to the charge store for the respective integration period have been selected to be read out by the read out circuitry. The reset circuitry initiates a next subsequent integration period before all of the voltages transferred to the charge store for the prior integration period have been selected to be read out by the read out circuitry. The reset circuit has a first state to reset the voltage difference across each optically sensitive layer, a second state to integrate charge based on the flow of current across each optically sensitive layer, and a third state to transfer a voltage from the respective first electrode to the respective charge store. It comprises read out circuitry to read out a signal from the charge store for each pixel circuit corresponding to a selected row of pixel regions. The read out circuit is one or more of integrated on and integrated in the semiconductor substrate below the plurality of pixel regions. The read out circuitry reads out sequential rows of the pixel regions. A distance between the first electrode and the second electrode of each pixel region is less than approximately 3 micrometers, or 2 micrometers, or 1.5 micrometers.

In an embodiment, he optically sensitive layer for each pixel region has a top surface area of less than approximately 6, or 5, or 4 square micrometers. The pixel circuit applies a voltage difference across an optically sensitive layer. At least one optically sensitive layer has a photoconductive gain when the voltage difference is applied and the optically sensitive layer is exposed to the light. At least one optically sensitive layer comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V).

In an embodiment, responsivity is achieved when a bias is applied across the optically sensitive layer, wherein the bias is approximately in a range of 1 volt to 5 volts. At least one optically sensitive layer comprises monodisperse nanocrystals. At least one optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the common electrode. The nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores. The plurality of nanocrystal cores are fused. A physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles. The physical proximity includes a separation distance of less than approximately 0.5 nm. The electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles. The plurality of nanocrystal cores are electrically interconnected with linker molecules. At least one optically sensitive layer comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

Embodiments are directed to an image sensor comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer creating a non-rectifying optically sensitive device, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer creating a non-rectifying optically sensitive device, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; a pixel circuit for each pixel region, each pixel circuit establishing a voltage over an integration period of time, wherein the voltage has a non-linear relationship with intensity of light absorbed by the optically sensitive layer of the respective pixel region. The pixel circuit comprises a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit providing a current flow through the respective optically sensitive layer, wherein a rate of the current flow through the respective optically sensitive layer has a non-linear relationship with intensity of the light absorbed by the optically sensitive layer. The pixel circuit comprises a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit providing a current flow through the respective optically sensitive layer, the current flow varying with a photoconductive gain of the optically sensitive layer, wherein the photoconductive gain has a non-linear relationship with intensity of the light absorbed by the optically sensitive layer. It has a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer comprising nanocrystals, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions; wherein a dark current of respective optically sensitive layers of respective pixel regions is different. The at least one adjacent layer comprises at least one metal. The at least one adjacent layer comprises at least one insulator. The at least one adjacent layer comprises at least one of a metal layer and an insulator layer. The at least one set of other pixel regions includes three other pixel regions. The at least one set of other pixel regions includes five other pixel regions. The at least one set of other pixel regions includes seven other pixel regions. Each pixel circuit is formed on the semiconductor substrate below the plurality of pixel regions.

In an embodiment each pixel circuit includes only a single transistor that is not shared with an other pixel circuit. Each pixel circuit shares an amplifier and at least one transistor to transfer a voltage from the pixel circuit. Each pixel circuit shares a source follower transistor and at least one transistor to transfer a voltage from the pixel circuit.

In an embodiment, each pixel circuit shares a read out transistor and at least one transistor to transfer a voltage from the pixel circuit.

In an embodiment, the pixel circuits corresponding to 16 pixel circuits comprise less than 25 transistors. The pixel circuits comprise a single non-shared transistor for each of 16 pixel regions and two read out transistors each shared by 8 pixel regions of the 16 pixel regions.

In an embodiment, the pixel circuits corresponding to 8 pixel circuits comprise less than 16 transistors. The pixel circuits comprise a single non-shared transistor for each of 8 pixel regions, and at least one read out transistor shared by the 8 pixel regions.

In an embodiment, he pixel circuits corresponding to 8 pixel circuits comprise at least two common transistors and each transistor has a single separate transistor between the optically sensitive layer and the at least two common transistors.

In an embodiment, the two common transistors comprise a reset transistor and a row select transistor to transfer a voltage to a row buffer.

In an embodiment, the two common transistors comprise a source follower transistor.

In an embodiment, each pixel region includes a respective first electrode and a common second electrode, wherein the optically sensitive layer adjoins the first electrode and the common second electrode, wherein the common second electrode is a common electrode for the plurality of pixel regions.

In an embodiment, the plurality of pixel regions including a vertical stacked pixel, the vertical stacked pixel comprising at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the semiconductor substrate and the second optically sensitive layer over the first optically sensitive layer.

In an embodiment, a pixel circuit for each pixel region includes a plurality of sets of the pixel circuits for the at least two optically sensitive layers.

In an embodiment, the plurality of sets of pixel circuits includes two sets of pixel circuits for two optically sensitive layers.

Embodiments include a photodetector comprising a semiconductor substrate; a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the substrate; a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit; and circuitry to select the charge store of a plurality of adjacent pixel regions for simultaneous reading to a shared read out circuit. The plurality of adjacent pixel regions includes two adjacent pixel regions. The plurality of adjacent pixel regions includes four adjacent pixel regions. The plurality of adjacent pixel regions includes 16 adjacent pixel regions.

In an embodiment, the plurality of adjacent pixel regions is a number of pixel regions, wherein the number is a multiple of two, or four, or eight, or sixteen.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions over the semiconductor substrate, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit; circuitry to electrically connect the first electrode for a set of pixel regions to a shared charge store during an integration period of time, the plurality of pixel regions including the set of pixel regions, wherein the shared charge store is the charge store corresponding to one pixel circuit of one pixel region; circuitry to read out a signal from the shared charge store, the signal based on intensity of light absorbed by each pixel region of the set of pixel regions during the integration period of time. The set of pixel regions includes two pixel regions.

In an embodiment, the set of pixel regions includes four pixel regions, or 16 pixel regions.

In an embodiment, the set of pixel regions includes a number of pixel regions, wherein the number is a multiple of two or a multiple of four, or a multiple of eight, or a multiple of sixteen.

Embodiments include a photodetector comprising: a semiconductor substrate; a plurality of pixel regions over the semiconductor substrate, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; pixel circuitry configured in a first mode to read out a signal for each pixel region based on the intensity of light absorbed by the optically sensitive layer of the respective pixel region, and configured in a second mode to read out a signal for a plurality of sets of pixel regions based on the intensity of light absorbed by the optically sensitive layers of each set of pixel regions. The pixel circuitry electrically connects the first electrode of each set of pixel regions to a common charge store for the respective set of pixel regions for an integration period of time.

In an embodiment, the pixel circuitry is configured in the first mode to electrically connect the first electrode of each pixel region to a separate charge store for an integration period of time and is configured in the second mode to electrically connect the first electrodes for each set of pixel regions to a shared charge store for the integration period of time.

In an embodiment, each set of pixel regions includes two pixel regions or four pixel regions. In an embodiment, each set of pixel regions includes 16 pixel regions. Each set of pixel regions includes a number of pixel regions, wherein the number is a multiple of two, or four, or eight, or sixteen.

Embodiments include a method comprising: providing a plurality of pixel regions, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; electronically selecting a set of the pixel regions, wherein the plurality of pixel regions includes the set of pixel regions; and reading out a signal from the set of the pixel regions, wherein the signal is based on intensity of light collectively absorbed by the optically sensitive layers of the set of pixel regions during the integration period of time.

Embodiments include a method comprising: providing a plurality of pixel regions, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; and selectively reading out a signal from a set of the pixel regions, the plurality of pixel regions including the set of pixel regions, the signal based on intensity of light absorbed by the optically sensitive layers of the set of pixel regions during an integration period of time.

Embodiments include a method comprising: providing a plurality of pixel regions, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; providing a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit; selectively controlling connection of the first electrode for a set of pixel regions to a shared charge store during an integration period of time, the plurality of pixel regions including the set of pixel regions, wherein the shared charge store is a charge store corresponding to one pixel circuit of one pixel region; and reading a signal from the shared charge store, the signal based on intensity of light collectively absorbed by the set of pixel regions during the integration period of time.

Embodiments include a method comprising: providing a plurality of pixel regions, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode; electronically selecting a set of the pixel regions, wherein the plurality of pixel regions includes the set of pixel regions; reading out signals from the set of the pixel regions; and generating an image using the signals, wherein the signals are based on intensity of light collectively absorbed by only the optically sensitive layers of the set of pixel regions and represent less than all pixel data available from the plurality of pixel regions.

Embodiments include a method comprising: exposing a plurality of pixel regions to light, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode, wherein an intensity of the light is below a minimum threshold for signal generation in a first pixel region of the pixel regions; providing a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit; selectively controlling connecting of the first electrode for a first set of the pixel regions to a shared charge store during an integration period of time, the first set of the pixel regions including the first pixel region and at least one adjacent pixel region, wherein the shared charge store is a charge store corresponding to a pixel circuit of the first set of the pixel regions; and reading out a signal from the first set of the pixel regions, wherein the signal is based on the intensity of light collectively absorbed by the optically sensitive layers of the first set of pixel regions during the integration period of time, wherein the intensity of the light collectively absorbed is above the minimum threshold.

Embodiments include a sensor comprising: at least one optically sensitive layer; and a circuit comprising at least one node in electrical communication with the optically sensitive layer, wherein the circuit stores an electrical signal proportional to the intensity of light incident on the optically sensitive layer during an integration period, wherein a non-linear relationship exists between electrical characteristics of the optically sensitive layer and the intensity of light absorbed by the optically sensitive layer, wherein a continuous function represents the non-linear relationship.

In an embodiment, at least one optically sensitive layer comprises closely-packed semiconductor nanoparticle cores.

In an embodiment, each core is partially covered with an incomplete shell, where the shell produces trap states having substantially a single time constant.

In an embodiment, the nanoparticle cores comprise PbS partially covered with a shell comprising PbSO3.

In an embodiment, the nanoparticle cores are passivated using ligands of at least two substantially different lengths.

In an embodiment, the nanoparticle cores are passivated using at least one ligand of at least one length.

In an embodiment, the nanoparticle cores are passivated and crosslinked using at least one crosslinking molecule of at least one length.

In an embodiment, the crosslinking molecule is a conductive crosslinker.

In an embodiment, each nanoparticle core is covered with a shell, where the shell comprises PbSO3.

In an embodiment, the nanoparticle cores comprise PbS that is partially oxidized and substantially lacking in PbSO4 (lead sulfate).

In an embodiment, at least one optically sensitive layer comprises a nanocrystalline solid, wherein at least a portion of a surface of the nanocrystalline solid is oxidized.

In an embodiment, a composition of the nanocrystalline solid excludes a first set of native oxides and includes a second set of native oxides.

In an embodiment, the first set of native oxides includes PbSO4 (lead sulfate) and the second set of native oxides includes PbSO3.

In an embodiment, trap states of the nanocrystalline solid provide persistence, wherein an energy to escape from a predominant trap state is less than or equal to approximately 0.1 eV.

In an embodiment, a non-predominant trap state, wherein an energy to escape from the non-predominant trap state is greater than or equal to approximately 0.2 eV.

In an embodiment, a continuous transparent layer, the continuous transparent layer comprising substantially transparent material, wherein the continuous transparent layer at least partially covers the optically sensitive layer.

In an embodiment, an adhesion layer anchoring constituents of the optically sensitive layer to circuitry of the integrated circuit.

In an embodiment, the second optically sensitive layer comprises a wavelength-selective light-absorbing material, wherein the first optically sensitive layer comprises a photoconductive material.

In an embodiment, an array of curved optical elements that determine a distribution of intensity across the optically sensitive layers.

In an embodiment, at least one optically sensitive layer comprises substantially fused nanocrystal cores having a dark current density less than approximately 0.1 nA/cm2.

In an embodiment, the circuit is an integrated circuit.

In an embodiment, a minimum feature spacing of the integrated circuit is in a range of approximately 100 nm to 200 um.

In an embodiment, the circuit is a complementary metal oxide semiconductor (CMOS) integrated circuit.

In an embodiment, a rate of the current flow through the optically sensitive layer has a non-linear relationship with the intensity of light absorbed by the optically sensitive layer.

In an embodiment, a gain of the optically sensitive layer has a non-linear relationship with the intensity of light absorbed by the optically sensitive layer.

In an embodiment, the optically sensitive layer has photoconductive gain when a voltage difference is applied across the optically sensitive layer and the optically sensitive layer is exposed to light.

In an embodiment, persistence of the optically sensitive layer is approximately in a range of 1 ms to 200 ms.

In an embodiment, the sensor is a non-rectifying device.

In an embodiment, the optically sensitive layer has a surface area determined by a width dimension and a length dimension.

In an embodiment, the width and/or length dimension is approximately 2 um. In an embodiment, the width dimension and/or length is less than approximately 2 um.

In an embodiment, the optically sensitive layer comprises a continuous film of interconnected nanocrystal particles.

In an embodiment, the nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores.

In an embodiment, the plurality of nanocrystal cores are fused.

In an embodiment, a physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles.

In an embodiment, the physical proximity includes a separation distance of less than approximately 0.5 nm.

In an embodiment, the electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles.

In an embodiment, the plurality of nanocrystal cores are electrically interconnected with linker molecules.

In an embodiment, the linker molecules include bidentate linker molecules. The linker molecules can include ethanedithiolor benzenedithiol.

In an embodiment, the optically sensitive layer comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type. The first carrier type is electrons or holes, and the second carrier type is holes or electrons.

In an embodiment, the optically sensitive layer comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V).

In an embodiment, the responsivity is achieved under a bias approximately in a range of 0.5 volts to 5 volts.

In an embodiment, the optically sensitive layer comprises nanocrystals of a material having a bulk bandgap, and wherein the nanocrystals are quantum confined to have an effective bandgap more than twice the bulk bandgap.

In an embodiment, the optically sensitive layer includes nanocrystals comprising nanoparticles, wherein a nanoparticle diameter of the nanoparticles is less than a Bohr exciton radius of bound electron-hole pairs within the nanoparticle.

In an embodiment, the optically sensitive layer comprises monodisperse nanocrystals.

In an embodiment, the optically sensitive layer comprises nanocrystals.

In an embodiment, the nanocrystals are colloidal quantum dots.

In an embodiment, the quantum dots include a first carrier type and a second carrier type, wherein the first carrier type is a flowing carrier and the second carrier type is one of a substantially blocked carrier and a trapped carrier.

In an embodiment, the colloidal quantum dots include organic ligands, wherein a flow of at least one of the first carrier type and the second carrier type is related to the organic ligands.

In an embodiment, the optically sensitive layer can be biased as both a current sink and a current source.

In an embodiment, at least a first metal layer and a second metal layer, the optically sensitive layer in electrical communication with the second metal layer.

In an embodiment, the at least two metal layers include metal interconnect layers.

In an embodiment, the second metal layer forms contacts in electrical communication with the optically sensitive layer.

In an embodiment, the contacts comprise an aluminum body, a first coating and a second coating, the first coating comprising titanium nitride and positioned between the aluminum body and the optically sensitive layer, the second coating comprising titanium oxynitride and positioned between the first coating and the optically sensitive layer.

In an embodiment, the contacts comprise an aluminum body, a first coating and a second coating, the first coating comprising titanium nitride and positioned between the aluminum body and the optically sensitive layer, the second coating located between the first coating and the optically sensitive layer and comprising a metal selected from the group consisting of gold, platinum, palladium, nickel and tungsten.

In an embodiment, the contacts are formed from a plurality of metal sub-layers, each metal sub-layer comprising a constituent selected from the group consisting of titanium nitride, titanium oxy nitride, gold, platinum, palladium, nickel and tungsten.

In an embodiment, the second metal layer consists of metal other than aluminum, the metal including at least one layer selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

In an embodiment, the second metal layer consists of metal other than copper, the metal including at least one layer selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

In an embodiment, the second metal layer comprises a constituent selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

In an embodiment, the optically sensitive layer makes direct contact with the second metal layer.

In an embodiment, the optically sensitive layer comprises a coating on the second metal layer.

In an embodiment, the metal layers comprise at least one additional metal layer between the first metal layer and the second metal layer.

In an embodiment, the first metal layer and the at least one additional metal layer comprises aluminum, wherein the at least one additional metal layer excludes aluminum.

In an embodiment, each of the first metal layer and the at least one additional metal layer comprises aluminum and titanium nitride, wherein the at least one additional metal layer excludes aluminum.

In an embodiment, each of the first metal layer and the at least one additional metal layer excludes aluminum.

In an embodiment, each of the first metal layer and the at least one additional metal layer excludes copper.

In an embodiment, the first metal layer has a first thickness dimension and the second metal layer has a second thickness dimension.

In an embodiment, the first metal layer has a first aspect ratio and the second metal layer has a second aspect ratio.

Embodiments include a sensor comprising: a first region of an optically sensitive material; and a second region of the optically sensitive material, the second region covering at least a portion of the first region; wherein the optically sensitive material creates a non-rectifying optically sensitive device, wherein a non-linear relationship exists between electrical characteristics of the optically sensitive material and the intensity of light absorbed by the optically sensitive material; wherein the first region and the second region possess substantially different spectral onset of absorption.

Embodiments include a sensor comprising: at least one optically sensitive layer; wherein a first region of the optically sensitive layer provides electronic signals corresponding to an intensity of light incident on the first region and lying within a first spectral region; wherein a second region of the optically sensitive layer provides electronic signals corresponding to the intensity of light incident on the second region and lying within a second spectral region. The first spectral region includes at least one of a visible spectral region, an X-ray spectral region, an ultraviolet (UV) spectral region, a near infrared (IR) (NIR) spectral region, a short-wavelength IR (SWIR) spectral region, and a mid-wavelength IR (MWIR) spectral region.

In an embodiment, the second spectral region includes at least one of a visible spectral region, an X-ray spectral region, an ultraviolet (UV) spectral region, a near infrared (IR) (NIR) spectral region, a short-wavelength IR (SWIR) spectral region, and a mid-wavelength IR (MWIR) spectral region

Embodiments include photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer.

Embodiments include a vertically stacked pixel, comprising: a plurality of optically sensitive layers including a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer overlying at least a portion of a first side of an integrated circuit and the second optically sensitive layer overlying at least a portion of a second side of the first optically sensitive layer; a plurality of electrodes, wherein the plurality of optically sensitive layers is interposed between a respective first electrode and a respective second electrode of the plurality of electrodes; and a coupling between the integrated circuit and the plurality of electrodes by which the integrated circuit selectively applies a bias and reads from the optically sensitive layers pixel information corresponding to light absorbed by the optically sensitive layers.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein at least one of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap, wherein the nanocrystals are quantum confined to have an effective bandgap more than twice the bulk bandgap.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein each of the at least two optically sensitive layers comprises nanocrystals of different materials and each of the different materials has a different bulk bandgap.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein each of the optically sensitive layers comprises nanocrystals having a different particle size.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a first increase in bandgap due to quantum confinement in the first optically sensitive layer is greater than a second increase in bandgap due to quantum confinement in the second optically sensitive layer.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a thickness of at least one optically sensitive layer is different from a thickness of at least one other optically sensitive layer.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein the first optically sensitive layer comprises a nanocrystal material having first photoconductive gain and the second optically sensitive layer comprises a nanocrystal material having a second photoconductive gain.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a dark current of at least one optically sensitive layer is different from a dark current of at least one other optically sensitive layer.

Embodiments are directed to a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a compensation applied to a signal from at least one optically sensitive layer is different from a compensation applied to a signal from at least one other optically sensitive layer.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a dark current compensation signal is received from a black pixel and separately and proportionally applied to signals of each optically sensitive layer.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a dark current compensation signal corresponding to each respective optically sensitive layer is received from a respective black pixel and applied to a respective signal of the respective optically sensitive layer.

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein a dark current of at least one optically sensitive layer is approximately in a range of 10 nanoamps (nA) per square centimeter (cm) to 500 nA per square cm.

Embodiments include a photodetector comprising: at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of a substrate and the second optically sensitive layer over the first optically sensitive layer; wherein at least one optically sensitive layer is a nanocrystal layer having a dark current approximately in a range of 10 nanoamps (nA) per square centimeter (cm) to 500 nA per square cm.

Embodiments are directed to a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein the first optically sensitive layer comprises a first composition including one of lead sulfide (PbS), lead selenide (PbSe), lead tellurium sulfide (PbTe), indium phosphide (InP), indium arsenide (InAs), and germanium (Ge), and the second optically sensitive layer comprises a second composition including one of indium sulfide (In_2S_3), indium selenide (In_2Se_3), indium tellurium (In_2Te_3), bismuth sulfide (Bi_2S_3), bismuth selenide (Bi_2Se_3), bismuth tellurium (Bi_2Te_3), indium phosphide (InP), silicon (Si), and germanium (Ge).

Embodiments include a photodetector comprising: an integrated circuit; and at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein the first optically sensitive layer comprises a nanocrystal material having an absorption onset at a first wavelength and the second optically sensitive layer comprises a nanocrystal material having an absorption onset at a second wavelength, wherein the first wavelength is shorter than the second wavelength, and a local absorption maximum is absent from an absorption spectrum of at least one of the first optically sensitive layer and the second optically sensitive layer.

Embodiments include a photodetector comprising: at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of an integrated circuit and the second optically sensitive layer over the first optically sensitive layer; wherein the first optically sensitive layer comprises a first absorption band including at least one first set of colors and is devoid of a local absorption maximum, and the second optically sensitive layer comprises a second absorption band including at least one second set of colors and is devoid of a local absorption maximum, wherein the second absorption band includes the first set of colors; wherein each optically sensitive layer is interposed between a respective first electrode and a respective second electrode; and wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers.

Embodiments include a photodetector comprising: an integrated circuit; and a plurality of optically sensitive layers including a first optically sensitive layer and a vertically stacked set of optically sensitive layers, the first optically sensitive layer in at least a portion of the integrated circuit and the vertically stacked set of optically sensitive layers over the first optically sensitive layer; wherein the vertically stacked optically sensitive layer is interposed between a respective first electrode and a respective second electrode; wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the vertically stacked optically sensitive layers, wherein the signal is related to the number of photons received by the respective vertically stacked optically sensitive layer.

Embodiments include a pixel array comprising a plurality of photodetectors, wherein each photodetector is a vertically stacked pixel, the vertically stacked pixel comprising: at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; and a plurality of electrodes including at least two electrodes between which the two optically sensitive layers are interposed, the electrodes including a respective first electrode and a respective second electrode; a coupling between the integrated circuit and the plurality of electrodes by which the integrated circuit selectively applies a bias and reads from the optically sensitive layers pixel information corresponding to light absorbed by the optically sensitive layers.

Embodiments are directed to a photosensor array comprising: an integrated circuit; and a plurality of photodetectors over the integrated circuit, wherein each photodetector forms a vertically stacked pixel that comprises, at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; and wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode, wherein the integrated circuit is coupled to the electrodes and selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signals are related to the number of photons received by the respective optically sensitive layer.

In an embodiment, he signal represents light absorbed by at least one optically sensitive layer. The signal can be a voltage proportional to light absorbed by at least one optically sensitive layer. The respective first electrode and second electrode for the first optically sensitive layer are different electrodes than the respective first electrode and second electrode for the second optically sensitive layer.

In an embodiment, the respective first electrode for the first optically sensitive layer is a different electrode than the respective first electrode for the second optically sensitive layer.

In an embodiment, the second respective electrode for the second optically sensitive layer is a common electrode common to both the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, each respective first electrode is in contact with the respective first optically sensitive layer.

In an embodiment, each respective second electrode is in contact with the respective second optically sensitive layer.

In an embodiment, each respective first electrode is positioned laterally relative to at least a portion of the respective second electrode.

In an embodiment, at least a portion of each respective second electrode is on the same layer of the integrated circuit as the respective first electrode and the respective optically sensitive layer.

In an embodiment, the respective second electrode for the first optically sensitive layer and the second optically layer comprises a common electrode.

In an embodiment, the common electrode extends vertically from the first optically sensitive layer to the second optically sensitive layer.

In an embodiment, the common electrode extends vertically from the integrated circuit along a portion of the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, each respective second electrode is disposed around the respective first electrode.

In an embodiment, the respective second electrode is configured to provide a barrier to carriers around the first electrode.

In an embodiment, the respective second electrode for the first optically sensitive layer and the second optically sensitive layer comprises a common electrode disposed around the first electrode.

In an embodiment, the common electrode extends vertically from the integrated circuit.

In an embodiment, the second electrode is at least partially transparent and is positioned over the respective optically sensitive layer.

In an embodiment, the respective first electrode and the respective second electrode are non-transparent and separated by a distance corresponding to a width dimension and a length dimension.

In an embodiment, the width and/or length dimension is approximately 2 um.

In an embodiment, the width and/or length dimension is less than approximately 2 um.

In an embodiment, the respective second electrode for the first optically sensitive layer and the second electrode for the second optically sensitive layer is a common electrode for both the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, the at least two optically sensitive layers includes a third optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive layer, wherein the respective second electrode for the first optically sensitive layer, the second electrode for the second optically sensitive layer and the third electrode for the third layer is a common electrode for the first optically sensitive layer, the second optically sensitive layer and the third layer, wherein the common electrode is non-transparent.

In an embodiment, a third optically sensitive layer integrated in the integrated circuit, wherein the respective second electrode for the first optically sensitive layer and the second electrode for the second optically sensitive layer is a common electrode for both the first optically sensitive layer and the second optically sensitive layer, wherein the respective second electrode for the third layer is different from the common electrode.

In an embodiment, at least one optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the respective second electrode.

In an embodiment, the nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores.

In an embodiment, the plurality of nanocrystal cores are fused.

In an embodiment, a physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles.

In an embodiment, the physical proximity includes a separation distance of less than approximately 0.5 nm.

In an embodiment, the electrical communication includes a hole mobility of at least approximately 1E-5 square centimeter per volt-second across the nanocrystal particles.

In an embodiment, the plurality of nanocrystal cores are electrically interconnected with linker molecules.

In an embodiment, the linker molecules include bidentate linker molecules.

In an embodiment, the linker molecules include ethanedithiol, or benzenedithiol.

In an embodiment, at least one of the optically sensitive layers comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

In an embodiment, the respective second electrode for the first optically sensitive layer and the second optically layer comprises a common electrode extending vertically from the first optically sensitive layer to the second optically sensitive layer.

In an embodiment, a thickness of the second optically sensitive layer is different than a thickness of the first optically sensitive layer.

In an embodiment, a thickness of the first optically sensitive layer is less than a thickness of the second optically sensitive layer.

In an embodiment, a thickness of the second optically sensitive layer is less than a thickness of the first optically sensitive layer.

In an embodiment, persistence of each of the optically sensitive layers is approximately equal.

In an embodiment, persistence of each of the optically sensitive layers is longer than approximately 1 millisecond (ms), or in a range of 1 ms to 30 ms, or in a range of 1 ms to 100 ms, or in a range of 1 ms to 200 ms, or in a range of 10 ms to 50 ms.

In an embodiment, at least one optically sensitive layer comprises closely-packed semiconductor nanoparticle cores. Each core is partially covered with an incomplete shell, where the shell produces trap states having substantially a single time constant. The nanoparticle cores comprise PbS partially covered with a shell comprising $PbSO_3$. The nanoparticle cores are passivated using ligands of at least two substantially different lengths. The nanoparticle cores are passivated using at least one ligand of at least one length. The nanoparticle cores are passivated and crosslinked using at least one crosslinking molecule of at least one length. The crosslinking molecule is a conductive crosslinker. Each nanoparticle core is covered with a shell, where the shell comprises $PbSO_3$. The nanoparticle cores comprise PbS that is partially oxidized and substantially lacking in $PbSO_4$ (lead sulfate).

In an embodiment, at least one optically sensitive layer comprises a nanocrystalline solid, wherein at least a portion of a surface of the nanocrystalline solid is oxidized.

In an embodiment, a composition of the nanocrystalline solid excludes a first set of native oxides and includes a second set of native oxides.

In an embodiment, the first set of native oxides includes $PbSO_4$ (lead sulfate) and the second set of native oxides includes $PbSO_3$.

In an embodiment, trap states of the nanocrystalline solid provide persistence, wherein an energy to escape from a predominant trap state is less than or equal to approximately 0.1 eV.

In an embodiment, a non-predominant trap state, wherein an energy to escape from the non-predominant trap state is greater than or equal to approximately 0.2 eV.

In an embodiment, a continuous transparent layer, the continuous transparent layer comprising substantially transparent material, wherein the continuous transparent layer at least partially covers the optically sensitive layer.

In an embodiment, an adhesion layer anchoring constituents of the optically sensitive layer to circuitry of the integrated circuit.

In an embodiment, the second optically sensitive layer comprises a wavelength-selective light-absorbing material, wherein the first optically sensitive layer comprises a photoconductive material.

In an embodiment, an array of curved optical elements that determine a distribution of intensity across the optically sensitive layers.

In an embodiment, at least one optically sensitive layer comprises substantially fused nanocrystal cores having a dark current density less than approximately 0.1 nA/cm2.

In an embodiment, a thickness of the second optically sensitive layer is less than a thickness of the first optically sensitive layer.

In an embodiment, the second optically sensitive layer is relatively completely absorbent of light in a first wavelength interval and relatively completely transmissive of light outside the first wavelength interval.

In an embodiment, the first optically sensitive layer is relatively completely absorbent of the light outside the first wavelength interval. The first wavelength interval corresponds to blue light. A second dark current of the second optically sensitive layer is less than a first dark current of the first optically sensitive layer.

In an embodiment, responsivities of each of the optically sensitive layers are approximately equal.

In an embodiment, the first optically sensitive layer comprises a first material having a first thickness, and the combination of the first material and the first thickness provides a first responsivity to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and the combination of the second material and the second thickness provides a second responsivity to light of a second wavelength, wherein the first responsivity and the second responsivity are approximately equal.

In an embodiment, the first optically sensitive layer comprises a first material having a first thickness, and the combination of the first material and the first thickness provides a first photoconductive gain to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and the combination of the second material and the second thickness provides a second photoconductive gain to light of a second wavelength, wherein the first photoconductive gain and the second photoconductive gain are approximately equal.

In an embodiment, the first optically sensitive layer comprises a first material having a first thickness, and the combination of the first material and the first thickness provides a first absorbance to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and the combination of the second material and the second thickness provides a second absorbance to light of a second wavelength, wherein the first absorbance and the second absorbance are approximately equal.

In an embodiment, gains of each of the optically sensitive layers are approximately equal. The persistence of each of the optically sensitive layers is approximately equal.

In an embodiment, a thickness of the first optically sensitive layer is less than a thickness of the second optically sensitive layer.

In an embodiment, the at least two optically sensitive layers includes a third optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive, wherein a thickness of the third optically sensitive layer is less than a thickness of the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, a thickness of the third optically sensitive layer is less than a thickness of the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, a thickness of the second optically sensitive layer is less than a thickness of the first optically sensitive layer.

In an embodiment, the third optically sensitive layer is relatively completely absorbent of light in a first wavelength interval and relatively completely transmissive of light outside the first wavelength interval

In an embodiment, the second optically sensitive layer is relatively completely absorbent of light in a second wavelength interval and relatively completely transmissive of light outside the second wavelength interval, wherein the second wavelength interval includes and is larger than the first wavelength interval.

In an embodiment, the first optically sensitive layer is relatively completely absorbent of light in a third wavelength interval, wherein the third wavelength interval includes and is larger than the second wavelength interval.

In an embodiment, a third dark current of the third optically sensitive layer is less than a second dark current of the second optically sensitive layer.

In an embodiment, a third dark current of the third optically sensitive layer is less than a first dark current of the first optically sensitive layer.

In an embodiment, a second dark current of the second optically sensitive layer is less than a first dark current of the first optically sensitive layer.

In an embodiment, at least two optically sensitive layers includes a fourth optically sensitive layer, wherein the fourth optically sensitive layer is over at least a portion of the third optically sensitive layer, wherein a thickness of the fourth optically sensitive layer is less than a thickness of one of the first optically sensitive layer, the second optically sensitive layer, and the third optically sensitive layer.

In an embodiment, a thickness of the fourth optically sensitive layer is less than a thickness of the third optically sensitive layer.

In an embodiment, a thickness of the third optically sensitive layer is less than a thickness of the second optically sensitive layer.

In an embodiment, a thickness of the second optically sensitive layer is less than a thickness of the first optically sensitive layer.

In an embodiment, the fourth optically sensitive layer is relatively completely absorbent of light in a first wavelength interval and relatively completely transmissive of light outside the first wavelength interval

In an embodiment, the third optically sensitive layer is relatively completely absorbent of light in a third wavelength interval and relatively completely transmissive of light outside the third wavelength interval, wherein the third wavelength interval includes and is larger than the fourth wavelength interval.

In an embodiment, the second optically sensitive layer is relatively completely absorbent of light in a second wavelength interval, wherein the second wavelength interval includes and is larger than the third wavelength interval.

In an embodiment, the first optically sensitive layer is relatively completely absorbent of light in a first wavelength interval, wherein the first wavelength interval includes and is larger than the second wavelength interval.

In an embodiment, a fourth dark current of the fourth optically sensitive layer is less than at least one of a third dark current of the third optically sensitive layer, a second dark current of the second optically sensitive layer, and a first dark current of the first optically sensitive layer.

In an embodiment, a third dark current of the third optically sensitive layer is less than at least one of a fourth dark current of the fourth optically sensitive layer, a second dark current of the second optically sensitive layer, and a first dark current of the first optically sensitive layer.

In an embodiment, a second dark current of the second optically sensitive layer is less than at least one of a fourth dark current of the fourth optically sensitive layer, a third dark current of the third optically sensitive layer, and a first dark current of the first optically sensitive layer.

In an embodiment, a first dark current of the first optically sensitive layer is less than at least one of a fourth dark current of the fourth optically sensitive layer, a third dark current of the third optically sensitive layer, and a second dark current of the second optically sensitive layer.

In an embodiment, at least one of the optically sensitive layers comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

In an embodiment, the first carrier type is electrons and the second carrier type is holes.

In an embodiment, the first carrier type is holes and the second carrier type is electrons.

In an embodiment, each of the optically sensitive layers comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

In an embodiment, the first carrier type is electrons and the second carrier type is holes.

In an embodiment, the first carrier type is holes and the second carrier type is electrons.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having first photoconductive gain and the second optically sensitive layer comprises a nanocrystal material having a second photoconductive gain.

In an embodiment, at least one of the optically sensitive layers comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V).

In an embodiment, the responsivity is achieved when a bias is applied between the respective first electrode and the respective second electrode, wherein the bias is approximately in a range of 1 volt to 5 volts. In an embodiment, the bias is approximately 0.5 volts, 1 volt, 1.2 volts, or 1.5 volts.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having first photoconductive gain and a first responsivity approximately in a range of 0.4 A/V to 100 A/V.

In an embodiment, the second optically sensitive layer comprises a nanocrystal material having a second photoconductive gain and a second responsivity approximately in a range of 0.4 A/V to 100 A/V.

In an embodiment, the second photoconductive gain is greater than the first photoconductive gain.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap, and wherein the nanocrystals are quantum confined to have an effective bandgap more than twice the bulk bandgap.

In an embodiment, at least one of the optically sensitive layers includes nanocrystals comprising nanoparticles, wherein a nanoparticle diameter of the nanoparticles is less than a Bohr exciton radius of bound electron-hole pairs within the nanoparticle.

In an embodiment, a first diameter of nanocrystals of the first optically sensitive layer is greater than a second diameter of nanocrystals of the second optically sensitive layer.

In an embodiment, a first diameter of nanocrystals of the first optically sensitive layer is less than a second diameter of nanocrystals of the second optically sensitive layer.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than approximately 0.5 electron volts (eV), and wherein the nanocrystals are quantum confined to have a bandgap more than 1.0 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 490 nm wavelength and approximately 2.5 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 560 nm wavelength and approximately 2.2 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 700 nm wavelength and approximately 1.8 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 1000 nm wavelength and approximately 1.2 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 1400 nm wavelength and approximately 0.9 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals quantum confined to a bandgap corresponding to 1700 nm wavelength and approximately 0.7 eV.

In an embodiment, at least one of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap approximately in a spectral range of 700 nanometer (nm) wavelength to 10 micrometer (um) wavelength, and wherein the nanocrystals are quantum confined to have a bandgap approximately in a spectral range of 400 nm to 700 nm.

In an embodiment, at least one of the optically sensitive layers comprises quantum confined nanocrystals having a diameter of less than approximately 1.5 nm.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than 0.5 eV, and wherein the nanocrystals in the first optically sensitive layer are quantum confined to have a bandgap of approximately 2.2 eV and the nanocrystals in the second optically sensitive layer are quantum confined to have a bandgap of more than approximately 2.5 eV.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than approximately 0.5 eV.

In an embodiment, the nanocrystals of the second optically sensitive layer are quantum confined to a bandgap corresponding to 490 nm wavelength.

In an embodiment, the nanocrystals of the second optically sensitive layer are quantum confined to a bandgap of approximately 2.5 eV.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap corresponding to 560 nm wavelength.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap of approximately 2.2 eV.

In an embodiment, a photoconductive component in the integrated circuit, wherein the photoconductive component is optically sensitive in a spectral range of 700 nm to 10 um wavelength.

In an embodiment, the at least two optically sensitive layers include a third optically sensitive layer.

In an embodiment, the third optically sensitive layer is on the integrated circuit.

In an embodiment, the third optically sensitive layer is integrated with the integrated circuit.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than 0.5 eV.

In an embodiment, the nanocrystals in the first optically sensitive layer are quantum confined to have a bandgap of approximately 2.2 eV and the nanocrystals in the second optically sensitive layer are quantum confined to have a bandgap of more than approximately 2.5 eV.

In an embodiment, the third optically sensitive layer senses light approximately in a spectral range of 700 nm to 10 um wavelength and the nanocrystals in the third optically sensitive layer are quantum confined to have a bandgap of more than approximately 1.8 eV.

In an embodiment, the third optically sensitive layer is a silicon photodiode.

In an embodiment, the at least two optically sensitive layers includes a third optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive layer.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than 0.5 eV, and wherein the nanocrystals in the first optically sensitive layer are quantum confined to have a bandgap of approximately 1.8 eV, the nanocrystals in the second optically sensitive layer are quantum confined to have a bandgap of approximately 2.2 eV, and the nanocrystals in the third optically sensitive layer are quantum confined to have a bandgap of more than approximately 2.5 eV.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than approximately 0.5 eV.

In an embodiment, the nanocrystals of the third optically sensitive layer are quantum confined to a bandgap corresponding to 490 nm wavelength.

In an embodiment, the nanocrystals of the third optically sensitive layer are quantum confined to a bandgap of approximately 2.5 eV.

In an embodiment, the nanocrystals of the second optically sensitive layer are quantum confined to a bandgap corresponding to 560 nm wavelength.

In an embodiment, nanocrystals of the second optically sensitive layer are quantum confined to a bandgap of approximately 2.2 eV.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap of approximately 1.8 eV, or 1.2 eV, or 0.9 eV, or 0.7 eV.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap corresponding to 650, or 700, or 800, or 900, or 1000, or 1300, or 1650 nm wavelength.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap corresponding to 3 um or 5 um wavelength.

In an embodiment, the at least two optically sensitive layers includes a third optically sensitive layer and a fourth optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive layer and the fourth optically sensitive layer is over at least a portion of the third optically sensitive layer.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than 0.5 eV, and wherein the nanocrystals in the first optically sensitive layer are quantum confined to have a bandgap corresponding to approximately 800 nm wavelength, the nanocrystals in the second optically sensitive layer are quantum confined to have a bandgap corresponding to approximately 630 nm wavelength, the nanocrystals in the third optically sensitive layer are quantum confined to have a bandgap corresponding to approximately 560 nm wavelength, and the nanocrystals in the fourth optically sensitive layer are quantum confined to have a bandgap corresponding to approximately 490 nm wavelength.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap of less than approximately 0.5 eV.

In an embodiment, the nanocrystals of the fourth optically sensitive layer are quantum confined to a bandgap corresponding to 490 nm wavelength.

In an embodiment, the nanocrystals of the fourth optically sensitive layer are quantum confined to a bandgap of approximately 2.5 eV.

In an embodiment, the nanocrystals of the third optically sensitive layer are quantum confined to a bandgap corresponding to 560 nm wavelength.

In an embodiment, the nanocrystals of the third optically sensitive layer are quantum confined to a bandgap of approximately 2.2 eV.

In an embodiment, the nanocrystals of the second optically sensitive layer are quantum confined to a bandgap corresponding to 630, or 650, or 670, or 700 nm wavelength.

In an embodiment, the nanocrystals of the second optically sensitive layer are quantum confined to a bandgap of approximately 1.8 eV.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap corresponding to 800, or 900, or 1000, or 1300, or 1650 nm wavelength.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap corresponding to 3 um or 5 um wavelength.

In an embodiment, the nanocrystals of the first optically sensitive layer are quantum confined to a bandgap of approximately 1.2 eV, 0.9 eV, or 0.7 eV.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of the same material.

In an embodiment, at least one of the optically sensitive layers comprises monodisperse nanocrystals.

In an embodiment, the nanocrystals are colloidal quantum dots.

In an embodiment, the quantum dots include a first carrier type and a second carrier type, wherein the first carrier type is a flowing carrier and the second carrier type is one of a substantially blocked carrier and a trapped carrier.

In an embodiment, the colloidal quantum dots include organic ligands, wherein a flow of at least one of the first carrier type and the second carrier type is related to the organic ligands.

In an embodiment, each of the optically sensitive layers comprises nanocrystals of different materials, wherein the first optically sensitive layer includes a first material having a first bulk bandgap and the second optically sensitive layer includes a second material having a second bulk bandgap.

In an embodiment, the first material comprises nanoparticles having a first diameter and the second material comprises nanoparticles having a second diameter.

In an embodiment, the first diameter is greater than or less than the second diameter.

In an embodiment, the first bulk bandgap is higher than the second bulk bandgap.

In an embodiment, the first optically sensitive layer comprises a composition including lead sulfide (PbS), or lead selenide (PbSe), or lead tellurium (PbTe), or indium phosphide (InP), or indium arsenide (InAs), or germanium (Ge).

In an embodiment, the second optically sensitive layer comprises a composition including indium sulfide (In_2S_3), or indium selenide (In_2Se_3), or indium tellurium (In_2Te_3), or bismuth sulfide (Bi_2S_3), or bismuth selenide (Bi_2Se_3), or bismuth tellurium (Bi_2Te_3), or indium phosphide (InP), or silicon (Si), or germanium (Ge), or gallium arsenide (GaAs).

In an embodiment, the first optically sensitive layer comprises a first composition including one of lead sulfide (PbS), lead selenide (PbSe), lead tellurium sulfide (PbTe), indium phosphide (InP), indium arsenide (InAs), and germanium (Ge), and the second optically sensitive layer comprises a second composition including one of indium sulfide (In_2S_3), indium selenide (In_2Se_3), indium tellurium (In_2Te_3), bismuth sulfide (Bi_2S_3), bismuth selenide (Bi_2Se_3), bismuth tellurium (Bi_2Te_3), indium phosphide (InP), silicon (Si), and germanium (Ge).

In an embodiment, each of the optically sensitive layers comprises different compound semiconductor nanocrystals, wherein the first optically sensitive layer comprises a composition including lead and the second optically sensitive layer comprises a composition including one of indium and bismuth.

In an embodiment, each of the optically sensitive layers comprises different compound semiconductor nanocrystals, wherein the second optically sensitive layer comprises a composition including cadmium selenide (CdSe).

In an embodiment, the first optically sensitive layer comprises a composition including lead sulfide (PbS), or lead selenide (PbSe), or indium phosphide (InP), or germanium (Ge).

In an embodiment, each of the optically sensitive layers comprises different compound semiconductor nanocrystals, wherein the first optically sensitive layer comprises a composition including one of lead sulfide (PbS), lead selenide (PbSe), indium phosphide (InP), and germanium (Ge), wherein the second optically sensitive layer comprises a composition including cadmium selenide (CdSe).

In an embodiment, each of the optically sensitive layers comprises nanocrystals of a different particle size.

In an embodiment, nanocrystal particles of the first optically sensitive layer are larger than nanocrystal particles of the second optically sensitive layer.

In an embodiment, nanocrystal particles of the first optically sensitive layer are smaller than nanocrystal particles of the second optically sensitive layer.

In an embodiment, a first bulk bandgap of the first optically sensitive layer is higher than a second bulk bandgap of the second optically sensitive layer.

In an embodiment, a first increase in bandgap due to quantum confinement in the first optically sensitive layer is greater than a second increase in bandgap due to quantum confinement in the second optically sensitive layer.

In an embodiment, the first optically sensitive layer comprises a composition including lead sulfide (PbS), or lead selenide (PbSe), or tellurium sulfide (TeS), or indium phosphide (InP), or indium arsenide (InAs), or germanium (Ge).

In an embodiment, the second optically sensitive layer comprises a composition including indium sulfide (In_2S_3), or indium selenide (In_2Se_3), or indium tellurium (In_2Te_3), or bismuth sulfide (Bi_2S_3), or bismuth selenide (Bi_2Se_3), or bismuth tellurium (Bi_2Te_3), or indium phosphide (InP), or silicon (Si), or germanium (Ge), or gallium arsenide (GaAs).

In an embodiment, the first optically sensitive layer comprises a first composition including one of lead sulfide (PbS), lead selenide (PbSe), lead tellurium sulfide (PbTe), indium phosphide (InP), indium arsenide (InAs), and germanium (Ge), and the second optically sensitive layer comprises a second composition including one of indium sulfide (In_2S_3), indium selenide (In_2Se_3), indium tellurium (In_2Te_3), bismuth sulfide (Bi_2S_3), bismuth selenide (Bi_2Se_3), bismuth tellurium (Bi_2Te_3), indium phosphide (InP), silicon (Si), and germanium (Ge).

In an embodiment, the second optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 490 nm wavelength and the first optically sensitive layer comprises a nanocrystal material having an absorption onset of less than approximately 560 nm wavelength, wherein a local absorption maximum is absent from an absorption spectrum of at least one of the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, the second optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light and transmissive to visible red light, and the first optically sensitive layer comprises a nanocrystal material absorptive to at least visible red light, visible green light and visible blue light.

In an embodiment, the at least two optically sensitive layers includes a third optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive layer, wherein a local absorption maximum is absent from an absorption spectrum of at least one of the first optically sensitive layer, the second optically sensitive layer, and the third optically sensitive layer.

In an embodiment, the third optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 490 nm wavelength and the second optically sensitive layer comprises a nanocrystal material having an absorption onset of less than approximately 560 nm wavelength.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 650, or 700, or 750, or 800, or 900, or 1000, or 1300, or 1650 nm wavelength.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 3 um or 5 um wavelength.

In an embodiment, the third optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light and transmissive to visible green light, visible red light, and infrared light, the second optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light and visible green light and transmissive to visible red light and infrared light, and the first optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light, visible green light, and visible red light.

In an embodiment, the first optically sensitive layer is absorptive to infrared light. The embodiment further comprising a fourth optically sensitive layer over at least a portion of the third optically sensitive layer

In an embodiment, a local absorption maximum is absent from an absorption spectrum of at least one of the first optically sensitive layer, the second optically sensitive layer, the third optically sensitive layer, and the fourth optically sensitive layer.

In an embodiment, the fourth optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 490 nm wavelength.

In an embodiment, the third optically sensitive layer comprises a nanocrystal material having an absorption onset of less than approximately 560 nm wavelength.

In an embodiment, the second optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 630 nm, or 650 nm, or 670, or 700 nm wavelength.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 800 nm, or 900 nm, or 1000 nm, or 1300, or 1650 nm wavelength.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having an absorption onset at approximately 3 um or 5 um wavelength.

In an embodiment, the fourth optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light and transmissive to visible green light, visible red light, and infrared light.

In an embodiment, the third optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light and visible green light and transmissive to visible red light and infrared light.

In an embodiment, the second optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light, visible green light, and visible red light.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material absorptive to at least visible blue light, visible green light, visible red light and infrared light.

In an embodiment, a third optically sensitive layer, the third optically sensitive layer comprising a doped silicon region on a substrate of the integrated circuit, the third optically sensitive layer positioned below the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, a third optically sensitive layer, the third optically sensitive layer comprising a doped silicon region integrated with a substrate of the integrated circuit, the third optically sensitive layer positioned below the first optically sensitive layer and the second optically sensitive layer.

In an embodiment, a rate of the current flow through an optically sensitive material of at least one optically sensitive layer has a non-linear relationship with intensity of the light absorbed by the optically sensitive material.

In an embodiment, gain of an optically sensitive material of at least one optically sensitive layer has a non-linear relationship with intensity of the light absorbed by the optically sensitive material.

Embodiments are directed to a photodetector wherein the bias comprises:

biasing the optically sensitive layers to operate as a current sink during a first period of time; and biasing the optically sensitive material to operate as a current source during a second period of time.

In an embodiment, the first period of time is an integration period during which a voltage is established based on the current flow through the optically sensitive material.

In an embodiment, the second period of time is a period of time during which a reset is applied to the optically sensitive material, the reset including resetting a voltage difference across the optically sensitive material.

In an embodiment, the optically sensitive layers comprise a non-rectifying optically sensitive device.

In an embodiment, the integrated circuit comprises for each pixel region a charge store and an integration circuit to establish a voltage based on intensity of light absorbed by the optically sensitive layers over an integration period of time.

In an embodiment, the integrated circuit includes at least one transistor in electrical communication with the respective first electrode, wherein the charge store comprises parasitic capacitance of the at least one transistor.

In an embodiment, the integrated circuit includes a source follower transistor having a gate in electrical communication with the respective first electrode.

In an embodiment, the parasitic capacitance comprises a parasitic capacitance between the gate and a source of the source follower transistor.

In an embodiment, the integrated circuit includes a reset transistor having a gate in electrical communication with the respective first electrode.

In an embodiment, the parasitic capacitance comprises a parasitic capacitance between a source and structures of a substrate of the reset transistor.

In an embodiment, the parasitic capacitance comprises metal-to-metal parasitic capacitance between nodes of the pixel circuit.

In an embodiment, the parasitic capacitance comprises metal-to-substrate parasitic capacitance between the charge store node and a silicon substrate.

In an embodiment, the parasitic capacitance is approximately in a range of 0.5 to 3 Femto Farads, or approximately in a range of 1 to 2 Femto Farads.

In an embodiment, charge stored at the charge store is discharged by a flow of current through the optically sensitive layers during the integration period of time.

In an embodiment, the photodetector comprises at least one color filter. It also comprises conversion circuitry.

In an embodiment, the integrated circuit includes the conversion circuitry, the conversion circuitry located under the at least two optically sensitive layers.

In an embodiment, the conversion circuitry is coupled to the integrated circuit.

In an embodiment, the conversion circuitry converts the signals from a first type to a second type.

In an embodiment, the conversion circuitry converts the signals from analog signals to digital signals.

In an embodiment, the conversion circuitry converts the signals from digital signals to analog signals.

In an embodiment, the photodetector further comprises compensation circuitry.

In an embodiment, the compensation circuitry is coupled to the integrated circuit.

In an embodiment, the integrated circuit includes the compensation circuitry, the compensation circuitry located under the at least two optically sensitive layers.

In an embodiment, the compensation circuitry adjusts the signal to compensate for different properties among the optically sensitive layers.

In an embodiment, the compensation circuitry at least partially compensates for nonlinearity of signals output from the optically sensitive layers.

In an embodiment, the compensation circuitry at least partially linearizes digital data derived from the signals.

In an embodiment, the compensation circuitry at least partially linearizes the signals using a polynomial function.

In an embodiment, the compensation circuitry at least partially linearizes the signals using piecewise linear inversion of a relationship between intensity of the light and electrical properties of at least one optically sensitive layer.

In an embodiment, the compensation circuitry at least partially compensates for variance in a rate of current flow in at least one optically sensitive layer over an integration period for a constant intensity of light.

In an embodiment, the compensation circuitry at least partially compensates for variance in a rate of current flow in at least one optically sensitive layer over an integration period for differing intensities of light.

In an embodiment, the compensation circuitry at least partially compensates for variance in gain in at least one optically sensitive layer over an integration period for a constant intensity of light.

In an embodiment, the compensation circuitry at least partially compensates for variance in gain in at least one optically sensitive layer over an integration period for differing intensities of light.

In an embodiment, the compensation circuitry: at least partially compensates for nonlinearity of signals output from the optically sensitive layers; and at least partially compensates for a difference between dark currents of signals output from the optically sensitive layers. The compensation circuitry includes a read out circuit and demosaicing algorithm that outputs a corrected color matrix based on analog quantities read out from the respective optically sensitive layers.

In an embodiment, the corrected color matrix includes a red, green, blue (RGB) matrix.

In an embodiment, the compensation circuitry compensates for transmission leakage between layers.

In an embodiment, the compensation circuitry includes image circuitry to generate image data.

In an embodiment, the first optically sensitive layer comprises a nanocrystal material having first photoconductive gain and the second optically sensitive layer comprises a nanocrystal material having a second photoconductive gain, the image circuitry compensating for a difference between the first photoconductive gain and the second photoconductive gain.

In an embodiment, the compensation circuitry applies black level correction that compensates for a difference between dark currents among the at least two optically sensitive layers by applying a plurality of dark current compensations to the signal.

In an embodiment, the compensation circuitry applies a first dark current compensation to a first signal from the first optically sensitive layer and a second dark current compensation to a second signal from the second optically sensitive layer.

In an embodiment, the first dark current compensation is different from the second dark current compensation. The photodetector comprises at least one black pixel. The at least one black pixel comprises at least two optically sensitive opaque layers, a first optically sensitive opaque layer and a second optically sensitive opaque layer, the first optically sensitive opaque layer and the second optically sensitive opaque layer each comprising an optically sensitive layer covered with an opaque material, the first optically sensitive opaque layer over at least a portion of a black pixel integrated circuit and the second optically sensitive opaque layer over the first optically sensitive opaque layer, wherein each optically sensitive opaque layer is interposed between a respective first electrode of the black pixel and a respective second electrode of the black pixel, wherein the integrated circuit selectively applies a bias to the respective first and second electrodes of the black pixel and reads a dark current signal from the optically sensitive opaque layers, wherein the dark current signal is related to the number of photons received by the respective optically sensitive opaque layer.

In an embodiment, the black pixel generates a dark current.

In an embodiment, the dark current density is approximately in a range of 10 nanoamps (nA)/square centimeter (cm) to 500 nA/square cm.

In an embodiment, the dark current compensations include subtracting the dark current from the signals of the optically sensitive layers in different proportions.

In an embodiment, the dark current compensations include subtracting a first portion of the dark current from a first signal of the second optically sensitive layer and subtracting a second portion of the dark current from a second signal of the second optically sensitive layer.

In an embodiment, the first portion is larger than the second portion.

In an embodiment, the at least one black pixel comprises a first black pixel corresponding to the first optically sensitive layer and a second black pixel corresponding to the second optically sensitive layer.

In an embodiment, the first black pixel generates a first dark current and the second black pixel that generates a second dark current.

In an embodiment, the dark current compensation includes subtracting the first dark current from a first signal of the first optically sensitive layer and subtracting the second dark current from a second signal of the second optically sensitive layer.

In an embodiment, the at least one black pixel comprises a plurality of black pixels generating a plurality of dark currents, wherein the compensation circuitry generates the plurality of dark current compensations from the plurality of dark currents.

In an embodiment, responsivities of each of the optically sensitive layers are approximately equal when a thickness of the second optically sensitive layer is less than a thickness of the first optically sensitive layer.

In an embodiment, a photodetector comprises bandgap reference circuitry, the bandgap reference circuitry at least one of integrated in the integrated circuit and coupled to the integrated circuit.

In an embodiment, the black level correction is based on temperature monitoring by tracking a voltage from the bandgap reference circuitry.

In an embodiment, a fill factor is at least 80 percent, wherein the fill factor is a ratio of absorbing area of each photodetector to a total area of the photodetector.

In an embodiment, the fill factor is approximately in a range of 80 percent to 100 percent.

In an embodiment, the respective second electrode for the first optically sensitive layer and the second optically sensitive layer comprises a mesh between at least two adjacent photodetectors of the plurality of photodetectors.

In an embodiment, each photodetector comprises the first respective electrode, wherein the respective second electrode for the first optically sensitive layer and the second optically sensitive layer of each photodetector of the plurality of photodetectors comprises a common electrode disposed around the respective first electrode, wherein the common electrode forms a mesh interposed between the plurality of photodetectors and is a common electrode for each optically sensitive layer in the plurality of photodetectors.

CLAIMS

What is claimed is:

1. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer.

2. The photodetector of claim 1, wherein at least one of the optically sensitive layers comprises nanocrystals of a material having a bulk bandgap, and wherein the nanocrystals are quantum confined to have an effective bandgap more than twice the bulk bandgap.

3. The photodetector of claim 1, wherein at least one of the optically sensitive layers includes nanocrystals comprising nanoparticles, wherein a nanoparticle diameter of the nanoparticles is less than a Bohr exciton radius of bound electron-hole pairs within the nanoparticle.

4. The photodetector of claim 1, wherein at least one optically sensitive layer comprises a continuous film of interconnected nanocrystal particles in contact with the respective first electrode and the respective second electrode.

5. The photodetector of claim 4, wherein the nanocrystal particles comprise a plurality of nanocrystal cores and a shell over the plurality of nanocrystal cores.

6. The photodetector of claim 5, wherein the plurality of nanocrystal cores are fused.

7. The photodetector of claim 5, wherein a physical proximity of the nanocrystal cores of adjacent nanocrystal particles provides electrical communication between the adjacent nanocrystal particles.

8. The photodetector of claim 5, wherein the plurality of nanocrystal cores are electrically interconnected with linker molecules.

9. The photodetector of claim 4, wherein at least one of the optically sensitive layers comprises a unipolar photoconductive layer including a first carrier type and a second carrier type, wherein a first mobility of the first carrier type is higher than a second mobility of the second carrier type.

10. The photodetector of claim 4, wherein the nanocrystal particles include closely-packed semiconductor nanoparticle cores.

11. The photodetector of claim 10, wherein each core is partially covered with an incomplete shell, where the shell produces trap states having substantially a single time constant.

12. The photodetector of claim 10, wherein the nanoparticle cores are passivated and crosslinked using at least one crosslinking molecule of at least one length.

13. The photodetector of claim 1, wherein the first optically sensitive layer comprises a first material having a first thickness, and a combination of the first material and the first thickness provides a first responsivity to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and a combination of the second material and the second thickness provides a second responsivity to light of a second wavelength, wherein the first responsivity and the second responsivity are approximately equal.

14. The photodetector of claim 1, wherein the first optically sensitive layer comprises a first material having a first thickness, and a combination of the first material and the first thickness provides a first photoconductive gain to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and a combination of the second material and the second thickness provides a second photoconductive gain to light of a second wavelength, wherein the first photoconductive gain and the second photoconductive gain are approximately equal.

15. The photodetector of claim 1, wherein the first optically sensitive layer comprises a first material having a first thickness, and a combination of the first material and the first thickness provides a first absorbance to light of a first wavelength, wherein the second optically sensitive layer comprises a second material having a second thickness, and a combination of the second material and the second thickness provides a second absorbance to light of a second wavelength, wherein the first absorbance and the second absorbance are approximately equal.

16. The photodetector of claim 1, wherein at least one of the optically sensitive layers comprises monodisperse nanocrystal particles.

17. The photodetector of claim 16, wherein the nanocrystal particles are colloidal quantum dots.

18. The photodetector of claim 17, wherein the quantum dots include a first carrier type and a second carrier type, wherein the first carrier type is a flowing carrier and the second carrier type is one of a substantially blocked carrier and a trapped carrier.

19. The photodetector of claim 1, wherein the first optically sensitive layer comprises a first composition including one of lead sulfide (PbS), lead selenide (PbSe), lead tellurium sulfide (PbTe), indium phosphide (InP), indium arsenide (InAs), and germanium (Ge), and the second optically sensitive layer comprises a second composition including one of indium sulfide (In_2S_3), indium selenide (In_2Se_3), indium tellurium (In_2Te_3), bismuth sulfide (Bi_2S_3), bismuth selenide (Bi_2Se_3), bismuth tellurium (Bi_2Te_3), indium phosphide (InP), silicon (Si), and germanium (Ge).

20. The photodetector of claim 1, wherein the bias comprises:
biasing the optically sensitive layers to operate as a current sink during a first period of time; and
biasing the optically sensitive material to operate as a current source during a second period of time.

21. The photodetector of claim 1, wherein the respective first electrode and second electrode for the first optically sensitive layer are different electrodes than the respective first electrode and second electrode for the second optically sensitive layer.

22. The photodetector of claim 1, wherein the respective first electrode for the first optically sensitive layer is a different electrode than the respective first electrode for the second optically sensitive layer.

23. The photodetector of claim 22, wherein second respective electrode for the second optically sensitive layer is a common electrode common to both the first optically sensitive layer and the second optically sensitive layer.

24. The photodetector of claim 1, wherein each respective first electrode is in contact with the respective first optically sensitive layer.

25. The photodetector of claim 1, wherein each respective second electrode is in contact with the respective second optically sensitive layer.

26. The photodetector of claim 1, wherein each respective first electrode is positioned laterally relative to at least a portion of the respective second electrode.

27. The photodetector of claim 26, wherein at least a portion of each respective second electrode is on the same layer of the integrated circuit as the respective first electrode and the respective optically sensitive layer.

28. The photodetector of claim 26, wherein the respective second electrode for the first optically sensitive layer and the second optically layer comprises a common electrode.

29. The photodetector of claim 28, wherein the common electrode extends vertically from the first optically sensitive layer to the second optically sensitive layer.

30. The photodetector of claim 28, wherein the common electrode extends vertically from the integrated circuit along a portion of the first optically sensitive layer and the second optically sensitive layer.

31. The photodetector of claim 26, wherein each respective second electrode is disposed around the respective first electrode.

32. The photodetector of claim 31, wherein the respective second electrode is configured to provide a barrier to carriers around the first electrode.

33. The photodetector of claim 26, wherein the respective second electrode for the first optically sensitive layer and the second optically sensitive layer comprises a common electrode disposed around the first electrode.

34. The photodetector of claim 33, wherein the common electrode extends vertically from the integrated circuit.

35. The photodetector of claim 1, wherein the second electrode is at least partially transparent and is positioned over the respective optically sensitive layer.

36. The photodetector of claim 1, wherein the respective first electrode and the respective second electrode are non-transparent and separated by a distance corresponding to a width dimension and a length dimension.

37. The photodetector of claim 36, wherein the width dimension is less than approximately 2 um.

38. The photodetector of claim 36, wherein the length dimension is less than approximately 2 um.

39. The photodetector of claim 1, wherein the at least two optically sensitive layers includes a third optically sensitive layer, wherein the third optically sensitive layer is over at least a portion of the second optically sensitive layer, wherein the respective second electrode for the first optically sensitive layer, the second electrode for the second optically sensitive layer and the third electrode for the third layer is a common electrode for the first optically sensitive layer, the second optically sensitive layer and the third layer, wherein the common electrode is non-transparent.

40. The photodetector of claim 1, comprising a third optically sensitive layer integrated in the integrated circuit, wherein the respective second electrode for the first optically sensitive layer and the second electrode for the second optically sensitive layer is a common electrode for both the first optically sensitive layer and the second optically sensitive layer, wherein the respective second electrode for the third layer is different from the common electrode.

41. The photodetector of claim 1, wherein the at least two optically sensitive layers includes a third optically sensitive layer and a fourth optically sensitive layer, wherein the fourth optically sensitive layer is over at least a portion of the third optically sensitive layer, wherein a thickness of the fourth optically sensitive layer is less than a thickness of one of the first optically sensitive layer, the second optically sensitive layer, and the third optically sensitive layer.

42. The photodetector of claim 1, wherein persistence of each of the optically sensitive layers is approximately equal.

43. The photodetector of claim 1, wherein persistence of each of the optically sensitive layers is longer than approximately 1 millisecond (ms).

44. The photodetector of claim 1, wherein at least one of the optically sensitive layers comprises a nanocrystal material having photoconductive gain and a responsivity of at least approximately 0.4 amps/volt (A/V).

45. The photodetector of claim 44, wherein the responsivity is achieved when a bias is applied between the respective first electrode and the respective second electrode, wherein the bias is approximately in a range of 0.5 volts to 5 volts.

46. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including lead sulfide (PbS).

47. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including lead selenide (PbSe).

48. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including lead tellurium (PbTe).

49. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including indium phosphide (InP).

50. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including indium arsenide (InAs).

51. The photodetector of claim 1, wherein the first optically sensitive layer comprises a composition including germanium (Ge).

52. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including indium sulfide (In_2S_3).

53. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including indium selenide (In_2Se_3).

54. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including indium tellurium (In_2Te_3).

55. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including bismuth sulfide (Bi_2S_3).

56. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including bismuth selenide (Bi_2Se_3).

57. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including bismuth tellurium (Bi_2Te_3).

58. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including indium phosphide (InP).

59. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including silicon (Si).

60. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including germanium (Ge).

61. The photodetector of claim 1, wherein the second optically sensitive layer comprises a composition including gallium arsenide (GaAs).

62. The photodetector of claim 1, wherein each of the optically sensitive layers comprises nanocrystals of a different particle size.

63. The photodetector of claim 62, wherein nanocrystal particles of the first optically sensitive layer are larger than nanocrystal particles of the second optically sensitive layer.

64. The photodetector of claim 62, wherein nanocrystal particles of the first optically sensitive layer are smaller than nanocrystal particles of the second optically sensitive layer.

65. The photodetector of claim 64, wherein a first bulk bandgap of the first optically sensitive layer is higher than a second bulk bandgap of the second optically sensitive layer.

66. The photodetector of claim 64, wherein a first increase in bandgap due to quantum confinement in the first optically sensitive layer is greater than a second increase in bandgap due to quantum confinement in the second optically sensitive layer.

67. The photodetector of claim 1, wherein a rate of the current flow through an optically sensitive material of at least one optically sensitive layer has a non-linear relationship with intensity of the light absorbed by the optically sensitive material.

68. The photodetector of claim 1, wherein gain of an optically sensitive material of at least one optically sensitive layer has a non-linear relationship with intensity of the light absorbed by the optically sensitive material.

69. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a first increase in bandgap due to quantum confinement in the first optically sensitive layer is greater than a second increase in bandgap due to quantum confinement in the second optically sensitive layer.

70. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a thickness of at least one optically sensitive layer is different from a thickness of at least one other optically sensitive layer.

71. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein the first optically sensitive layer comprises a nanocrystal material having first photoconductive gain and the second optically sensitive layer comprises a nanocrystal material having a second photoconductive gain.

72. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a dark current of at least one optically sensitive layer is different from a dark current of at least one other optically sensitive layer.

73. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a compensation applied to a signal from at least one optically sensitive layer is different from a compensation applied to a signal from at least one other optically sensitive layer.

74. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a dark current compensation signal is received from a black pixel and separately and proportionally applied to signals of each optically sensitive layer.

75. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a dark current compensation signal corresponding to each respective optically sensitive layer is received from a respective black pixel and applied to a respective signal of the respective optically sensitive layer.

76. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein a dark current of at least one optically sensitive layer is approximately in a range of 10 nanoamps (nA) per square centimeter (cm) to 500 nA per square cm.

77. A photodetector comprising:

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of a substrate and the second optically sensitive layer over the first optically sensitive layer;

wherein at least one optically sensitive layer is a nanocrystal layer having a dark current approximately in a range of 10 nanoamps (nA) per square centimeter (cm) to 500 nA per square cm.

78. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and

wherein the first optically sensitive layer comprises a first composition including one of lead sulfide (PbS), lead selenide (PbSe), lead tellurium sulfide (PbTe), indium phosphide (InP), indium arsenide (InAs), and germanium (Ge), and the second optically sensitive layer comprises a second composition including one of indium sulfide (In_2S_3), indium selenide (In_2Se_3), indium tellurium (In_2Te_3), bismuth sulfide (Bi_2S_3), bismuth selenide (Bi_2Se_3), bismuth tellurium (Bi_2Te_3), indium phosphide (InP), silicon (Si), and germanium (Ge).

79. A photodetector comprising:

an integrated circuit; and

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signal is related to the number of photons received by the respective optically sensitive layer; and wherein the first optically sensitive layer comprises a nanocrystal material having an absorption onset at a first wavelength and the second optically sensitive layer comprises a nanocrystal material having an absorption onset at a second wavelength, wherein the first wavelength is shorter than the second wavelength, and a local absorption maximum is absent from an absorption spectrum of at least one of the first optically sensitive layer and the second optically sensitive layer.

80. A photodetector comprising:

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of an integrated circuit and the second optically sensitive layer over the first optically sensitive layer;

wherein the first optically sensitive layer comprises a first absorption band including at least one first set of colors and is devoid of a local absorption maximum, and the second optically sensitive layer comprises a second absorption band including at least one second set of colors and is devoid of a local absorption maximum, wherein the second absorption band includes the first set of colors;

wherein each optically sensitive layer is interposed between a respective first electrode and a respective second electrode; and

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the optically sensitive layers.

81. A photodetector comprising:

an integrated circuit; and

a plurality of optically sensitive layers including a first optically sensitive layer and a vertically stacked set of optically sensitive layers, the first optically sensitive layer in at least a portion of the integrated circuit and the vertically stacked set of optically sensitive layers over the first optically sensitive layer;

wherein the vertically stacked optically sensitive layer is interposed between a respective first electrode and a respective second electrode;

wherein the integrated circuit selectively applies a bias to the electrodes and reads signals from the vertically stacked optically sensitive layers, wherein the signal is related to the number of photons received by the respective vertically stacked optically sensitive layer.

82. A pixel array comprising a plurality of photodetectors, wherein each photodetector is a vertically stacked pixel, the vertically stacked pixel comprising:

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; and

a plurality of electrodes including at least two electrodes between which the two optically sensitive layers are interposed, the electrodes including a respective first electrode and a respective second electrode;

a coupling between the integrated circuit and the plurality of electrodes by which the integrated circuit selectively applies a bias and reads from the optically sensitive layers pixel information corresponding to light absorbed by the optically sensitive layers.

83. A photosensor array comprising:

an integrated circuit; and

a plurality of photodetectors over the integrated circuit, wherein each photodetector forms a vertically stacked pixel that comprises,

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; and

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode, wherein the integrated circuit is coupled to the electrodes and selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signals are related to the number of photons received by the respective optically sensitive layer.

84. A vertically stacked pixel, comprising:

a plurality of optically sensitive layers including a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer overlying at least a portion of a first side of an integrated circuit and the second optically sensitive layer overlying at least a portion of a second side of the first optically sensitive layer;

a plurality of electrodes, wherein the plurality of optically sensitive layers is interposed between a respective first electrode and a respective second electrode of the plurality of electrodes; and

a coupling between the integrated circuit and the plurality of electrodes by which the integrated circuit selectively applies a bias and reads from the optically sensitive layers pixel information corresponding to light absorbed by the optically sensitive layers.

85. A photosensor array comprising:

an integrated circuit; and

a plurality of photodetectors over the integrated circuit, wherein each photodetector forms a vertically stacked pixel that comprises,

at least two optically sensitive layers, a first optically sensitive layer and a second optically sensitive layer, the first optically sensitive layer over at least a portion of the integrated circuit and the second optically sensitive layer over the first optically sensitive layer; and

wherein each optically sensitive layer is interposed between two electrodes, the electrodes including a respective first electrode and a respective second electrode, wherein the integrated circuit is coupled to the electrodes and selectively applies a bias to the electrodes and reads signals from the optically sensitive layers, wherein the signals are related to the number of photons received by the respective optically sensitive layer.

86. A photodetector comprising:

a plurality of pixel regions, each pixel region having a respective first electrode and a respective second electrode;

an optically sensitive material between the first electrode and the second electrode, wherein the optically sensitive material with the first electrode and second electrode is non-rectifying;

a transistor coupled to one of the respective first electrode and the respective second electrode in electrical communication with the optically-sensitive material, the transistor including a gate configured to store charge, wherein the respective first electrode of a pixel region electrically communicates with the gate, wherein charge stored at the gate is discharged by a flow of current through the optically sensitive material during an integration period of time; and

circuitry generating a signal from the gate based on the amount of charge remaining in the charge store after the integration period of time.

87. A photodetector comprising:

a pixel region, each pixel region having a first electrode and a second electrode;

a plurality of layers of optically sensitive material between the first electrode and the second electrode, wherein the optically sensitive material with the first electrode and second electrode is non-rectifying;

a transistor coupled to the optically sensitive material, the transistor including a gate configured to store charge, wherein the respective first electrode of the pixel region electrically communicates with the gate, wherein charge stored at the gate is discharged by a flow of current through the optically sensitive material during an integration period of time; and

circuitry generating a signal from the gate based on the amount of charge remaining in the charge store after the integration period of time.

88. A photodetector comprising:

a pixel region comprising an optically sensitive material between a first electrode and a second electrode, wherein the optically sensitive material with the first electrode and second electrode is non-rectifying;

pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry establishing a voltage over an integration period of time, wherein a signal is generated based on the voltage after the integration period of time;

a converter configured to convert the signal into digital pixel data.

89. The photodetector of claim 88, wherein the pixel circuitry comprises a charge store and integration circuitry to establish the voltage based on intensity of light absorbed by the optically sensitive material of the pixel region over the integration period of time.

90. The photodetector of claim 89, wherein the pixel circuitry includes at least one transistor in electrical communication with the first electrode, wherein the charge store comprises parasitic capacitance of the at least one transistor.

91. The photodetector of claim 90, wherein the pixel circuitry includes a source follower transistor having a gate in electrical communication with the first electrode.

92. The photodetector of claim 91, wherein the parasitic capacitance comprises a parasitic capacitance between the gate and a source of the source follower transistor.

93. The photodetector of claim 90, wherein the pixel circuitry includes a reset transistor having a gate in electrical communication with the first electrode.

94. The photodetector of claim 93, wherein the parasitic capacitance comprises a parasitic capacitance between a source and structures of a substrate of the reset transistor.

95. The photodetector of claim 90, wherein the parasitic capacitance comprises metal-to-metal parasitic capacitance between nodes of the pixel circuit.

96. The photodetector of claim 90, wherein the parasitic capacitance comprises metal-to-substrate parasitic capacitance between the charge store node and a silicon substrate.

97. The photodetector of claim 90, wherein the parasitic capacitance is approximately in a range of 0.5 to 3 Femto Farads.

98. The photodetector of claim 90, wherein the parasitic capacitance is approximately in a range of 1 to 2 Femto Farads.

99. A method comprising:
exposing an optically sensitive material to light;
generating a signal based on a current flow through the optically sensitive material;
biasing the optically sensitive material to operate as a current sink during a first period of time; and
biasing the optically sensitive material to operate as a current source during a second period of time.

100. An image sensor comprising:

a plurality of pixel regions, each pixel region including a respective first electrode and a common second electrode, wherein the common second electrode is a common electrode for the plurality of pixel regions;

each pixel region comprising an optically sensitive material between the respective first electrode and the common second electrode;

pixel circuitry for each pixel region in electrical communication with the respective first electrode of the pixel region, the pixel circuitry for each pixel region including integration circuitry to establish a voltage based on the intensity of light absorbed by the optically sensitive material of the respective pixel region over an integration period of time, the pixel circuitry including read out circuitry to read out a signal after the integration period of time; and

bias circuitry in electrical communication with the common second electrode to vary the voltage of the common second electrode.

101. An image sensor comprising:

a semiconductor substrate;

a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the substrate, the optically sensitive layer positioned to receive light;

a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, the charge store and the read out circuit in electrical communication with the optically sensitive layer of the respective pixel region; and

conductive material positioned between the charge store of the respective pixel region and the optically sensitive layer of the corresponding pixel region such that the respective charge store is substantially shielded from the light incident on the optically sensitive layer, wherein the light is in a wavelength band, wherein at least a portion of the conductive material is a metal layer in electrical communication with the optically sensitive layer.

102. The image sensor of claim 101, wherein the pixel circuit for each pixel region comprises a charge store and an integration circuit to establish a voltage based on intensity of the light absorbed by the optically sensitive material of the respective pixel region over an integration period of time.

103. The image sensor of claim 102, wherein the pixel circuit includes at least one transistor in electrical communication with a respective first electrode of the respective pixel region, wherein the charge store comprises parasitic capacitance of the at least one transistor.

104. The image sensor of claim 103, wherein the pixel circuit includes a source follower transistor having a gate in electrical communication with the respective first electrode.

105. The image sensor of claim 104, wherein the parasitic capacitance comprises a parasitic capacitance between the gate and a source of the source follower transistor.

106. The image sensor of claim 3, wherein the pixel circuit includes a reset transistor having a gate in electrical communication with the respective first electrode.

107. The image sensor of claim 106, wherein the parasitic capacitance comprises a parasitic capacitance between a source and structures of a substrate of the reset transistor.

108. The image sensor of claim 103, wherein the parasitic capacitance comprises metal-to-metal parasitic capacitance between nodes of the pixel circuit.

109. The image sensor of claim 103, wherein the parasitic capacitance comprises metal-to-substrate parasitic capacitance between the charge store node and a silicon substrate.

110. The image sensor of claim 103, wherein the parasitic capacitance is approximately in a range of 0.5 to 3 Femto Farads.

111. The image sensor of claim 103, wherein the parasitic capacitance is approximately in a range of 1 to 2 Femto Farads.

112. A photodetector comprising:

a semiconductor substrate;

a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the substrate, the optically sensitive layer positioned to receive light; and

a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a switching element between the charge store and the optically sensitive layer for the respective pixel region, the charge store and the switching element one or more of integrated on and integrated in the semiconductor substrate below the plurality of pixel regions.

113. The photodetector of claim 112, wherein the switching element controls an integration period simultaneously for the plurality of pixel regions.

114. The photodetector of claim 112, comprising conductive material positioned between the charge store of the respective pixel region and the optically sensitive layer of the corresponding pixel region such that the respective charge store is shielded from the light incident on the optically sensitive layer, wherein the light is

in a wavelength band, wherein at least a portion of the conductive material is a metal layer in electrical communication with the optically sensitive layer.

115. The photodetector of claim 112, wherein the switching element is a transistor.

116. The photodetector of claim 112, wherein the switching element is a diode.

117. The photodetector of claim 112, wherein the switching element is a parasitic diode.

118. The photodetector of claim 112, comprising an opaque material between each pixel circuit and the corresponding pixel region, the opaque material shielding the charge store and the switching element from the light received by the optically sensitive layer.

119. The photodetector of claim 112, comprising circuitry configured to simultaneously switch the switching element of each of the pixel regions.

120. An image sensor comprising:

a semiconductor substrate;

a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the semiconductor substrate, the optically sensitive layer separated from the semiconductor substrate on a side by at least one adjacent layer, wherein vias couple the optically sensitive layer and the semiconductor substrate; and

a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit, wherein the charge store is separate for each pixel region and wherein the read out circuit is common with the read out circuit for at least one set of other pixel regions.

121. A photodetector comprising:

a semiconductor substrate;

a plurality of pixel regions, each pixel region comprising an optically sensitive layer over the substrate;

a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit; and

circuitry to select the charge store of a plurality of adjacent pixel regions for simultaneous reading to a shared read out circuit.

122. A photodetector comprising:

a semiconductor substrate;

a plurality of pixel regions over the semiconductor substrate, each pixel region comprising a first electrode, a second electrode and an optically sensitive layer between the first electrode and the second electrode;

a pixel circuit for each pixel region, each pixel circuit comprising a charge store and a read out circuit;

circuitry to electrically connect the first electrode for a set of pixel regions to a shared charge store during an integration period of time, the plurality of pixel regions including the set of pixel regions, wherein the shared charge store is the charge store corresponding to one pixel circuit of one pixel region;

circuitry to read out a signal from the shared charge store, the signal based on intensity of light absorbed by each pixel region of the set of pixel regions during the integration period of time.

123. A sensor comprising:

at least one optically sensitive layer; and

a circuit comprising at least one node in electrical communication with the optically sensitive layer, wherein the circuit stores an electrical signal proportional to the intensity of light incident on the optically sensitive layer during an integration period, wherein a non-linear relationship exists between electrical characteristics of the optically sensitive layer and the intensity of light absorbed by the optically sensitive layer, wherein a continuous function represents the non-linear relationship.

124. The sensor of claim 123, wherein at least one optically sensitive layer comprises closely-packed semiconductor nanoparticle cores.

125. The sensor of claim 124, wherein each core is partially covered with an incomplete shell, where the shell produces trap states having substantially a single time constant.

126. The sensor of claim 125, wherein the nanoparticle cores comprise PbS partially covered with a shell comprising PbSO3.

127. The sensor of claim 124, wherein the nanoparticle cores are passivated using ligands of at least two substantially different lengths.

128. The sensor of claim 124, wherein the nanoparticle cores are passivated using at least one ligand of at least one length.

129. The sensor of claim 124, wherein the nanoparticle cores are passivated and crosslinked using at least one crosslinking molecule of at least one length.

130. The sensor of claim 129, wherein the crosslinking molecule is a conductive crosslinker.

131. The sensor of claim 124, wherein each nanoparticle core is covered with a shell, where the shell comprises PbSO3.

132. The sensor of claim 124, wherein the nanoparticle cores comprise PbS that is partially oxidized and substantially lacking in PbSO4 (lead sulfate).

133. The sensor of claim 123, wherein at least one optically sensitive layer comprises a nanocrystalline solid, wherein at least a portion of a surface of the nanocrystalline solid is oxidized.

134. The sensor of claim 133, wherein a composition of the nanocrystalline solid excludes a first set of native oxides and includes a second set of native oxides.

135. The sensor of claim 134, wherein the first set of native oxides includes PbSO4 (lead sulfate) and the second set of native oxides includes PbSO3.

136. The sensor of claim 133, wherein trap states of the nanocrystalline solid provide persistence, wherein an energy to escape from a predominant trap state is less than or equal to approximately 0.1 eV.

137. The sensor of claim 136, comprising a non-predominant trap state, wherein an energy to escape from the non-predominant trap state is greater than or equal to approximately 0.2 eV.

138. An optoelectronic device comprising:

an integrated circuit comprising a silicon substrate, at least one diffusion layer, at least one polysilicon layer and at least two metal layers, including at least a first metal layer and a second metal layer;

an optically sensitive layer in electrical communication with the second metal layer; and

the at least one polysilicon layer and the at least one diffusion layer forming a plurality of transistors in electrical communication with the optically sensitive layer through at least the second metal layer.

139. The device of claim 138, wherein the integrated circuit is a complementary metal oxide semiconductor (CMOS) integrated circuit.

140. The device of claim 138, wherein a minimum feature spacing of the integrated circuit is in a range of approximately 100 nm to 200 um.

141. The device of claim 138, wherein the at least two metal layers include metal interconnect layers.

142. The device of claim 138, wherein the second metal layer forms contacts in electrical communication with the optically sensitive layer.

143. The device of claim 142, wherein the contacts comprise an aluminum body, a first coating and a second coating, the first coating comprising titanium nitride and positioned between the aluminum body and the optically sensitive layer, the second coating comprising titanium oxynitride and positioned between the first coating and the optically sensitive layer.

144. The device of claim 142, wherein the contacts comprise an aluminum body, a first coating and a second coating, the first coating comprising titanium nitride and positioned between the aluminum body and the optically sensitive layer, the second coating located between the first coating and the optically sensitive layer and comprising a metal selected from the group consisting of gold, platinum, palladium, nickel and tungsten.

145. The device of claim 142, wherein the contacts have a thickness less than approximately half the thickness of the first metal layer.

146. The device of claim 142, wherein the contacts have a thickness less than approximately 50 nanometers and a width in a range of approximately 100 nm to 500 nm.

147. The device of claim 142, wherein the contacts have an aspect ratio of thickness to width of at least 1:2.

148. The device of claim 142, wherein the contacts have an aspect ratio of thickness to width of at least 1:3.

149. The device of claim 142, wherein the contacts have an aspect ratio of thickness to width of at least 1:4.

150. The device of claim 142, wherein the contacts are formed from a plurality of metal sub-layers, each metal sub-layer having a thickness of less than approximately 50 nm, each metal sub-layer comprising a constituent selected from the group consisting of titanium nitride, titanium oxy nitride, gold, platinum, palladium, nickel and tungsten.

151. The device of claim 138, wherein the second metal layer consists of metal other than aluminum, the metal including at least one layer selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

152. The device of claim 138, wherein the second metal layer consists of metal other than copper, the metal including at least one layer selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

153. The device of claim 138, wherein the second metal layer comprises a constituent selected from the group consisting of titanium nitride, titanium oxynitride, gold, platinum, palladium, nickel and tungsten.

154. The device of claim 138, wherein the optically sensitive layer makes direct contact with the second metal layer.

155. The device of claim 138, wherein the optically sensitive layer comprises a coating on the second metal layer.

156. The device of claim 138, wherein the first metal layer has a thickness in the range of approximately 100 nm to 500 nm.

157. The device of claim 138, wherein the metal layers comprise at least one additional metal layer between the first metal layer and the second metal layer.

158. A method comprising:
exposing an optically sensitive material to light;
providing a current flow through the optically sensitive material, wherein a rate of the current flow through the optically sensitive material has a non-linear relationship with intensity of the light absorbed by the optically sensitive material;
using the current flow to discharge a portion of charge from a charge store over a period of time; and
generating a signal from the charge store based on the amount of charge remaining in the charge store after the period of time.

159. A photodetector comprising:
a pixel region comprising an optically sensitive material;
pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry establishing a voltage over an integration period of time, wherein the voltage has a non-linear relationship with intensity of light absorbed by the optically sensitive material of the respective pixel region, wherein a signal is generated based on the voltage after the integration period of time, the signal having a noise level;
a converter configured to convert the signal into digital pixel data, wherein the converter has an input range; and
at least one of the pixel circuitry and the optically sensitive layer providing a dynamic range more than at least twice the ratio of the input range of the converter divided by the noise level.

160. A photodetector comprising:
a pixel region comprising an optically sensitive material;
pixel circuitry in electrical communication with the optically sensitive material, the pixel circuitry establishing a voltage over an integration period of time, wherein the voltage has a non-linear relationship with intensity of light absorbed by the optically sensitive material of the respective pixel region;
read out circuitry configured to generate a signal based on the voltage after the integration period of time;
an analog-to-digital converter configured to convert the signal into digital pixel data, wherein the analog-to-digital converter has an input range and wherein the signal from the pixel circuitry has a noise level; and
wherein the pixel circuitry and the optically sensitive layer are configured to provide a dynamic range more than at least twice the ratio of the input range of the analog-to-digital converter divided by the noise level.

161. The photodetector of claim 160, wherein the dynamic range is in a range of more than at least three times to approximately ten times the ratio of the input range divided by the noise level.

162. The photodetector of claim 160, wherein the dynamic range is more than at least three times the ratio of the input range divided by the noise level.

163. The photodetector of claim 160, wherein the dynamic range is more than at least five times the ratio of the input range divided by the noise level.

164. The photodetector of claim 160, wherein the dynamic range is more than at least ten times the ratio of the input range divided by the noise level.

165. The photodetector of claim 160, wherein a non-linear relationship exists between electrical characteristics of the optically sensitive material and intensity of light absorbed by the optically sensitive material, wherein a continuous function represents the non-linear relationship.

166. The photodetector of claim 165, wherein the continuous function is a continuous polynomial function representing the non-linear relationship between photoconductive gain of the optically sensitive material and intensity of light absorbed by the optically sensitive material.

167. The photodetector of claim 165, wherein a digital number corresponding to the digital pixel data has a linear relationship to the intensity.

168. A photodetector comprising:
a pixel region comprising an optically sensitive material;
pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry providing a current flow through the optically sensitive material, wherein a rate of the current flow through the optically sensitive material has a non-linear relationship with intensity of the light absorbed by the optically sensitive material;
charge collection circuitry that collects charge relating to the current flow over a period of time; and
read out circuitry that generates a signal from the charge collected over the period of time.

169. A photodetector comprising:
a pixel region comprising an optically sensitive material;
pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry providing a current flow through the optically sensitive material, wherein a rate of the current flow through the optically sensitive material has a non-linear relationship with intensity of the light absorbed by the optically sensitive material;
charge collection circuitry that collects charge relating to the current flow over a period of time; and
read out circuitry configured to generate a signal based on the collected charge;
an analog-to-digital converter configured to convert the signal into digital pixel data, wherein the analog-to-digital converter has an input range and wherein the signal from the pixel circuitry has a noise level; and
wherein the pixel circuitry and the optically sensitive layer are configured to provide a dynamic range more than at least twice the ratio of the input range of the analog-to-digital converter divided by the noise level.

170. The photodetector of claim 169, wherein the dynamic range is in a range of more than at least three times to approximately ten times the ratio of the input range divided by the noise level.

171. The photodetector of claim 169, wherein a non-linear relationship exists between electrical characteristics of the optically sensitive material and intensity of light absorbed by the optically sensitive material, wherein a continuous function represents the non-linear relationship.

172. The photodetector of claim 171, wherein the continuous function is a continuous polynomial function representing the non-linear relationship.

173. The photodetector of claim 171, wherein a digital number corresponding to the digital pixel data has a linear relationship to the intensity.

174. A photodetector comprising:
a plurality of electrodes, including at least a first electrode and a second electrode;
an optically sensitive material between the first electrode and the second electrode;
circuitry that applies a voltage difference between the first electrode and the second electrode such that current flows through the optically sensitive material during an integration period of time, wherein the rate of the current flow through the optically sensitive material has a non-linear relationship with intensity of light absorbed by the optically sensitive material;
a charge store in electrical communication with at least one of the electrodes, the quantity of charge in the charge store based on the current flow through the optically sensitive material during the integration period of time; and
read out circuitry configured to generate a signal based on the charge in the charge store after the integration period of time.

175. A photodetector comprising:
a photosensor array having a plurality of pixel regions, the pixel regions arranged into a plurality of rows and a plurality of columns;

each pixel region comprising at least one optically sensitive material;

pixel circuitry for each of the respective pixel regions, the pixel circuitry for each respective pixel region applying a voltage difference across the optically sensitive material for the respective pixel region, wherein the rate of the current flow through the optically sensitive material has a non-linear relationship with intensity of light absorbed by the optically sensitive material of the respective pixel region;

the pixel circuitry including a charge store to provide a charge related to the current flow through the optically sensitive material of the respective pixel region during the integration period of time;

the pixel circuitry including read out circuitry to generate a signal based on the charge of the charge store for the respective pixel region after the integration period of time; and

pixel select circuitry to select the pixel circuitry for a subset of the pixel regions to be read out.

176. A method comprising:

providing an optically sensitive material;

causing a current to flow through the optically sensitive material during an integration period of time by providing a voltage difference across the optically sensitive material and exposing the optically sensitive material to light, wherein the rate of the current flow through the optically sensitive material depends upon the voltage difference across the optically sensitive material and intensity of the light absorbed by the optically sensitive material;

using the current flow through the optically sensitive material to discharge a portion of charge from a charge store during the integration period of time;

varying both the voltage difference across the optically sensitive material and the rate of the current flow through the optically sensitive material during at least a portion of the integration period; and

generating a signal based on the amount of charge remaining in the charge store after the integration period of time.

177. A method comprising:

providing an optically sensitive material;

causing a current to flow through the optically sensitive material during an integration period of time by providing a voltage difference across the optically sensitive material and exposing the optically sensitive material to light, wherein the rate of the current flow through the optically sensitive material depends upon the voltage difference across the optically sensitive material and intensity of the light absorbed by the optically sensitive material;

collecting charge from the current flow during the integration period of time;

varying both the voltage difference across the optically sensitive material and the rate of the current flow through the optically sensitive material during at least a portion of the integration period while maintaining the intensity of the light substantially constant; and

generating a signal based on the charge collected during the integration period of time.

178. A photodetector comprising:

a plurality of electrodes, including at least a first electrode and a second electrode;

an optically sensitive material between the first electrode and the second electrode;

circuitry configured to apply a voltage difference between the first electrode and the second electrode such that current flows through the optically sensitive material during an integration period of time, wherein the rate of the current flow through the optically sensitive material depends upon the voltage difference across the optically sensitive material and an intensity of light absorbed by the optically sensitive material;

the circuitry configured to vary both the voltage difference across the optically sensitive material and the rate of the current flow through the optically sensitive material for a constant intensity of light during at least a portion of the integration period;

a charge store in electrical communication with at least one of the electrodes, the charge store configured to provide a charge responsive to the current flow through the optically sensitive material during the integration period of time; and

read out circuitry configured to generate a signal based on the charge of the charge store after the integration period of time.

179. A photodetector comprising:

a photosensor array having a plurality of pixel regions, the pixel regions arranged into a plurality of rows and a plurality of columns;

each pixel region comprising at least one optically sensitive material;

pixel circuitry for each of the respective pixel regions, the pixel circuitry for each respective pixel region configured to apply a voltage difference across the optically sensitive material for the respective pixel region, wherein the rate of the current flow through the optically sensitive material depends upon the voltage difference across the optically sensitive material and an intensity of light absorbed by the optically sensitive material of the respective pixel region;

the pixel circuitry configured to vary both the voltage difference across the optically sensitive material and the rate of the current flow through the optically sensitive material for a constant intensity of light during at least a portion of the integration period;

the pixel circuitry including a charge store, the charge store configured to provide a charge in response to the current flow through the optically sensitive material of the respective pixel region during the integration period of time;

the pixel circuitry including read out circuitry configured to generate a signal based on the charge of the charge store for the respective pixel region after the integration period of time; and

pixel select circuitry configured to select the pixel circuitry for a subset of the pixel regions to be read out.

180. A method comprising:

exposing an optically sensitive material to light;

providing a current flow through the optically sensitive material, wherein optical sensitivity of the optically sensitive material depends upon intensity of light absorbed by the optically sensitive material;

using the current flow to discharge a portion of charge from a charge store over a period of time; and

generating a signal from the charge store based on the amount of charge remaining in the charge store after the period of time.

181. The method of claim 180, wherein the optical sensitivity of the optically sensitive material at an intensity of light less than approximately 1 lux is more than twice the optical sensitivity of the optically sensitive material at an intensity of light of at least 100 lux.

182. The method of claim 180, wherein the optical sensitivity of the optically sensitive material at an intensity of light less than approximately 1 lux is more than ten times the optical sensitivity of the optically sensitive material at an intensity of light of at least 100 lux.

183. A photodetector comprising:

a pixel region comprising an optically sensitive material, wherein optical sensitivity of the optically sensitive material depends upon intensity of light absorbed by the optically sensitive material;

pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry establishing a voltage over an integration period of time, wherein a signal is generated based on the voltage after the integration period of time, the signal having a noise level;

a converter configured to convert the signal into digital pixel data, wherein the converter has an input range; and

at least one of the pixel circuitry and the optically sensitive layer providing a dynamic range more than at least twice the ratio of the input range of the converter divided by the noise level.

184. A method comprising:

exposing an optically sensitive material to light;

providing a current flow through the optically sensitive material, wherein the rate of the current flow through the optically sensitive material varies with optical sensitivity of the optically sensitive material, wherein optical sensitivity depends upon intensity of light absorbed by the optically sensitive material;

collecting charge from the current flow over a period of time; and

generating a signal from the charge collected over the period of time.

185. A photodetector comprising:

a plurality of electrodes, including at least a first electrode and a second electrode;

an optically sensitive material between the first electrode and the second electrode;

circuitry that applies a voltage difference between the first electrode and the second electrode such that current flows through the optically sensitive material during an integration period of time, wherein optical sensitivity of the optically sensitive material depends upon intensity of light absorbed by the optically sensitive material;

a charge store in electrical communication with at least one of the electrodes, the charge store storing energy based on the current flow through the optically sensitive material during the integration period of time; and

read out circuitry configured to generate a signal based on the energy of the charge store after the integration period of time.

186. A photodetector comprising:

a photosensor array having a plurality of pixel regions, the pixel regions arranged into a plurality of rows and a plurality of columns;

each pixel region comprising at least one optically sensitive material;

pixel circuitry for each of the respective pixel regions, the pixel circuitry for each respective pixel region applying a voltage difference across the optically sensitive material for the respective pixel region, wherein optical sensitivity of the optically sensitive material depends upon intensity of light absorbed by the optically sensitive material;

the pixel circuitry including a charge store to provide a charge related to the current flow through the optically sensitive material of the respective pixel region during the integration period of time;

the pixel circuitry including read out circuitry to generate a signal based on the charge of the charge store for the respective pixel region after the integration period of time; and

pixel select circuitry to select the pixel circuitry for a subset of the pixel regions to be read out.

187. A method comprising:

exposing an optically sensitive material to light;

providing a current flow through the optically sensitive material;

using the current flow to discharge a portion of stored charge from a charge store over a period of time;

generating a signal from the charge store based on the amount of charge remaining in the charge store after the period of time;

wherein a rate of the current flow through the optically sensitive material at relatively high light levels maintains the stored charge above a minimum threshold as a result of a non-linear relationship between the current flow and intensity of the light absorbed by the optically sensitive material, wherein generating of the signal occurs when the stored charge is greater than the minimum threshold.

188. A photodetector comprising:

a pixel region comprising an optically sensitive material;

pixel circuitry electrically coupled to the optically sensitive material, the pixel circuitry establishing a voltage over an integration period of time, wherein a signal is generated based on the voltage after the integration period of time, the signal having a noise level;

wherein a rate of the current flow through the optically sensitive material at relatively high light levels causes the voltage to remain above a minimum threshold as a result of a non-linear relationship between the voltage and intensity of the light absorbed by the optically sensitive material of the respective pixel region, wherein generating of the signal occurs when the voltage is greater than the minimum threshold;

a converter configured to convert the signal into digital pixel data, wherein the converter has an input range; and

at least one of the pixel circuitry and the optically sensitive layer providing a dynamic range more than at least twice the ratio of the input range of the converter divided by the noise level.

189. A method comprising:

exposing an optically sensitive material to light;

providing a current flow through the optically sensitive material;

collecting charge from the current flow over a period of time;

generating a signal from the charge collected over the period of time;

wherein a rate of the current flow through the optically sensitive material at relatively high light levels causes collected charge to remain above a minimum threshold as a result of a non-linear relationship between the current flow and intensity of the light absorbed by the optically sensitive material, wherein generating of the signal occurs when the collected charge is greater than the minimum threshold.

190. A photodetector comprising:

a plurality of electrodes, including at least a first electrode and a second electrode;

an optically sensitive material between the first electrode and the second electrode;

circuitry that applies a voltage difference between the first electrode and the second electrode such that current flows through the optically sensitive material during an integration period of time;

a charge store in electrical communication with at least one of the electrodes, the charge store storing energy based on the current flow through the optically sensitive material during the integration period of time; and

read out circuitry configured to generate a signal based on the energy of the charge store after the integration period of time;

wherein a rate of the current flow through the optically sensitive material at relatively high light levels causes the stored energy to remain above a minimum threshold as a result of a non-linear relationship between the current flow and intensity of the light absorbed by the optically sensitive material, wherein generating of the signal occurs when the stored energy is greater than the minimum threshold.

191. A photodetector comprising:

a photosensor array having a plurality of pixel regions, the pixel regions arranged into a plurality of rows and a plurality of columns;

each pixel region comprising at least one optically sensitive material;

pixel circuitry for each of the respective pixel regions, the pixel circuitry for each respective pixel region applying a voltage difference across the optically sensitive material for the respective pixel region;

the pixel circuitry including a charge store to provide a charge related to the current flow through the optically sensitive material of the respective pixel region during an integration period of time;

the pixel circuitry including read out circuitry to generate a signal based on the charge of the charge store for the respective pixel region after the integration period of time; and

pixel select circuitry to select the pixel circuitry for a subset of the pixel regions to be read out;

wherein a rate of the current flow through the optically sensitive material at relatively high light levels causes the stored charge to remain above a minimum threshold as a result of a non-linear relationship between the current flow and intensity of the light absorbed by the optically sensitive material, wherein generating of the signal occurs when the stored charge is greater than the minimum threshold.

192. A photodetector comprising:

a semiconductor substrate;

a photosensor array having a plurality of pixel regions, the pixel regions arranged into a plurality of rows and a plurality of columns;

each pixel region comprising at least one optically sensitive material over a portion of the semiconductor substrate;

pixel circuitry formed on the semiconductor substrate for each of the respective pixel regions, the pixel circuitry for each respective pixel region configured to apply a voltage difference across the optically sensitive material for the respective pixel region and to read out a signal based on a flow of current through the optically sensitive material over a period of time; and

at least a portion of the pixel circuitry for a first respective pixel region formed under the optically sensitive material for a different respective pixel region that is not read out by the pixel circuitry for the first respective pixel region.

193. The photodetector of claim 192, wherein the pixel circuitry for the first respective pixel region includes a plurality of circuit elements, wherein at least one circuit element is formed under both the optically sensitive material for the first respective pixel region and optically sensitive material for the different respective pixel region.

194. The photodetector of claim 192, wherein first pixel circuitry for the first respective pixel region is formed in a first half of a first region of the semiconductor substrate and a first half of a second region of the semiconductor substrate, wherein second pixel circuitry for a second respective pixel region is formed in a second half of the first region of the semiconductor substrate and a second half of the second region of the semiconductor substrate.

195. The photodetector of claim 194, wherein the first region forms a first rectangular region on the semiconductor substrate and the second region forms a second rectangular region on the semiconductor substrate, wherein a first size of the first region and a first size of the second region are related by a first aspect ratio.

196. The photodetector of claim 195, wherein the first aspect ratio is 1:1.

197. The photodetector of claim 195, wherein the first aspect ratio is 2:3.

198. The photodetector of claim 195, wherein the first aspect ratio is 3:4.

199. The photodetector of claim 195, wherein the first pixel circuitry is substantially contained in a third rectangular region and the second pixel circuitry is substantially contained in a fourth rectangular region, wherein a third size of the third rectangular region and a fourth size of the fourth rectangular region are related by a second aspect ratio.

200. The photodetector of claim 8, wherein the second aspect ratio is higher than the first aspect ratio.

201. The photodetector of claim 8, wherein the second aspect ratio is more than two times the first aspect ratio.

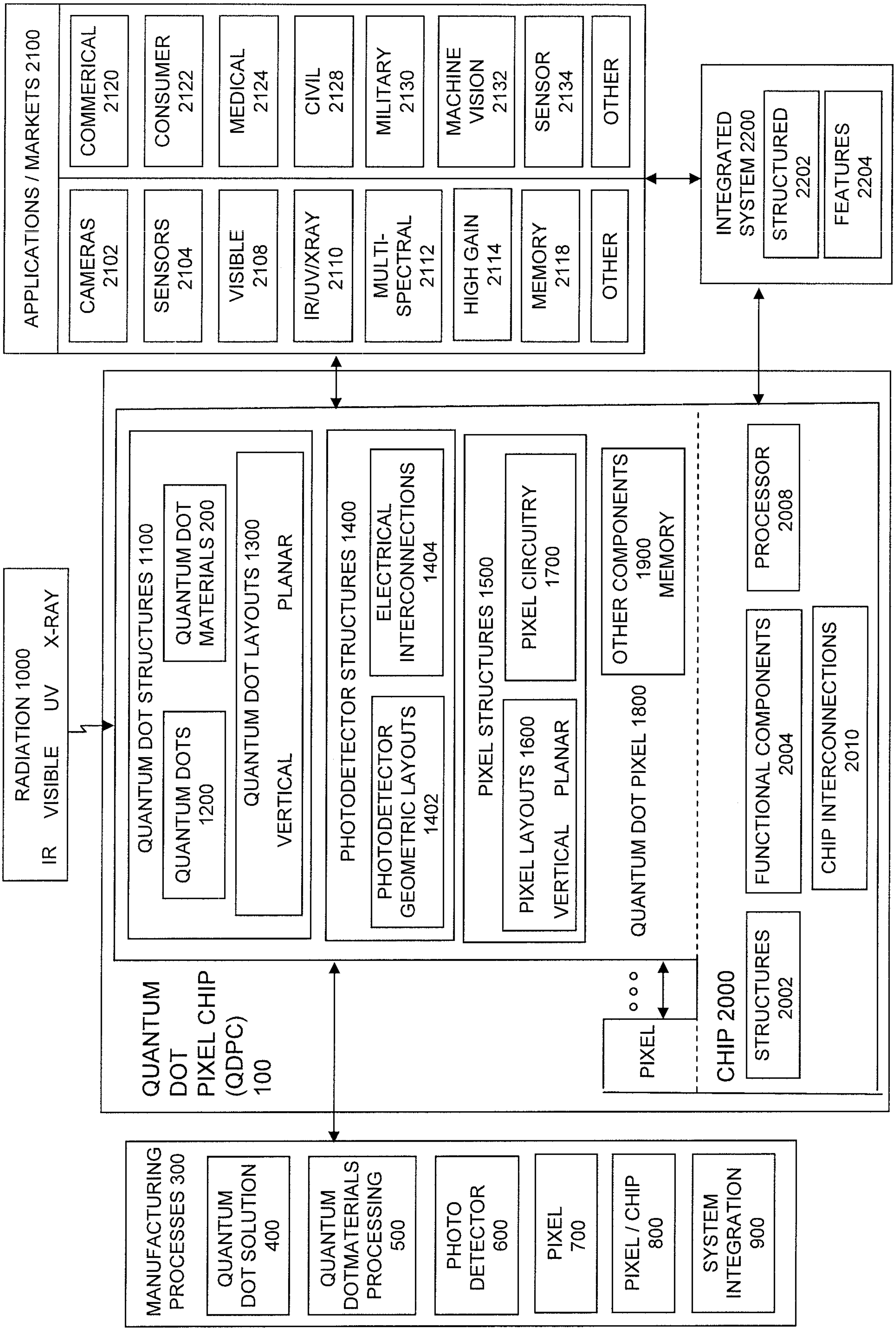

APPLICATIONS / MARKETS 2100
CAMERAS 2102
SENSORS 2104
VISIBLE 2108
IR/UV/XRAY 2110
MULTI-SPECTRAL 2112
HIGH GAIN 2114
MEMORY 2118
OTHER
COMMERICAL 2120
CONSUMER 2122
MEDICAL 2124
CIVIL 2128
MILITARY 2130
MACHINE VISION 2132
SENSOR 2134
OTHER
INTEGRATED SYSTEM 2200
STRUCTURED 2202
FEATURES 2204
RADIATION 1000
IR VISIBLE UV X-RAY
QUANTUM DOT PIXEL CHIP (QDPC) 100
QUANTUM DOT STRUCTURES 1100
QUANTUM DOTS 1200
QUANTUM DOT MATERIALS 200
QUANTUM DOT LAYOUTS 1300
VERTICAL PLANAR
PHOTODETECTOR STRUCTURES 1400
PHOTODETECTOR GEOMETRIC LAYOUTS 1402
ELECTRICAL INTERCONNECTIONS 1404
PIXEL STRUCTURES 1500
PIXEL LAYOUTS 1600
VERTICAL PLANAR
PIXEL CIRCUITRY 1700
OTHER COMPONENTS 1900
MEMORY
QUANTUM DOT PIXEL 1800
PIXEL
CHIP 2000
STRUCTURES 2002
FUNCTIONAL COMPONENTS 2004
CHIP INTERCONNECTIONS 2010
PROCESSOR 2008
MANUFACTURING PROCESSES 300
QUANTUM DOT SOLUTION 400
QUANTUM DOTMATERIALS PROCESSING 500
PHOTO DETECTOR 600
PIXEL 700
PIXEL / CHIP 800
SYSTEM INTEGRATION 900

Fig. 1

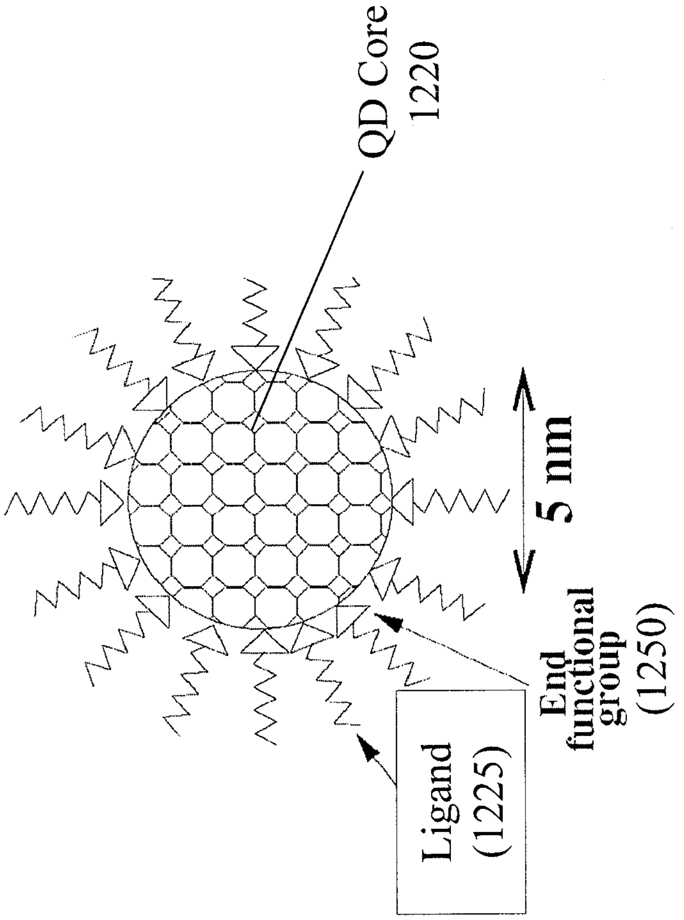


Fig. 2a

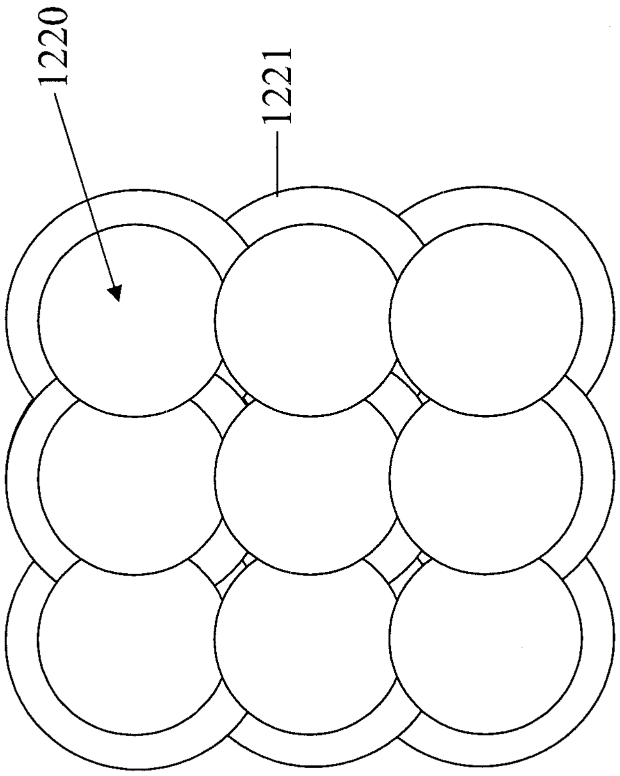


Fig. 2b

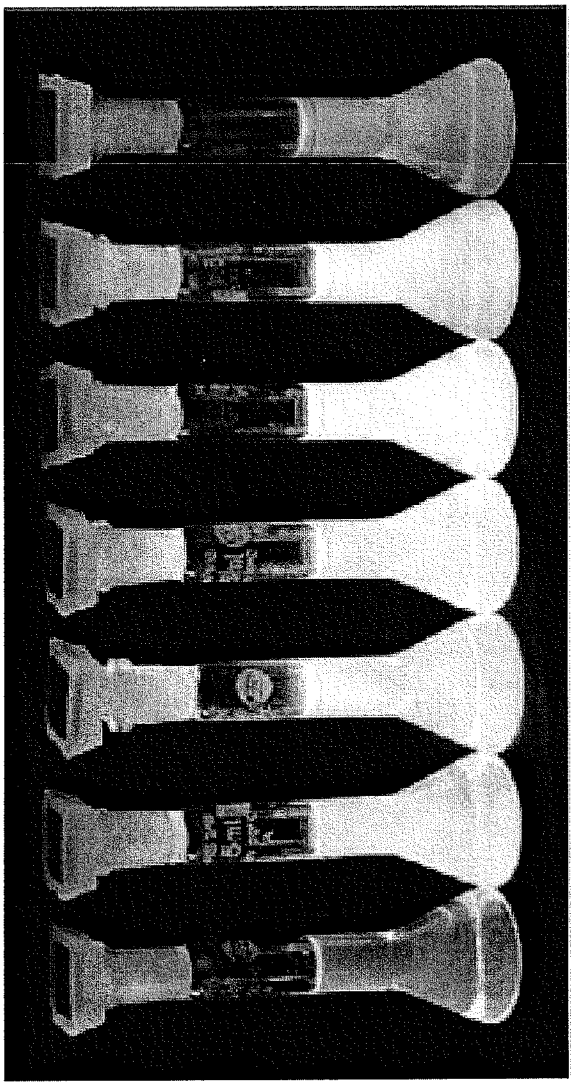


Fig. 2c

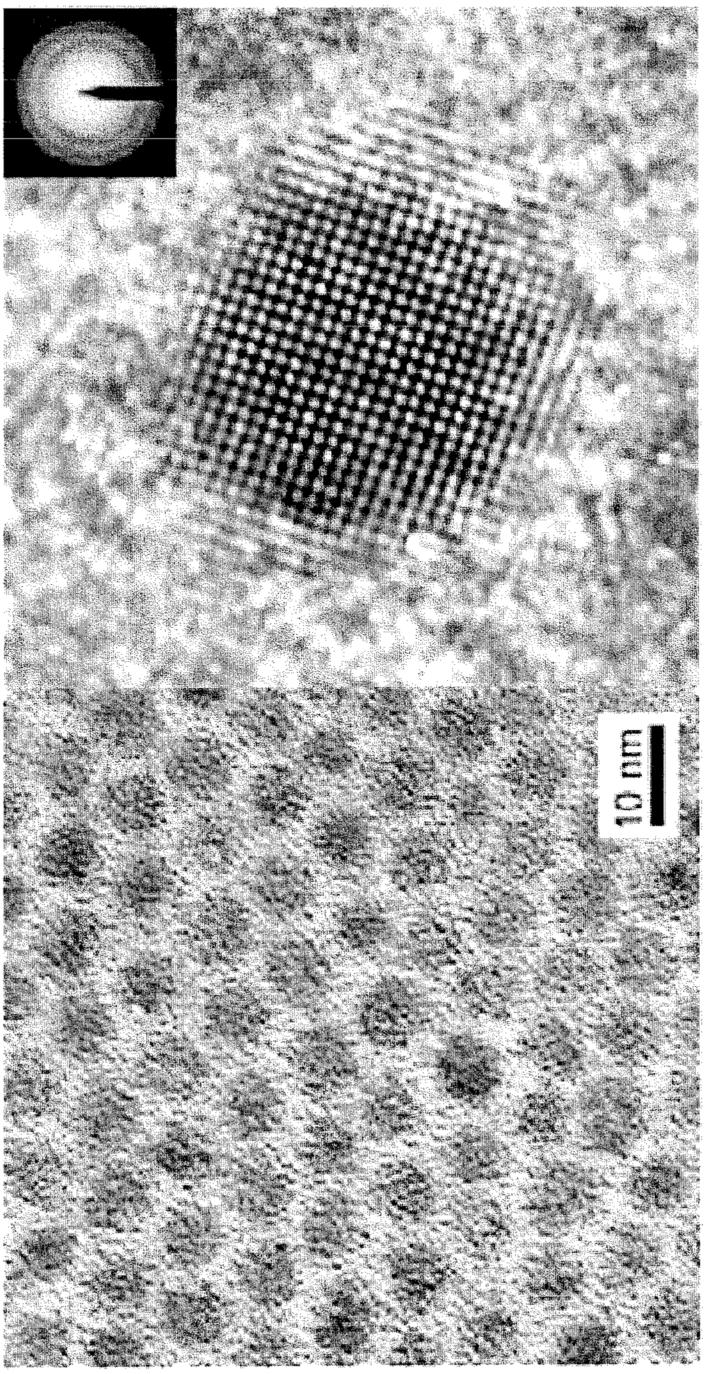
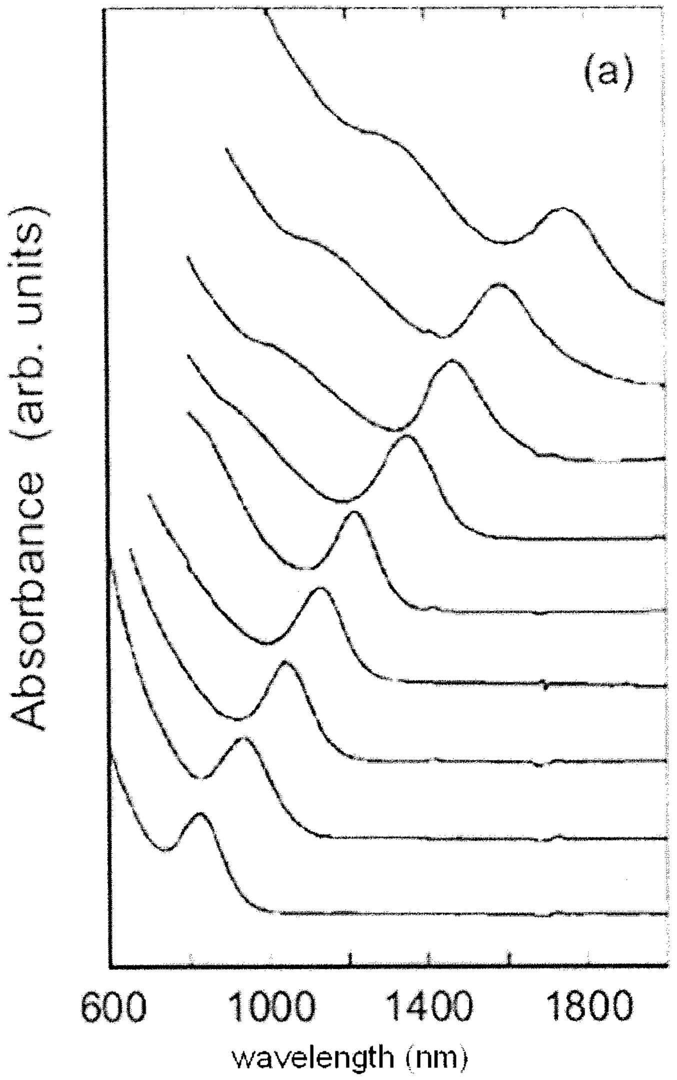


Fig. 2d



Colloidal PbS Nanocrystals with Size-Tunable Near IR Emission

Fig. 2e

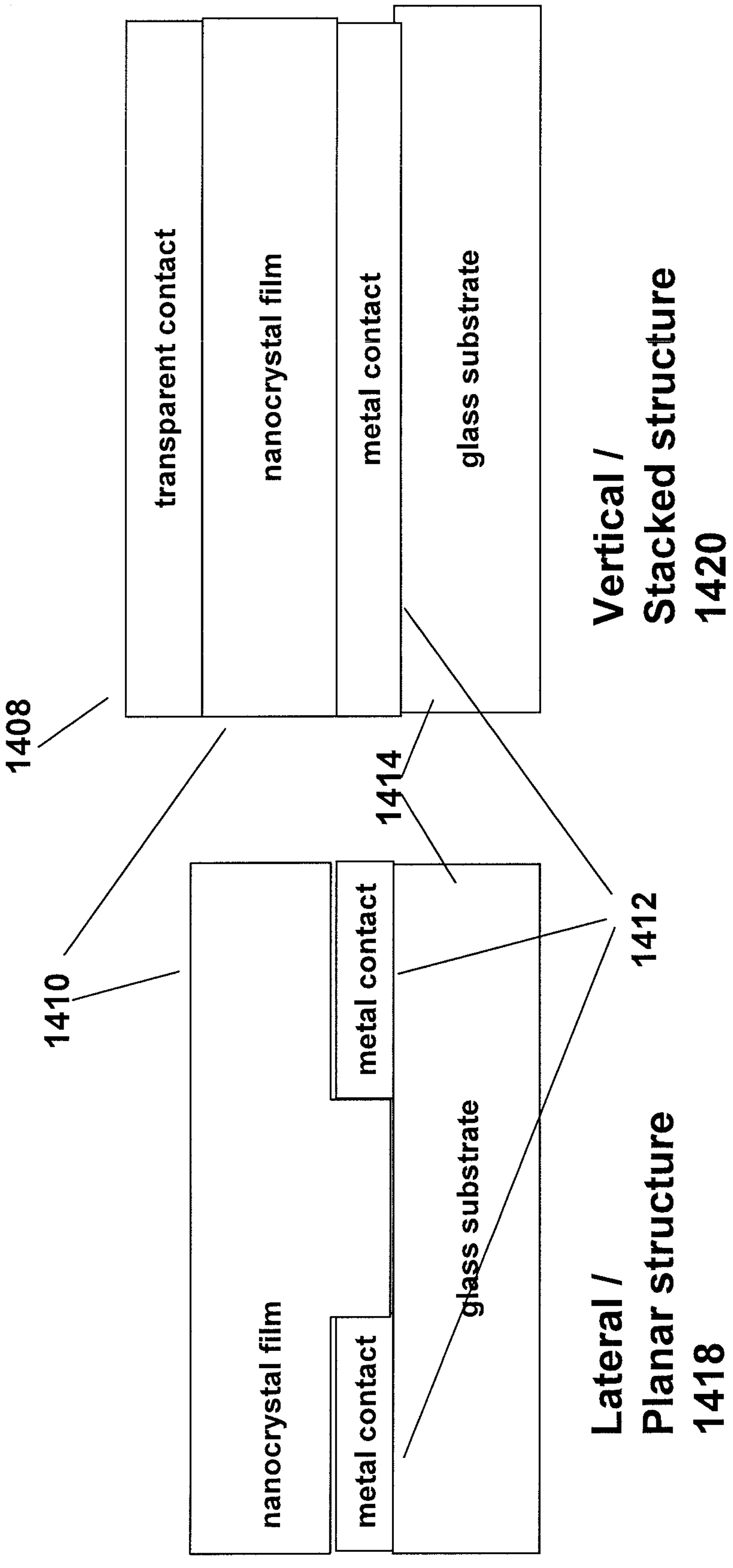

transparent contact
nanocrystal film
metal contact
glass substrate
Vertical /
Stacked structure
1420
1408
1410
1414
1412
nanocrystal film
metal contact
metal contact
glass substrate
Lateral /
Planar structure
1418

Fig. 3

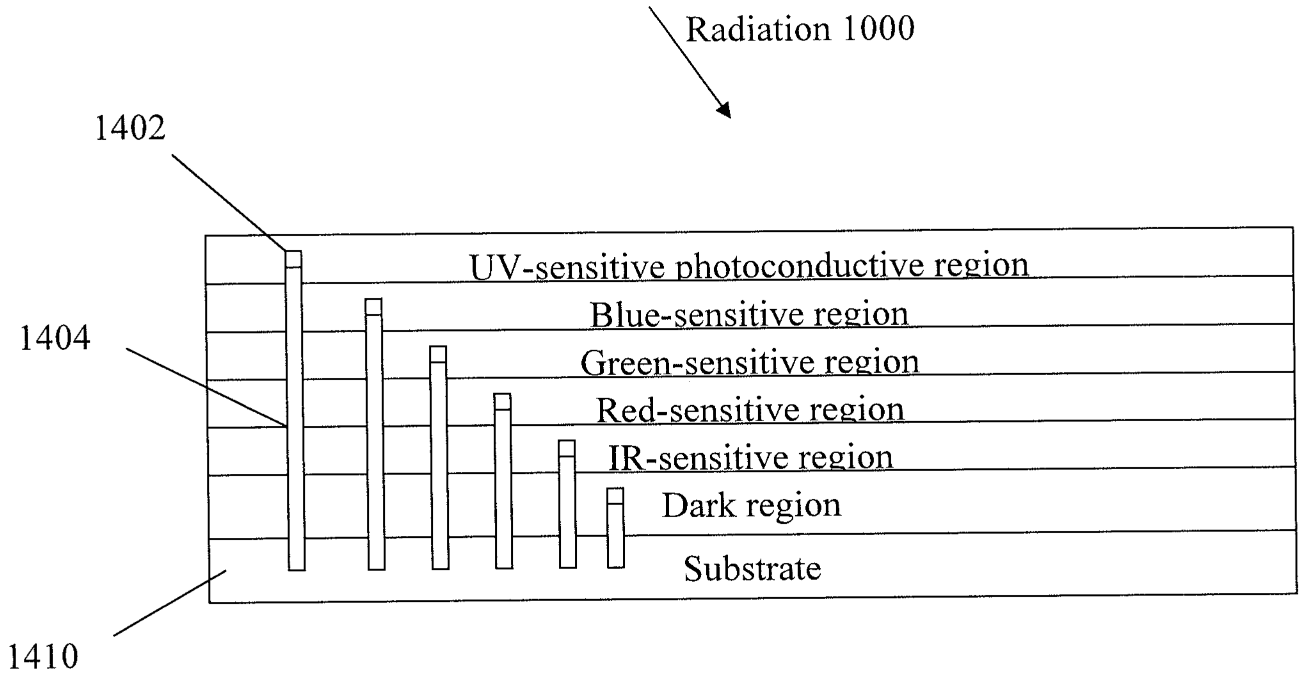

Radiation 1000
1402
1404
1410
UV-sensitive photoconductive region
Blue-sensitive region
Green-sensitive region
Red-sensitive region
IR-sensitive region
Dark region
Substrate

Fig. 3a

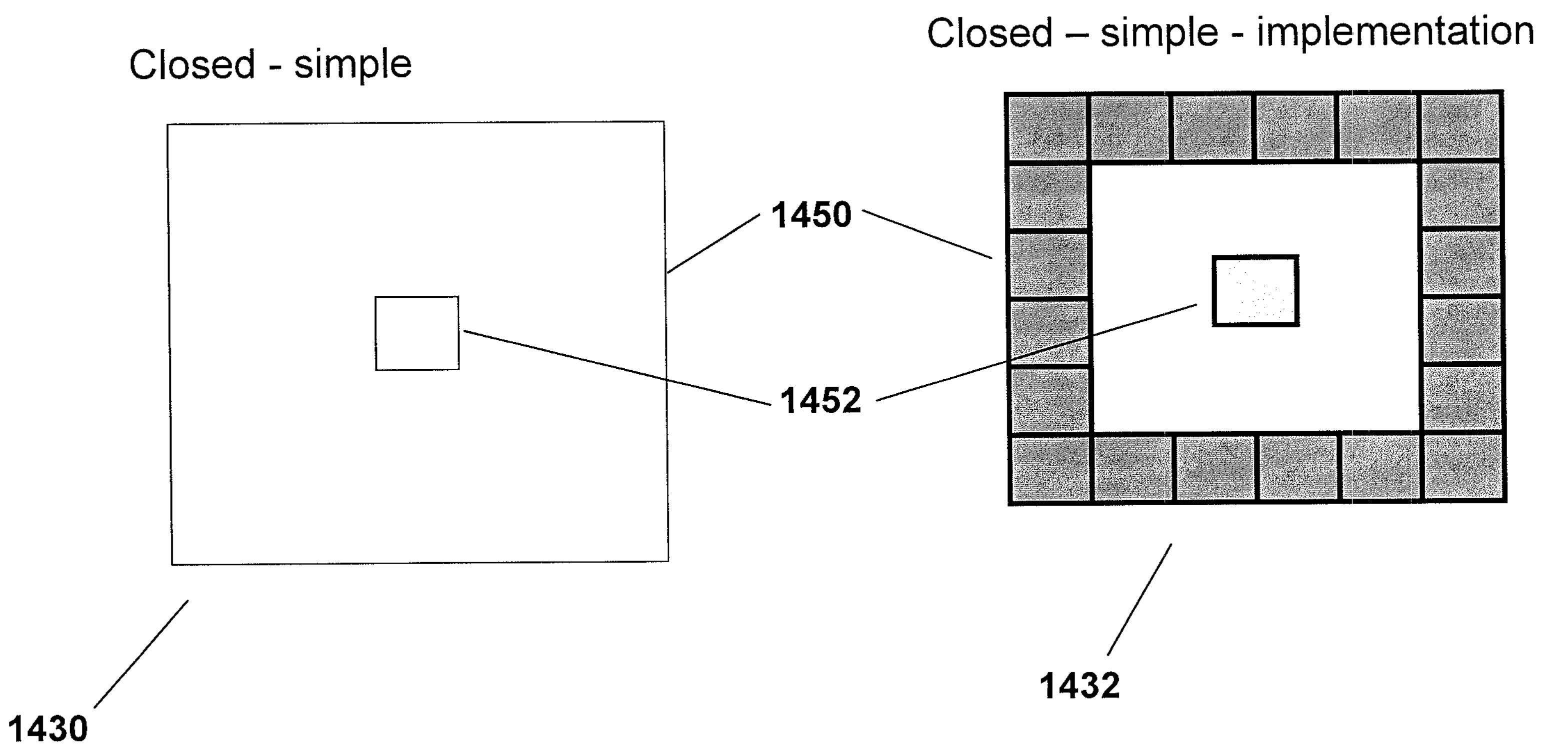

Closed - simple
Closed – simple - implementation
1450
1452
1430
1432

Fig. 3b

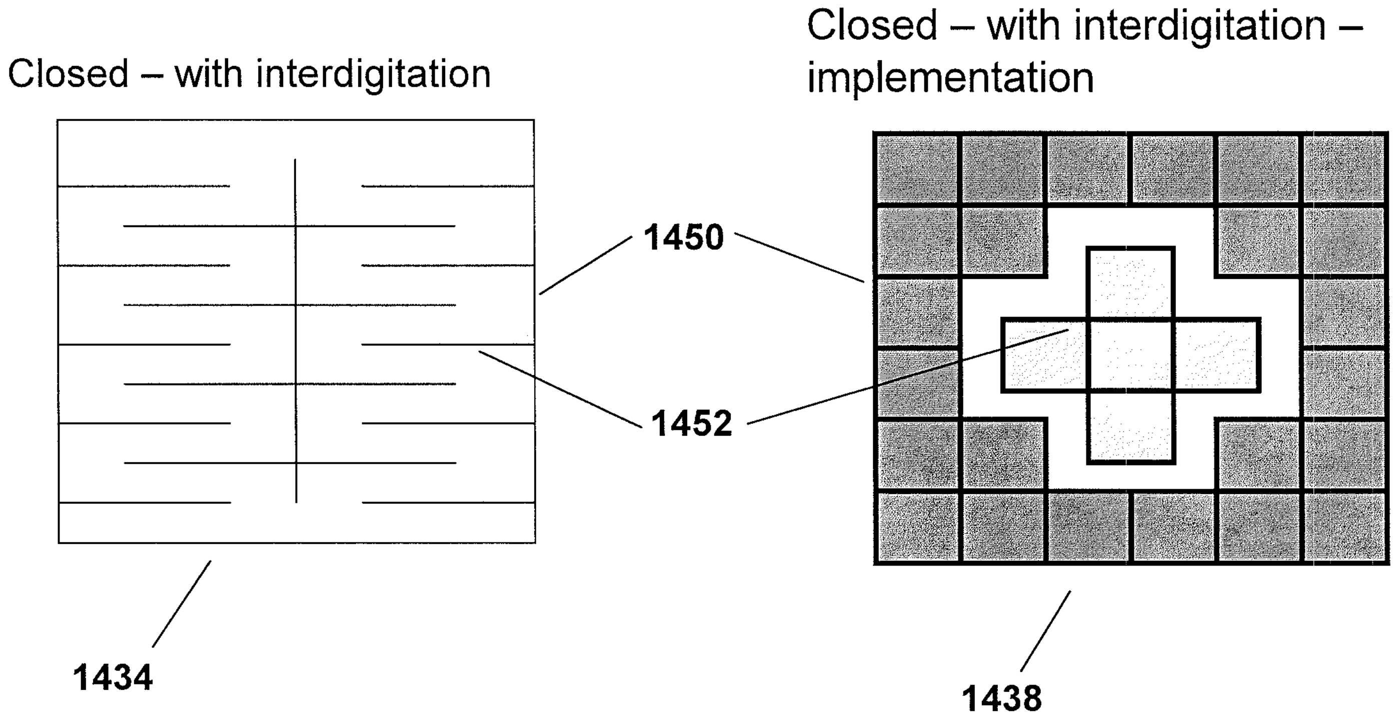

Closed – with interdigitation
Closed – with interdigitation – implementation
1450
1452
1434
1438

Fig. 3c

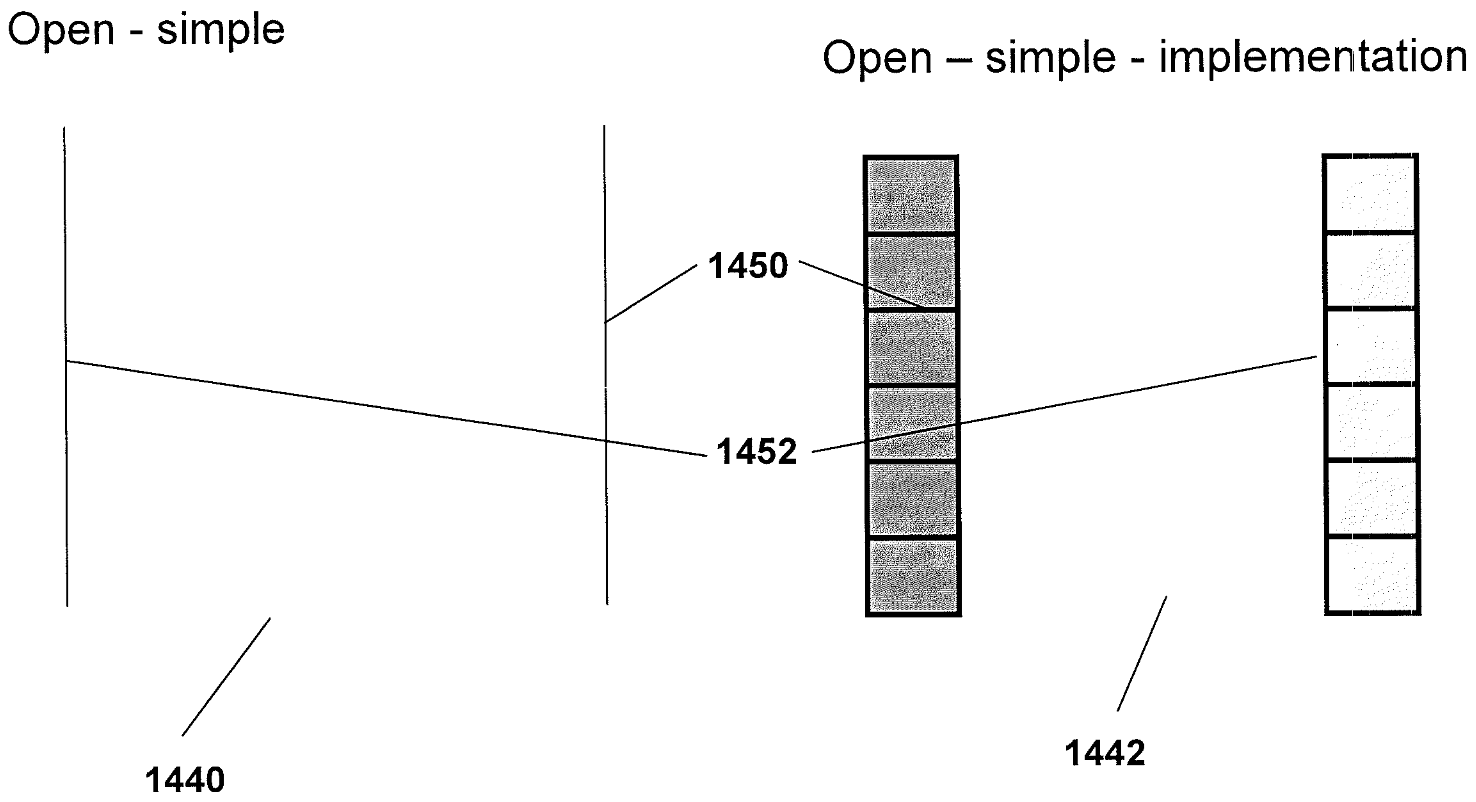
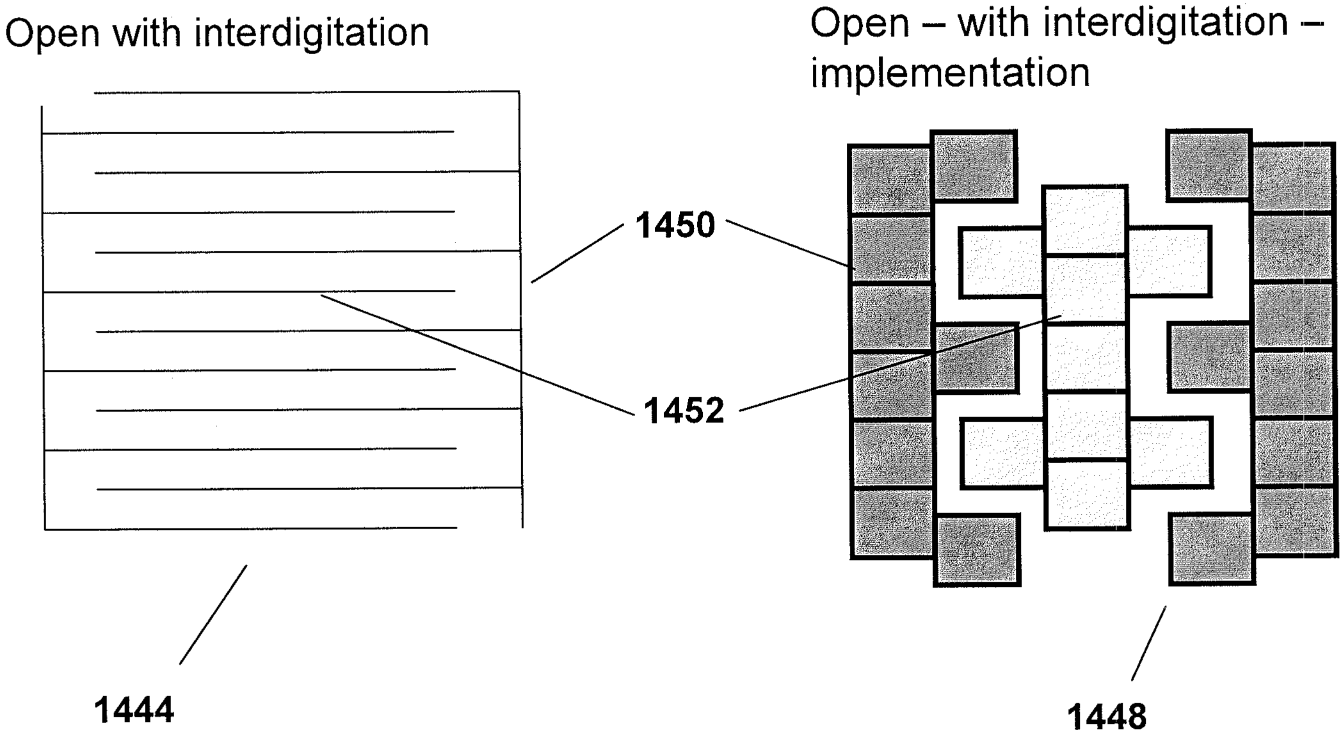

Open - simple
Open – simple - implementation
1450
1452
1440
1442

Fig. 3d


Open with interdigitation

Open – with interdigitation – implementation

Fig. 3e

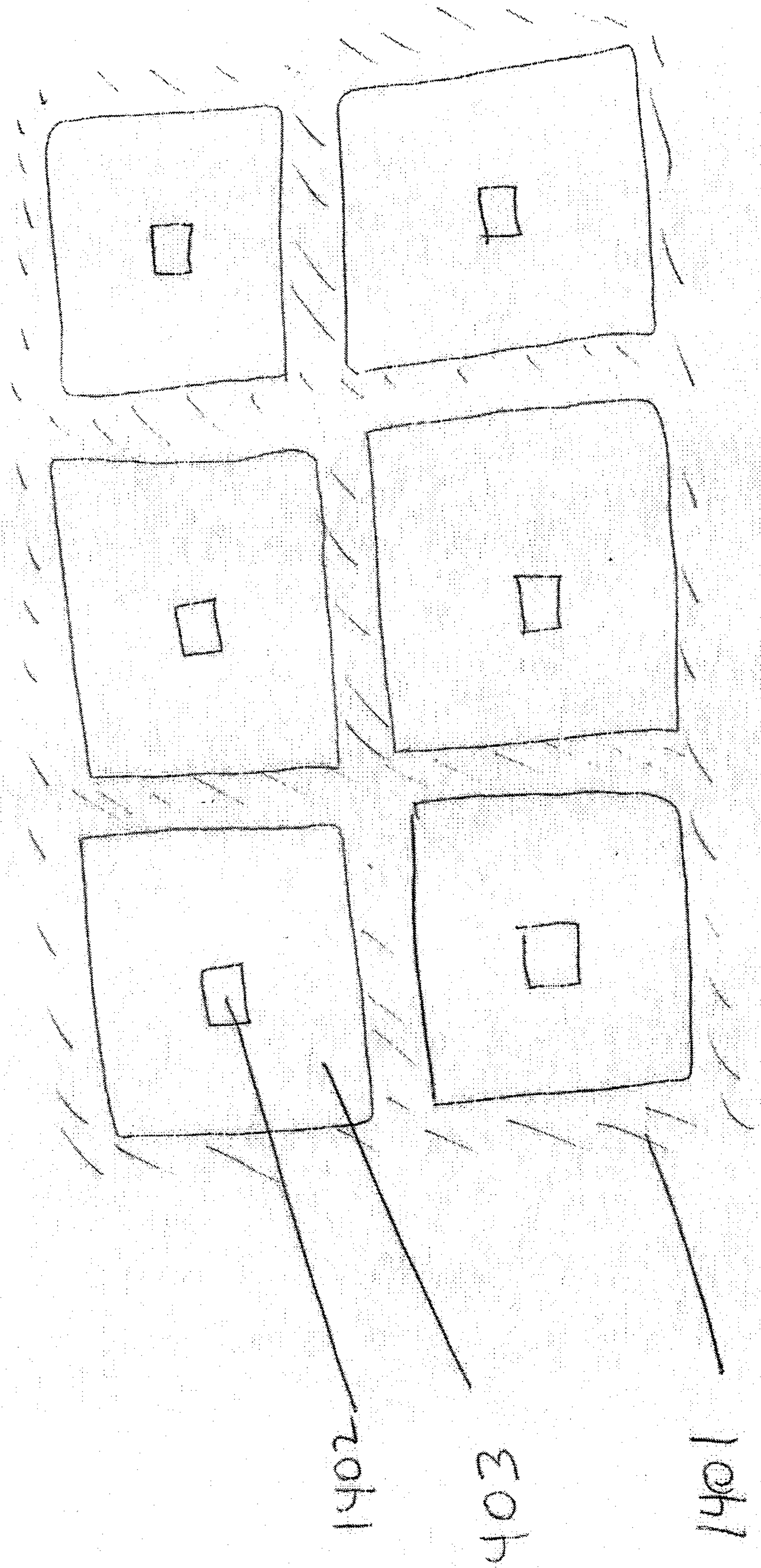


FIG. 3f

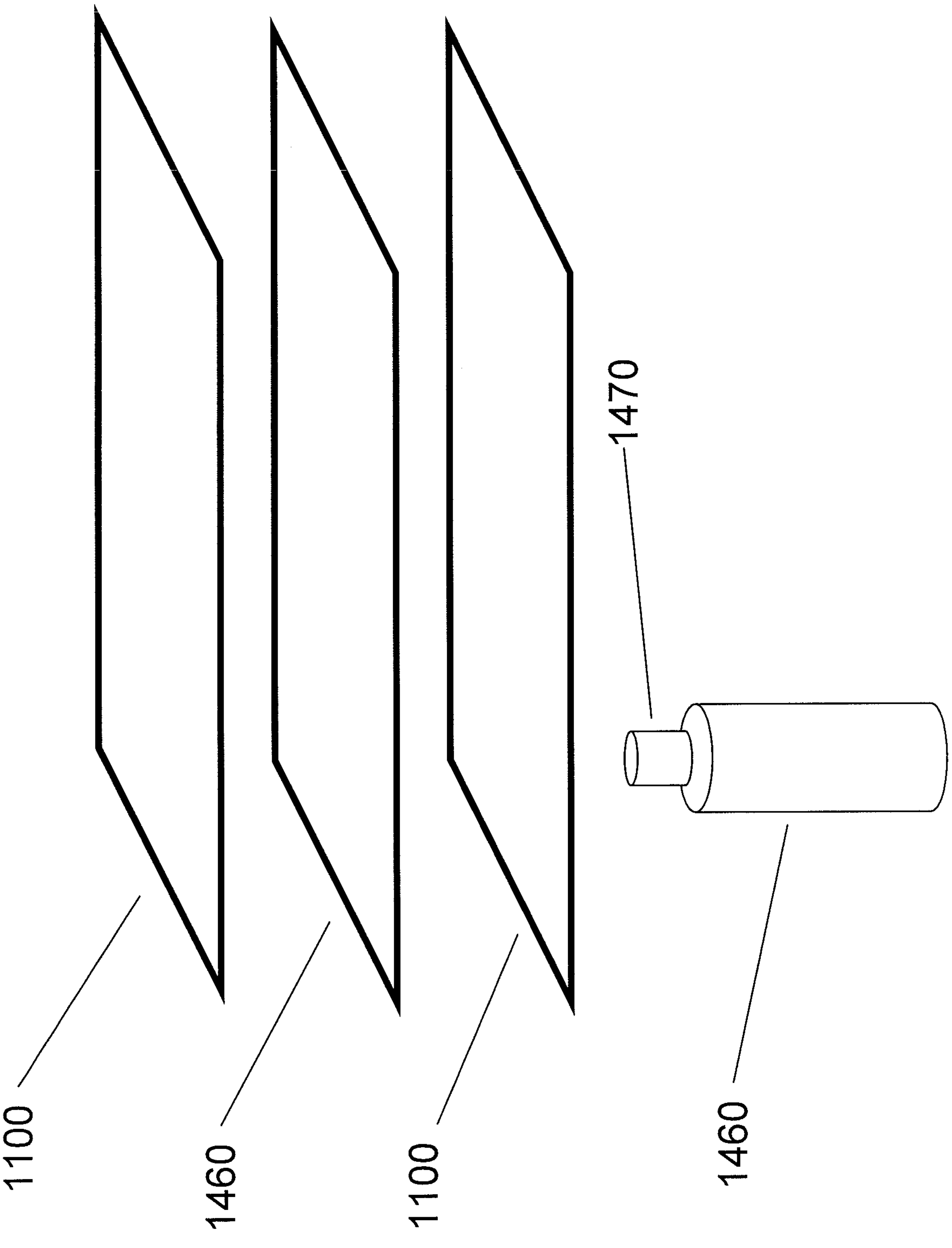


Fig. 3g

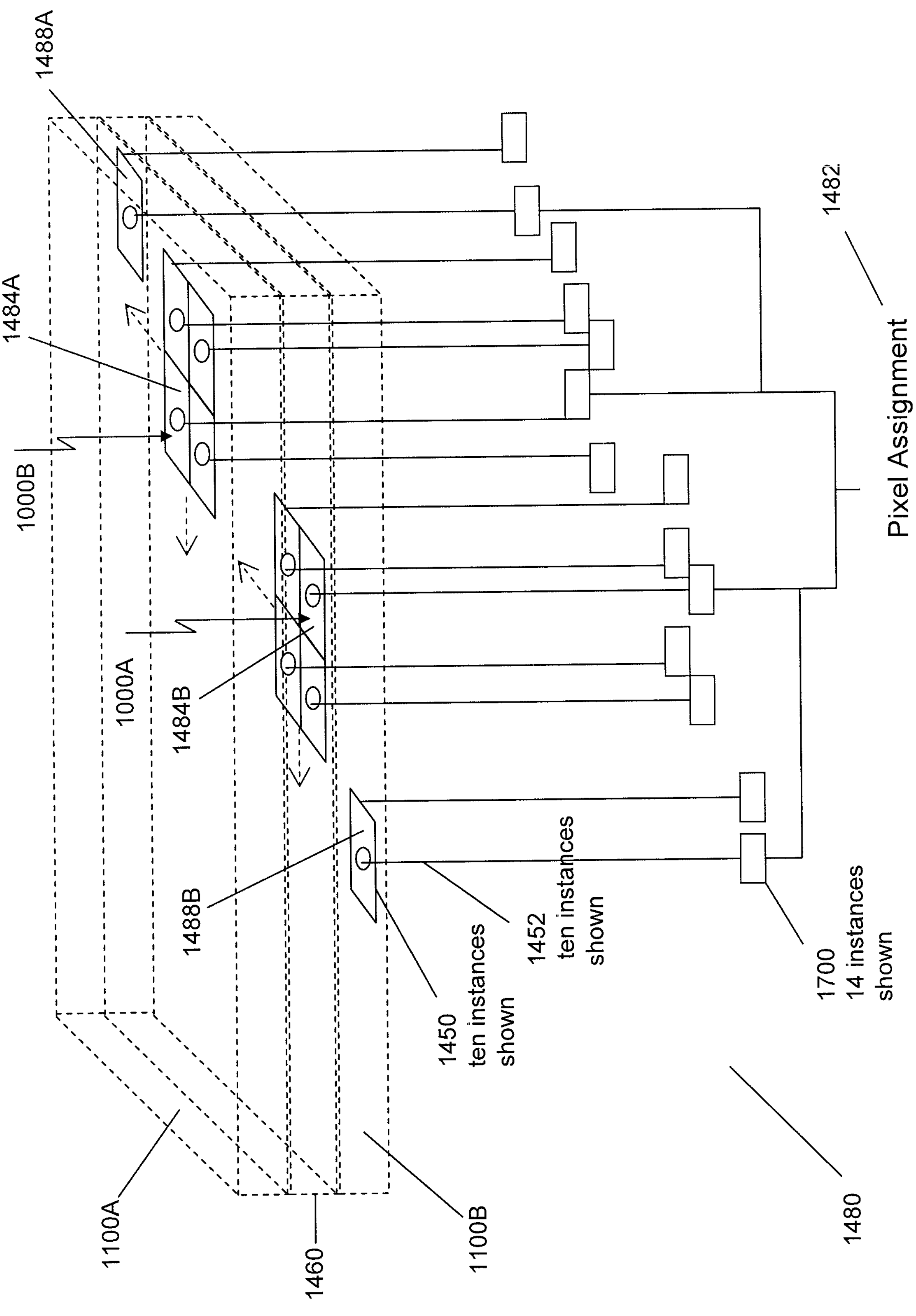

1488A
1484A
1000B
1000A
1484B
1488B
1482
Pixel Assignment
1450
ten instances
shown
1452
ten instances
shown
1700
14 instances
shown
1100A
1460
1100B
1480

Fig. 3h

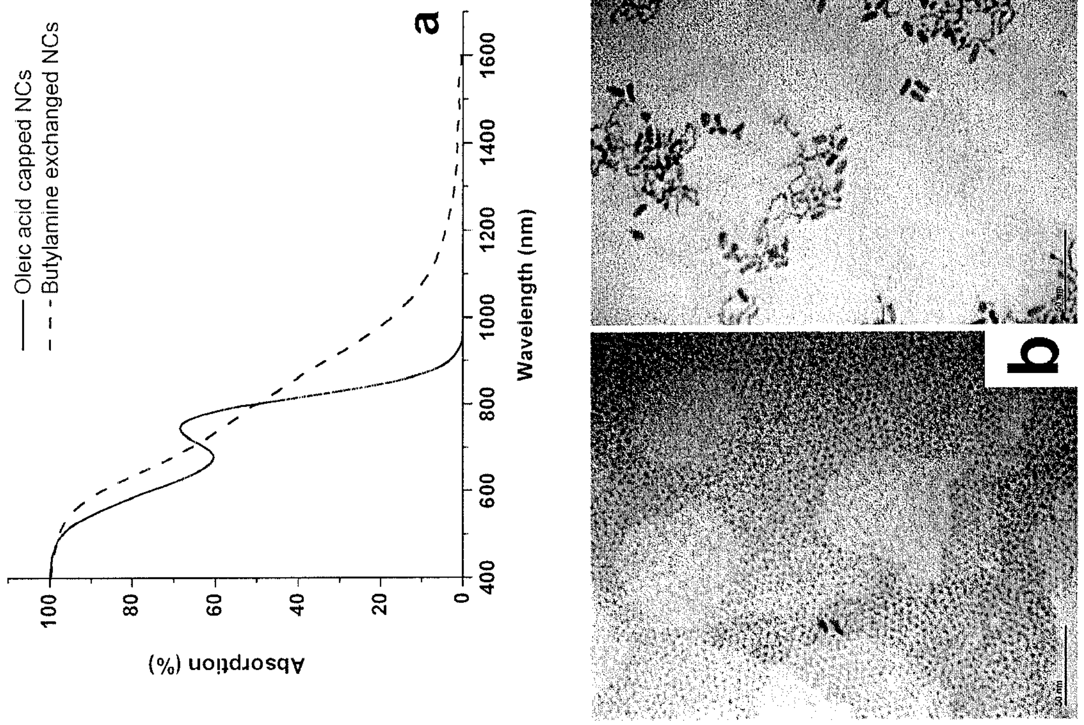

Oleic acid capped NCs
Butylamine exchanged NCs
Absorption (%)
100
80
60
40
20
0
400
600
800
1000
1200
1400
1600
Wavelength (nm)
a
b
c

Fig. 3i

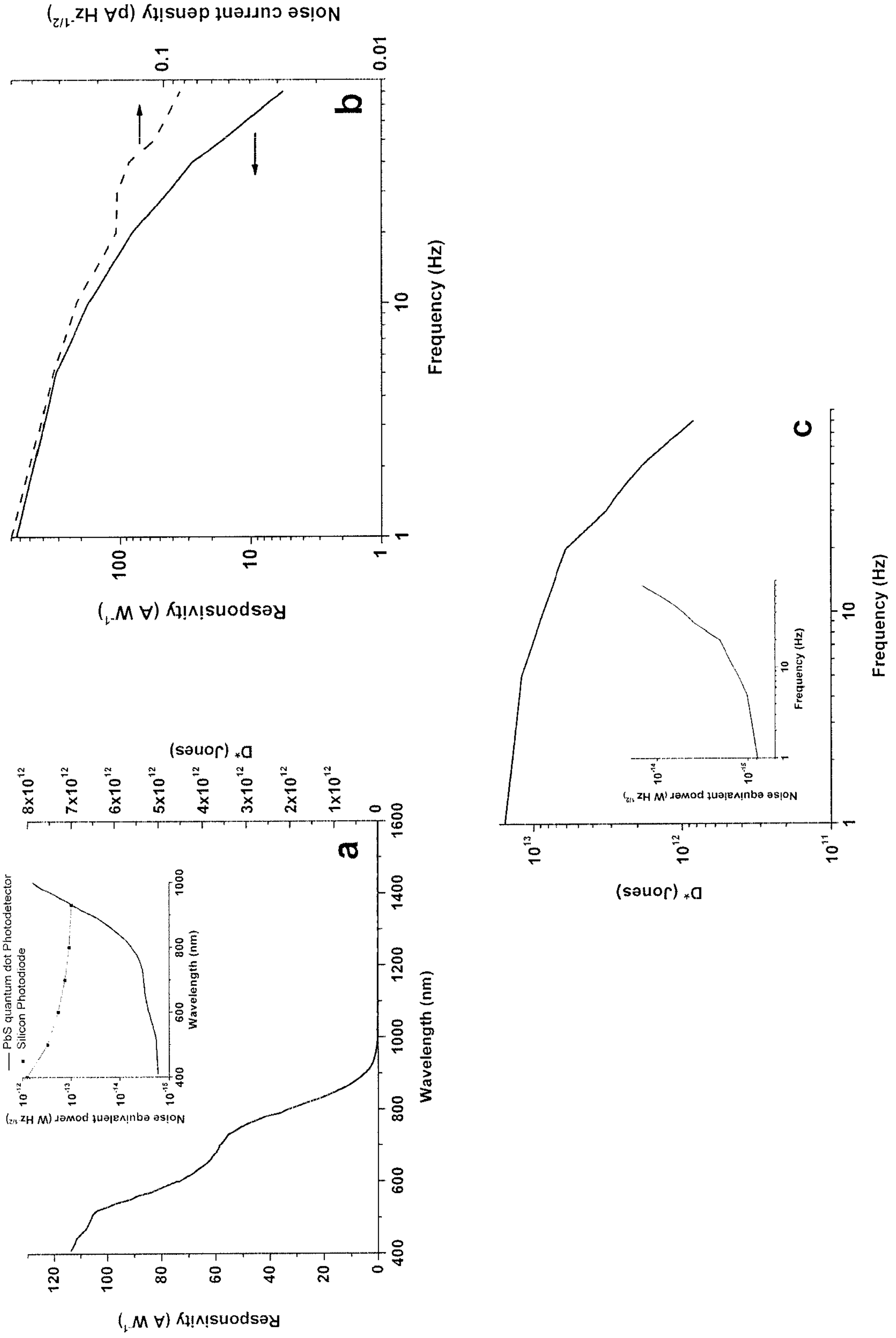

a
Responsivity (A W-1)
0
20
40
60
80
100
120
Wavelength (nm)
400
600
800
1000
1200
1400
1600
D* (Jones)
0
1x10^12
2x10^12
3x10^12
4x10^12
5x10^12
6x10^12
7x10^12
8x10^12
— PbS quantum dot Photodetector
▪ Silicon Photodiode
Noise equivalent power (W Hz-1/2)
10^-12
10^-13
10^-14
10^-15
Wavelength (nm)
400
600
800
1000
b
Responsivity (A W-1)
1
10
100
Frequency (Hz)
1
10
Noise current density (pA Hz-1/2)
0.01
0.1
c
D* (Jones)
10^11
10^12
10^13
Frequency (Hz)
1
10
Noise equivalent power (W Hz-1/2)
10^-14
10^-15
Frequency (Hz)
1
10

Fig. 3j

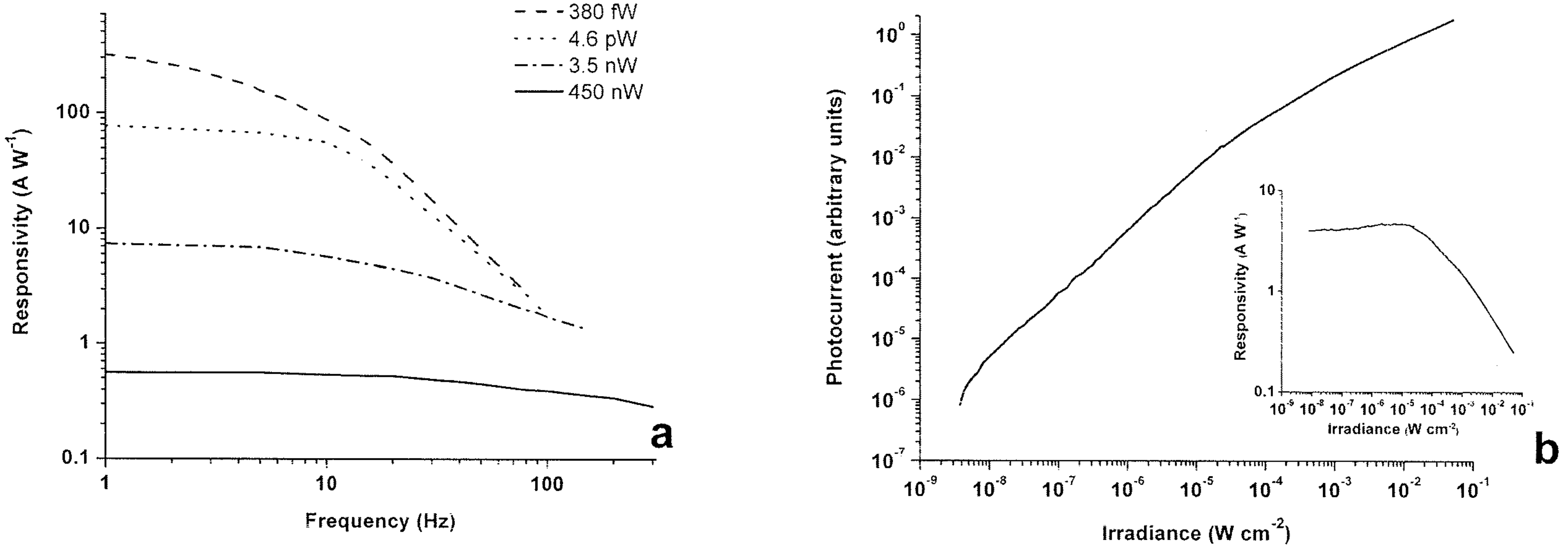

Responsivity (A W-1)
100
10
1
0.1
1
10
100
Frequency (Hz)
380 fW
4.6 pW
3.5 nW
450 nW
a
Photocurrent (arbitrary units)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
Irradiance (W cm-2)
Responsivity (A W-1)
10
1
0.1
Irradiance (W cm-2)
b

Fig. 3k

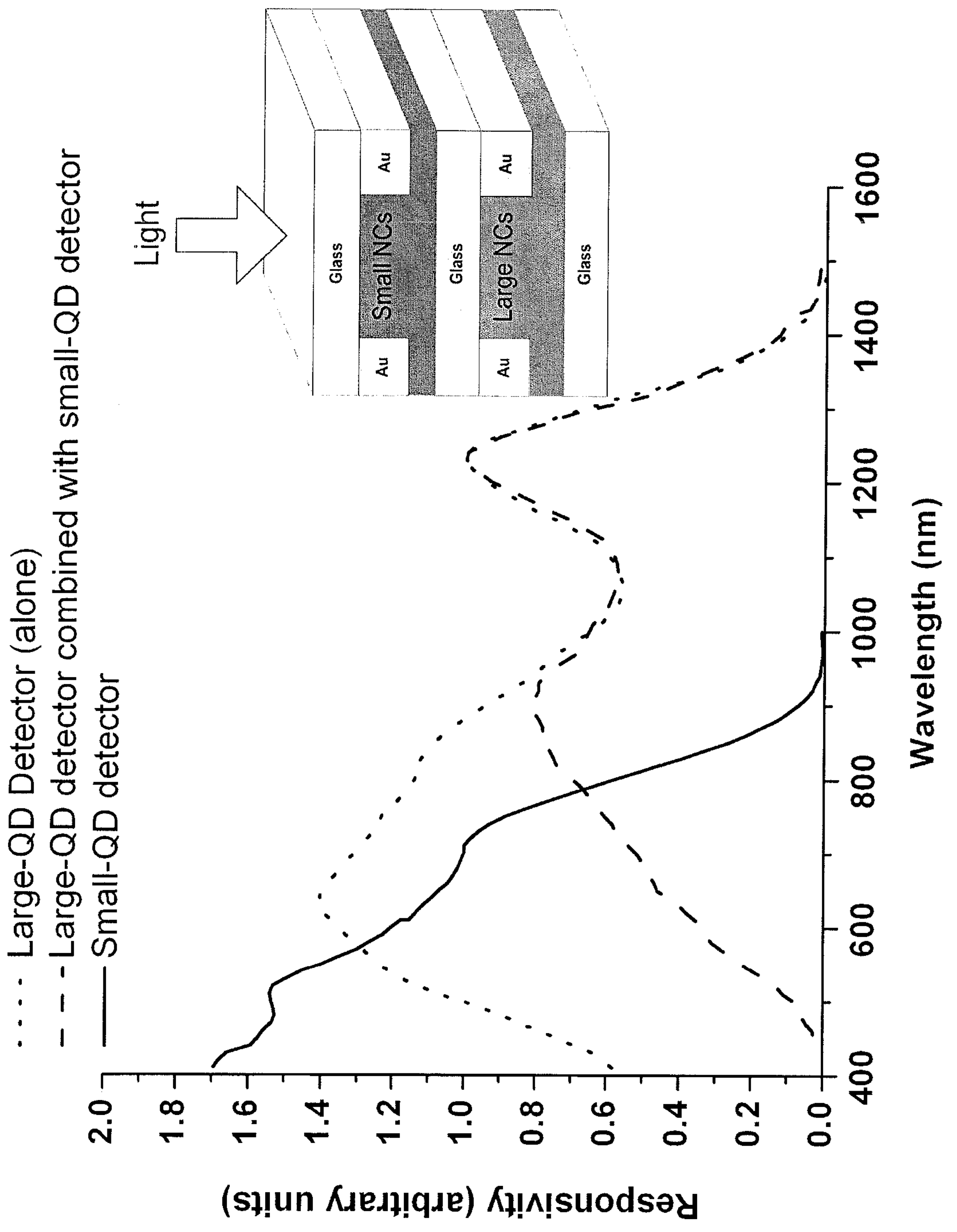

· · · · Large-QD Detector (alone)
– – – Large-QD detector combined with small-QD detector
—— Small-QD detector
Light
Glass
Au
Small NCs
Au
Glass
Au
Large NCs
Au
Glass
Responsivity (arbitrary units)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
400
600
800
1000
1200
1400
1600
Wavelength (nm)

Fig. 3I

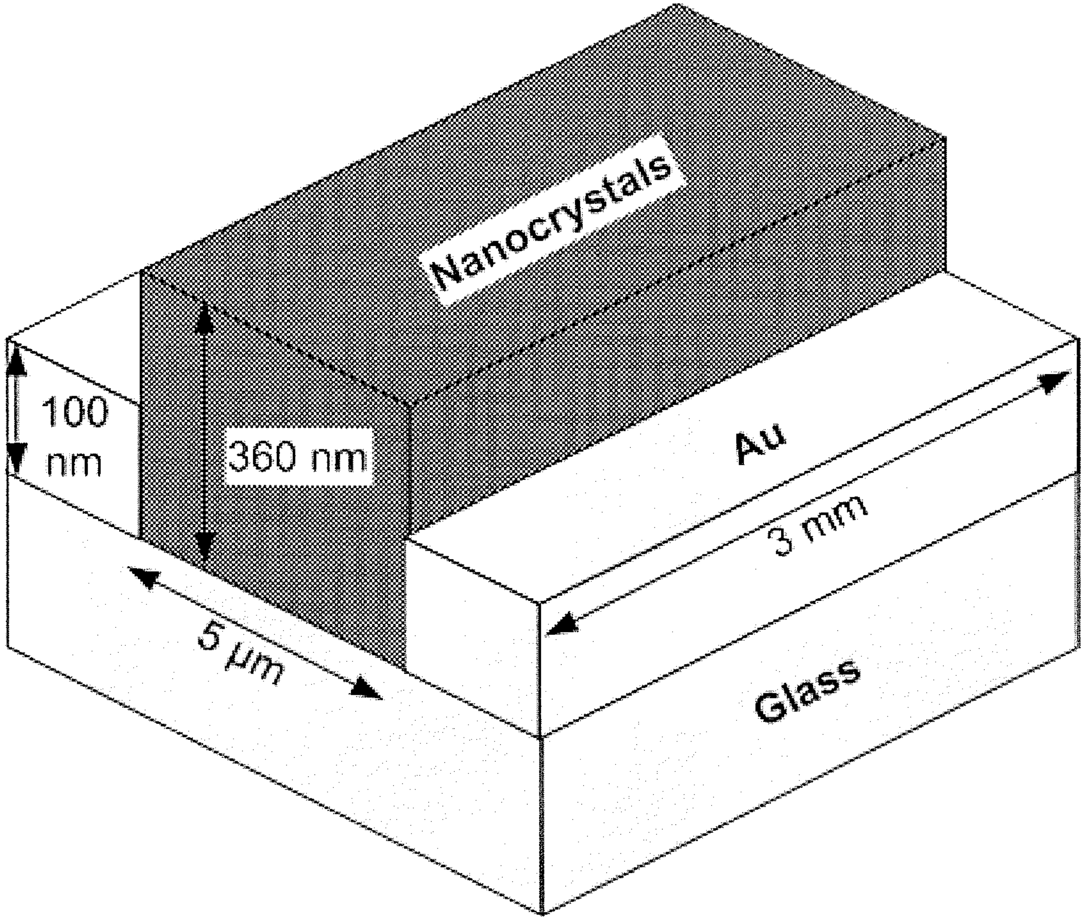


Fig. 3m

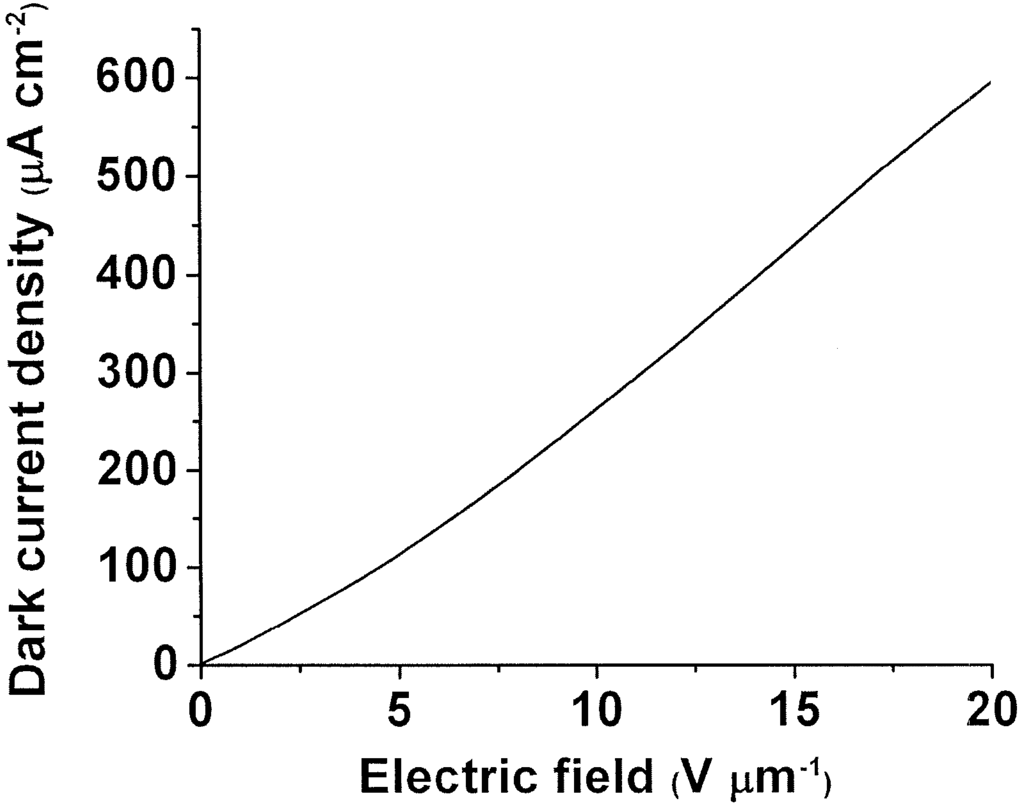

Dark current density (μA cm-2)
600
500
400
300
200
100
0
0
5
10
15
20
Electric field (V μm-1)

Fig. 3n

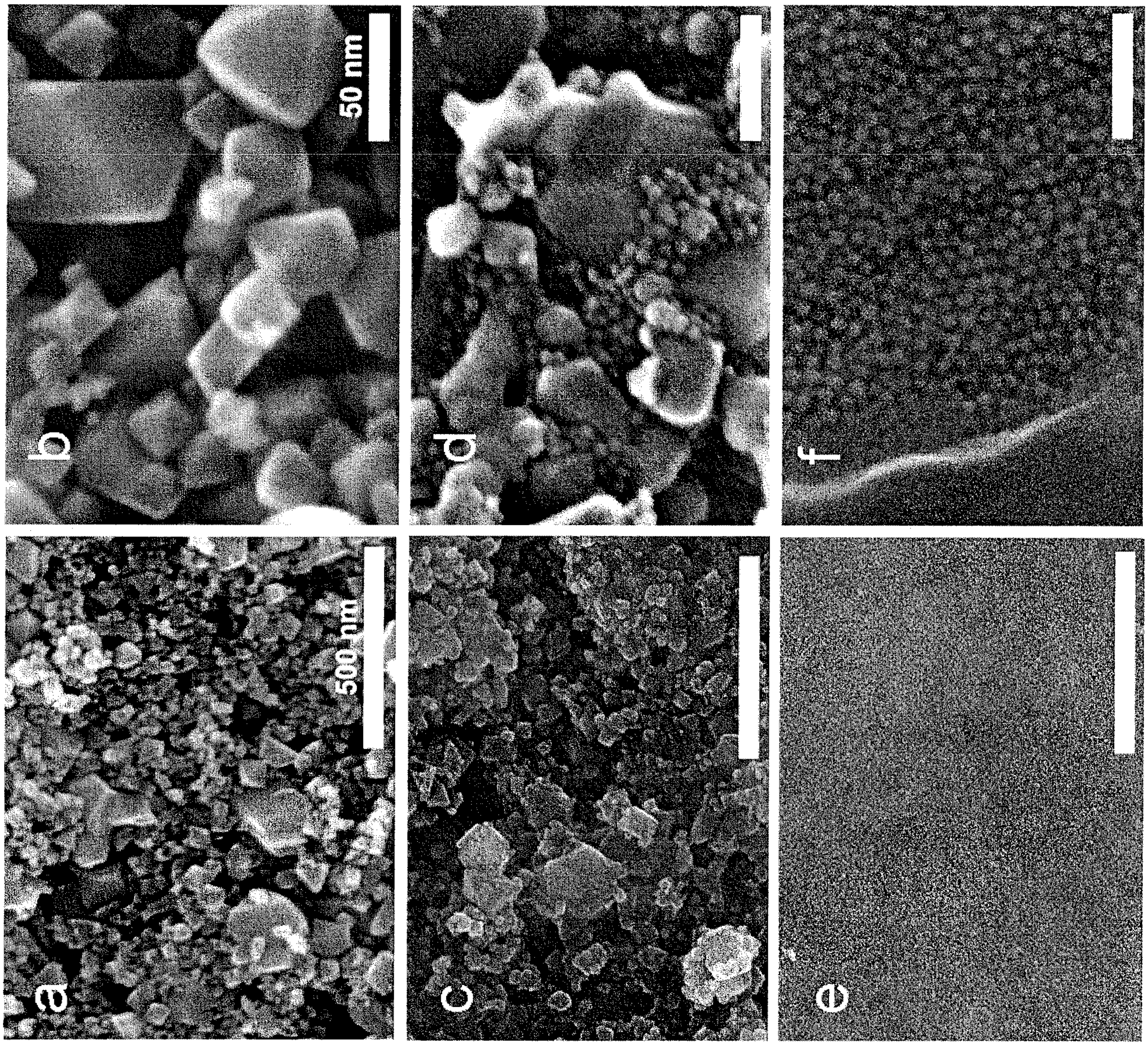


Fig. 3o

	Voc (mV)	Jsc (mA/cm^2)	η_P (%)	EQE (%)
1340 nm device no sintering	170	0.2	0.02	2.1
1340 nm device 150 C sintering	400	1.0	1.3	10
1590 nm device no sintering	70	0.02	0.003	0.2
1590 nm device 130 C sintering	85	1.5	0.3	16

Fig. 3p

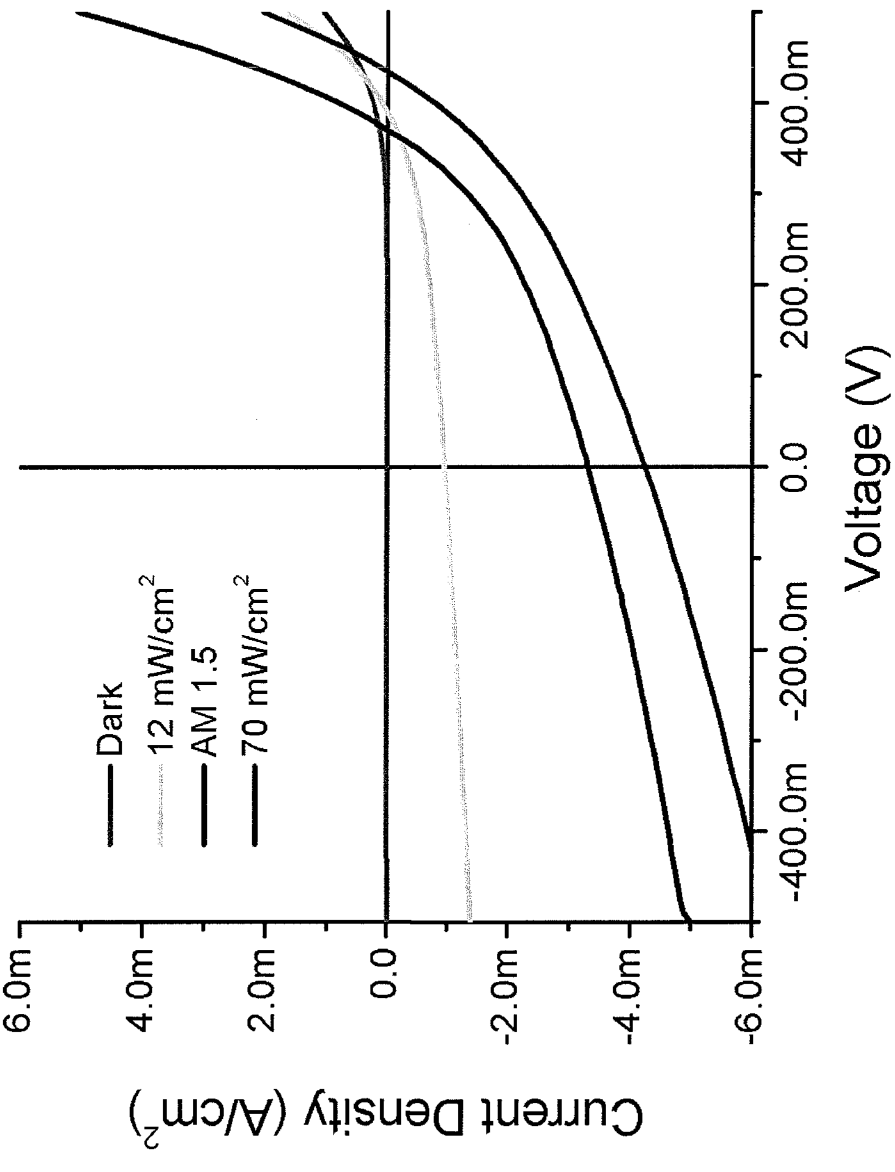

Dark
12 mW/cm^2
AM 1.5
70 mW/cm^2
Current Density (A/cm^2)
6.0m
4.0m
2.0m
0.0
-2.0m
-4.0m
-6.0m
Voltage (V)
-400.0m
-200.0m
0.0
200.0m
400.0m

Fig. 3q

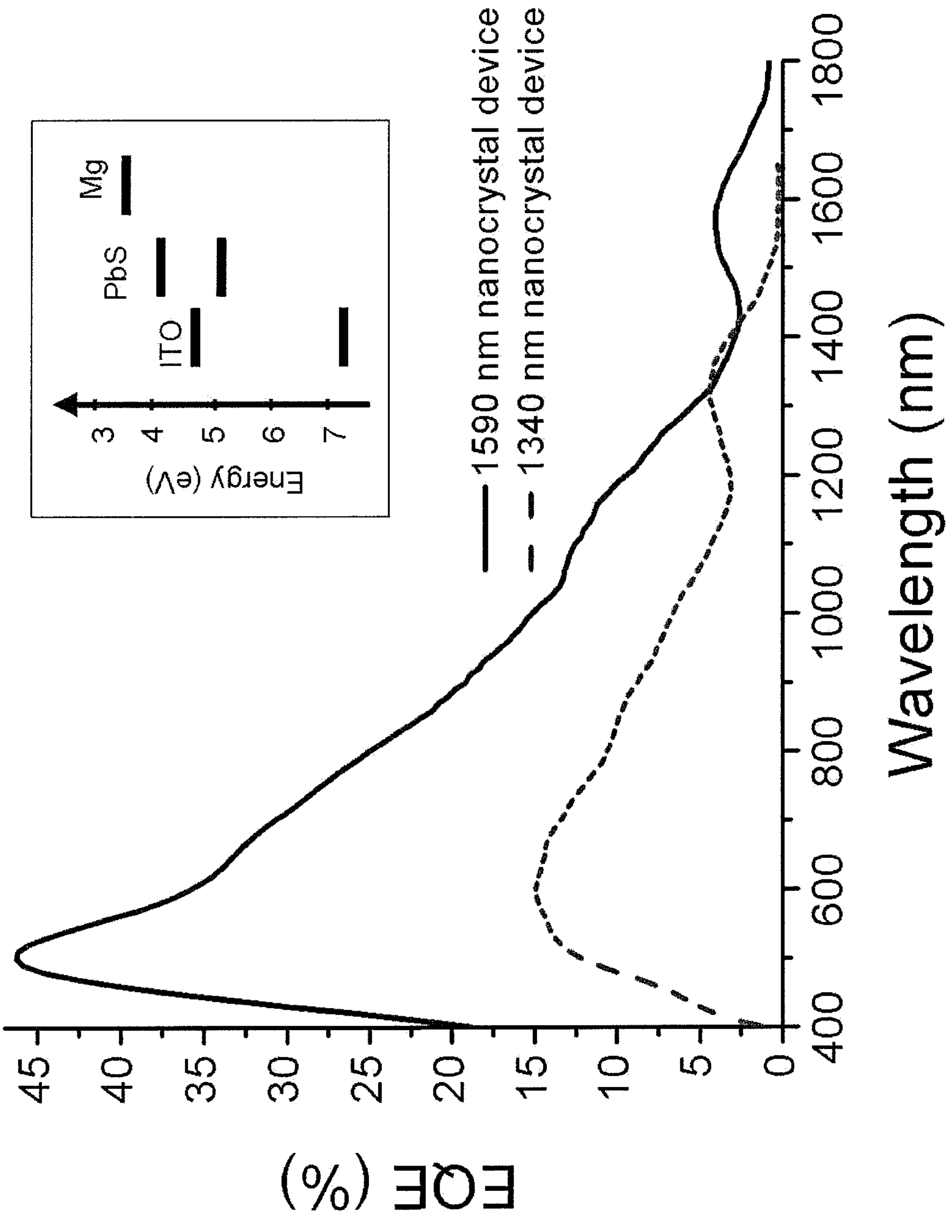
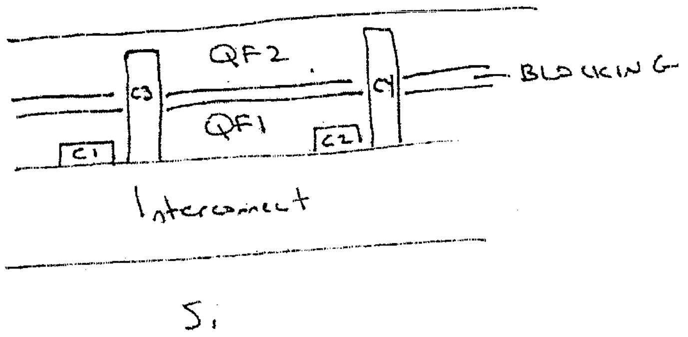
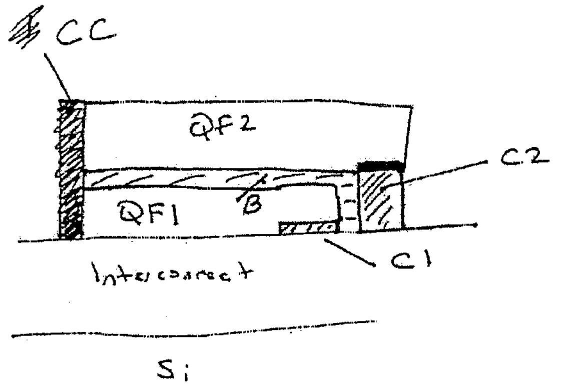

EQE (%)
0
5
10
15
20
25
30
35
40
45
Wavelength (nm)
400
600
800
1000
1200
1400
1600
1800
1590 nm nanocrystal device
1340 nm nanocrystal device
Energy (eV)
3
4
5
6
7
ITO
PbS
Mg

Fig. 3r



Side view

FIG. 3S



Side view

FIG. 3t

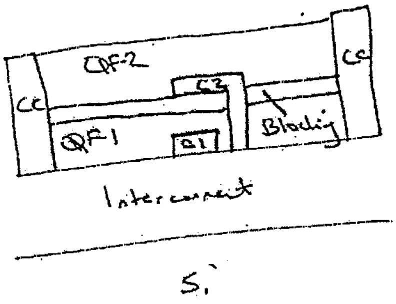


FIG. 3u - . Side

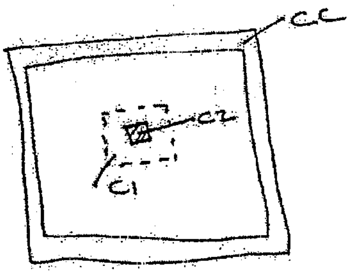


FIG. 3V - TOP.

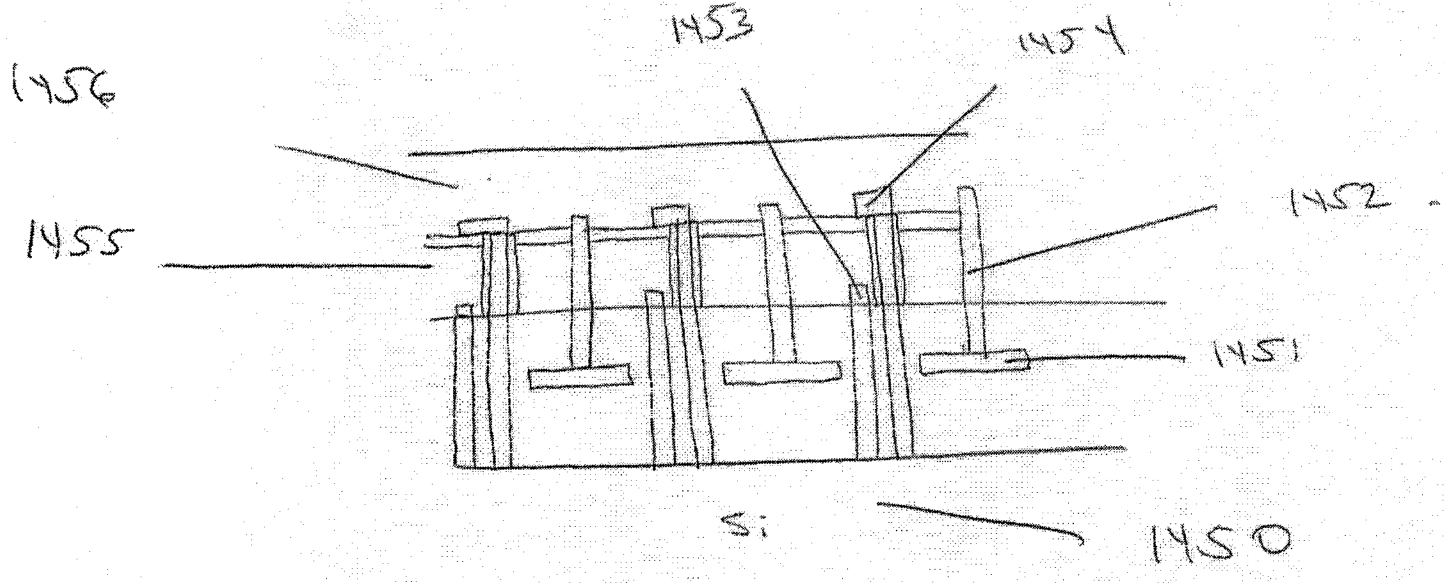


FIG. 3W

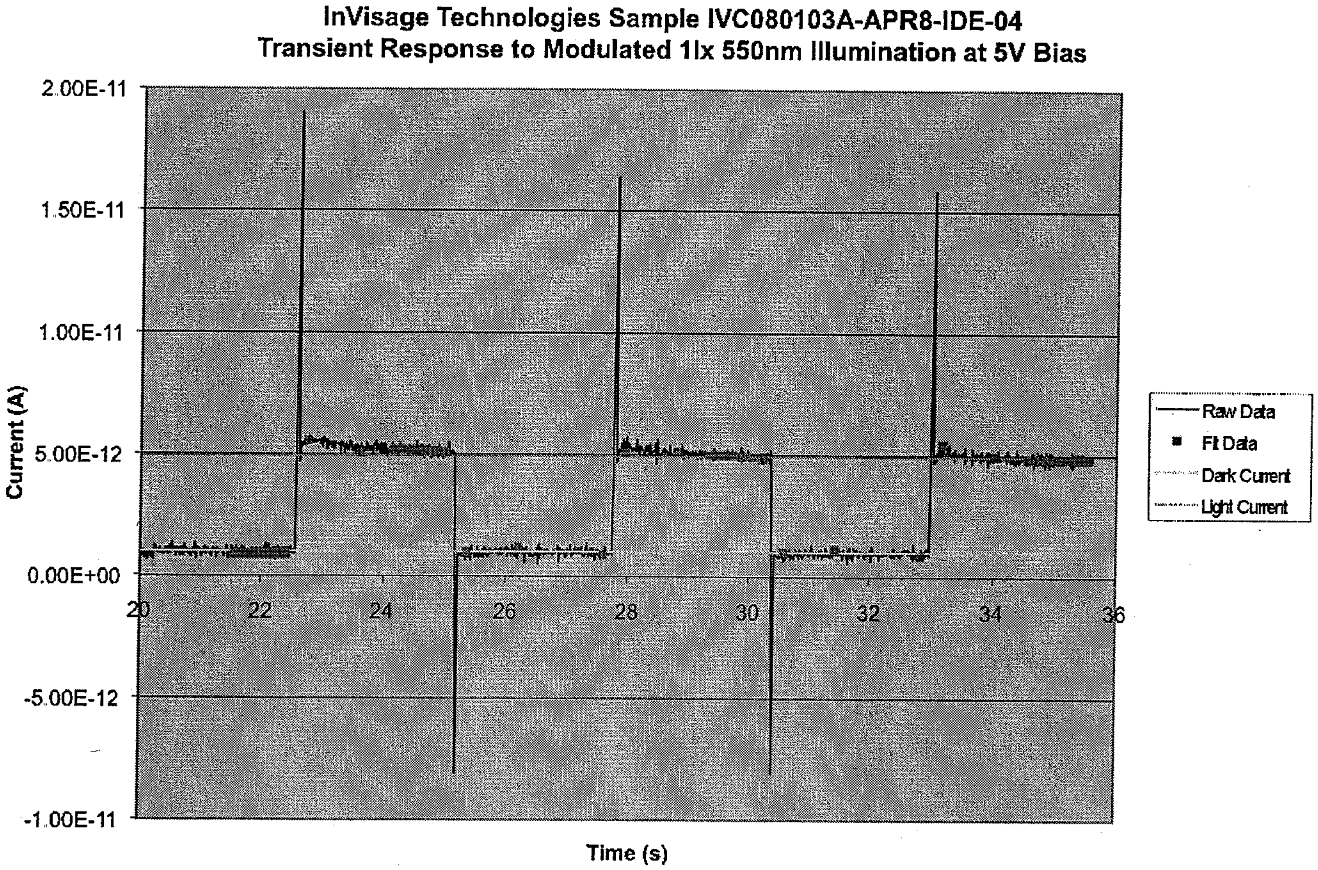
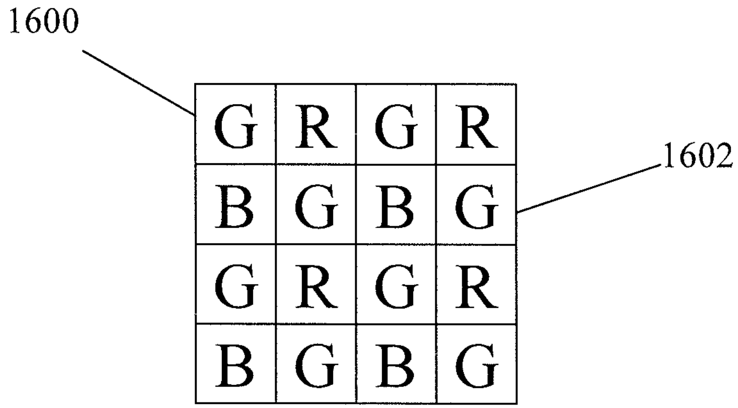

InVisage Technologies Sample IVC080103A-APR8-IDE-04
Transient Response to Modulated 1lx 550nm Illumination at 5V Bias
Current (A)
2.00E-11
1.50E-11
1.00E-11
5.00E-12
0.00E+00
-5.00E-12
-1.00E-11
20
22
24
26
28
30
32
34
36
Time (s)
Raw Data
Fit Data
Dark Current
Light Current

Fig. 4.



G	R	G	R
B	G	B	G
G	R	G	R
B	G	B	G

Fig. 5a

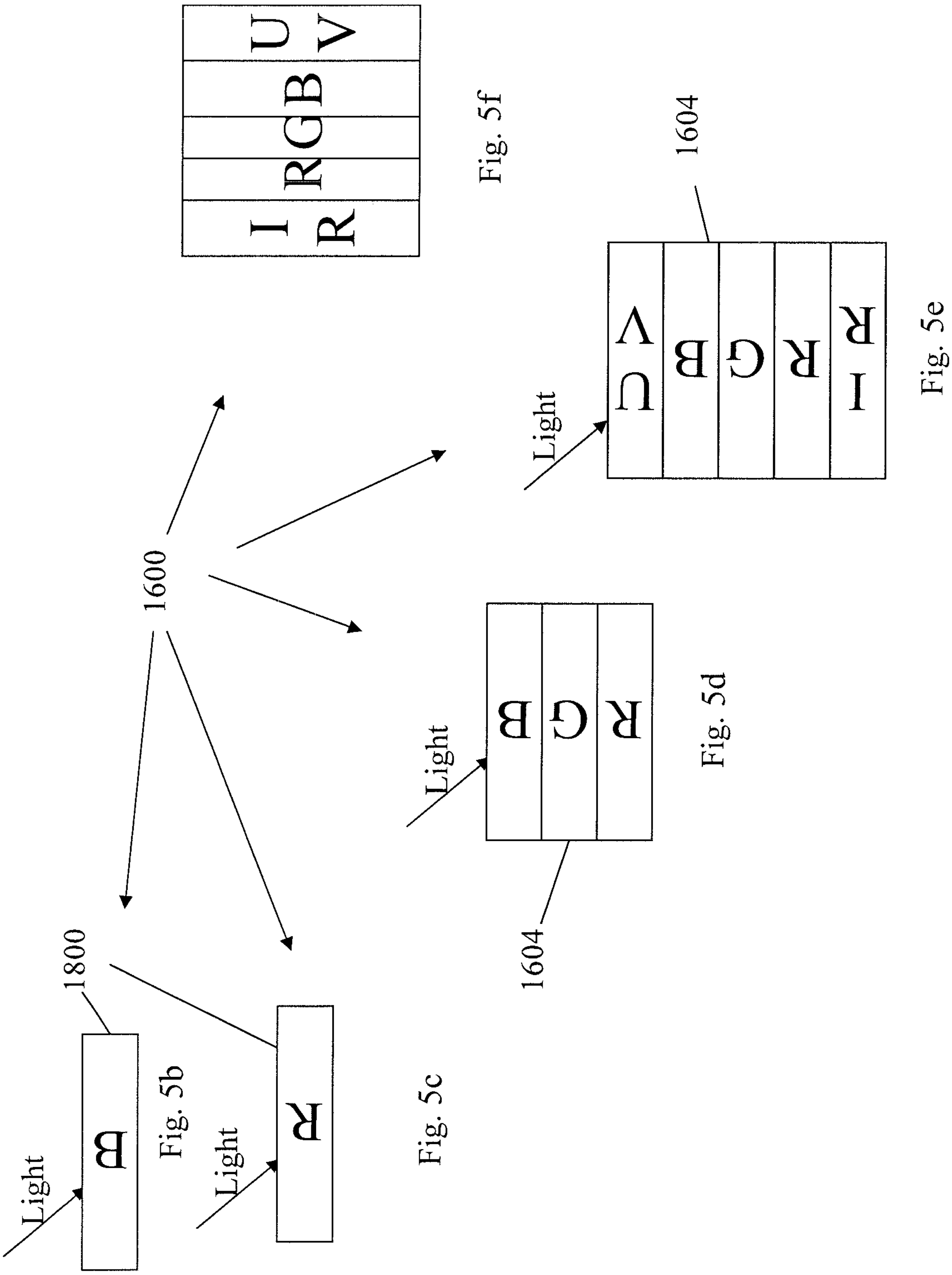


Fig. 5f

Fig. 5e

Fig. 5d

Fig. 5b

Fig. 5c

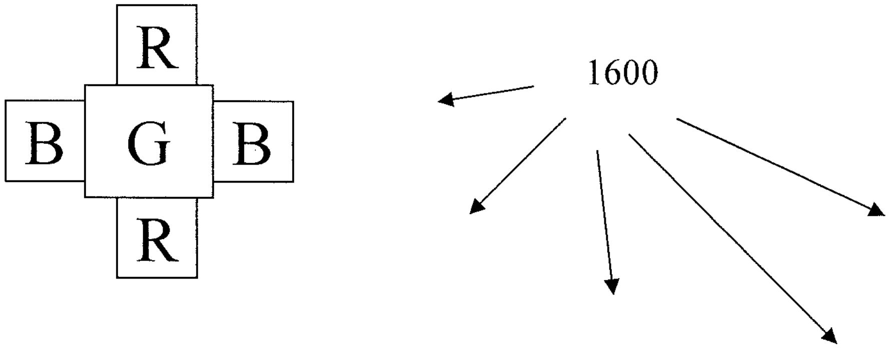


Fig. 5g

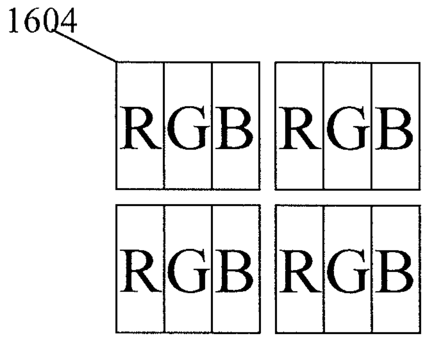


Fig. 5h

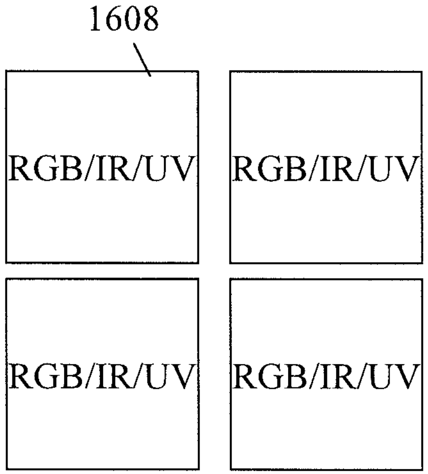


Fig. 5i

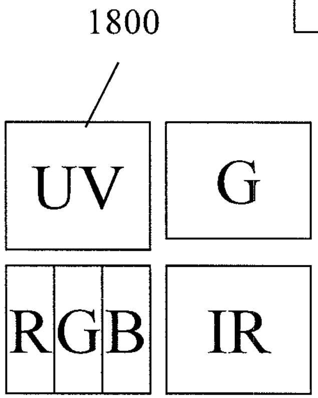


Fig. 5j

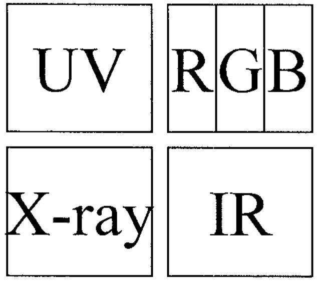


Fig. 5l

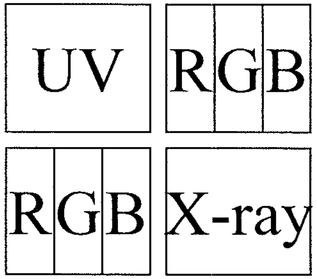


Fig. 5k

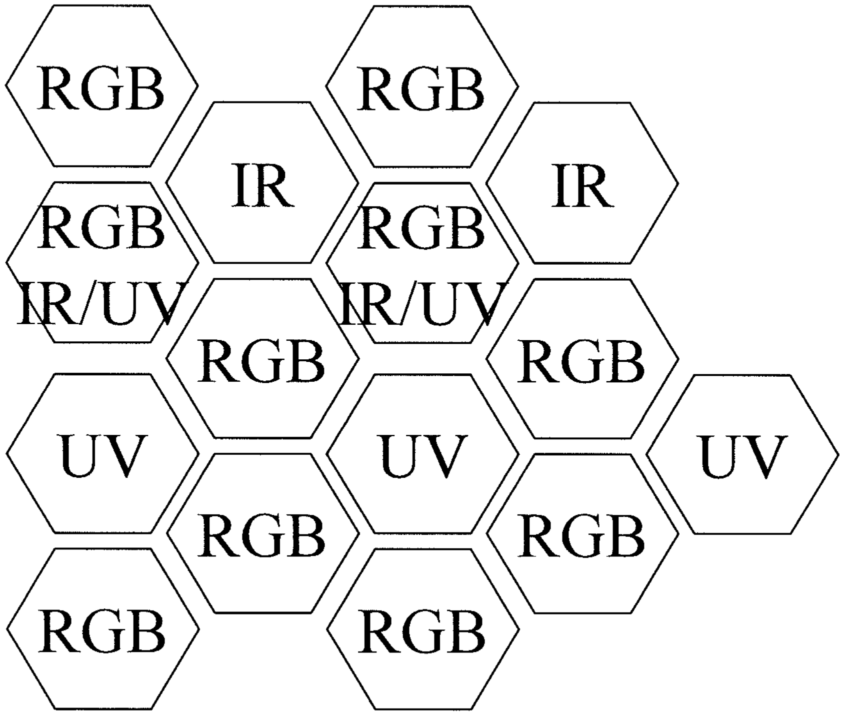


Fig. 5m

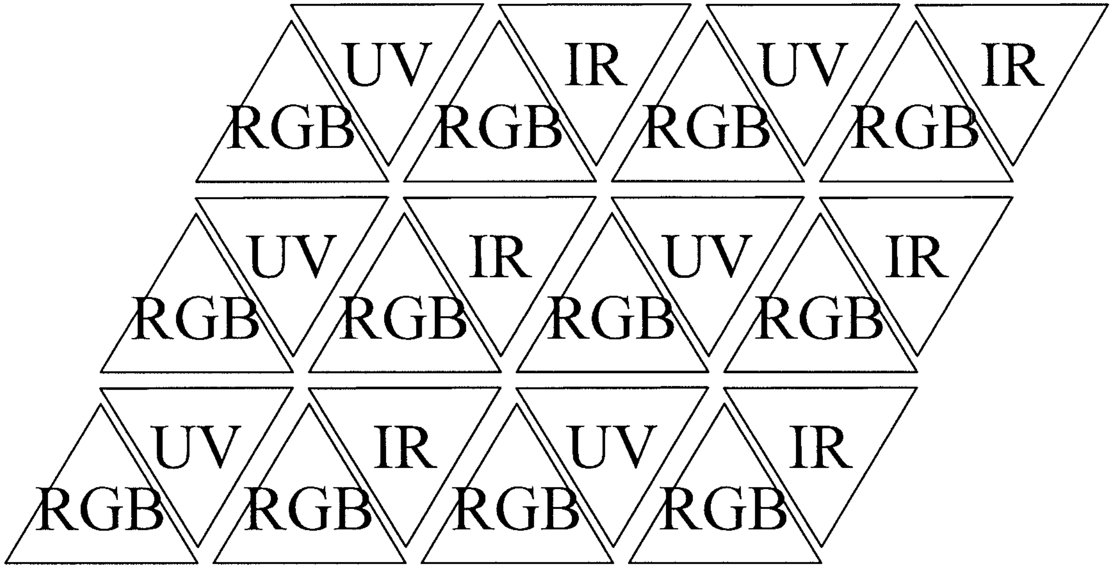

UV
IR
UV
IR
RGB
RGB
RGB
RGB
UV
IR
UV
IR
RGB
RGB
RGB
RGB
UV
IR
UV
IR
RGB
RGB
RGB
RGB

Fig. 5n

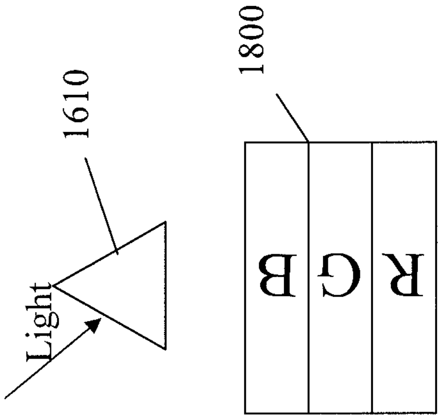


Fig. 5o

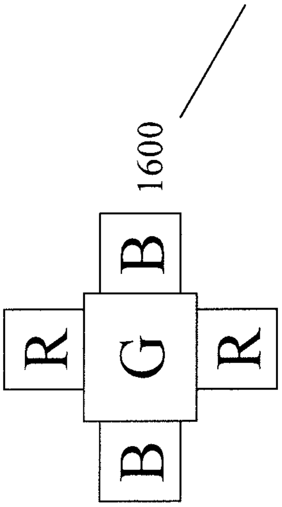


Fig. 5p

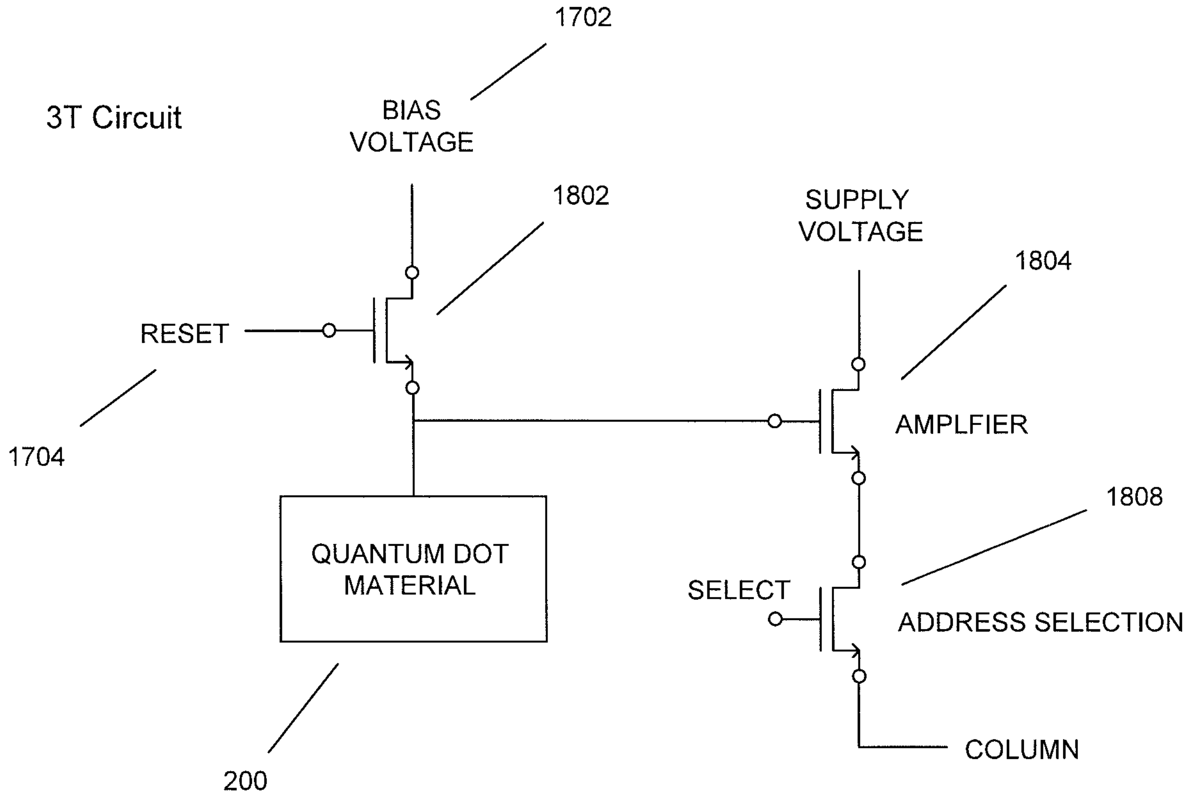

3T Circuit
1702
BIAS VOLTAGE
1802
RESET
1704
SUPPLY VOLTAGE
1804
AMPLFIER
1808
SELECT
ADDRESS SELECTION
COLUMN
QUANTUM DOT MATERIAL
200

Fig. 6a

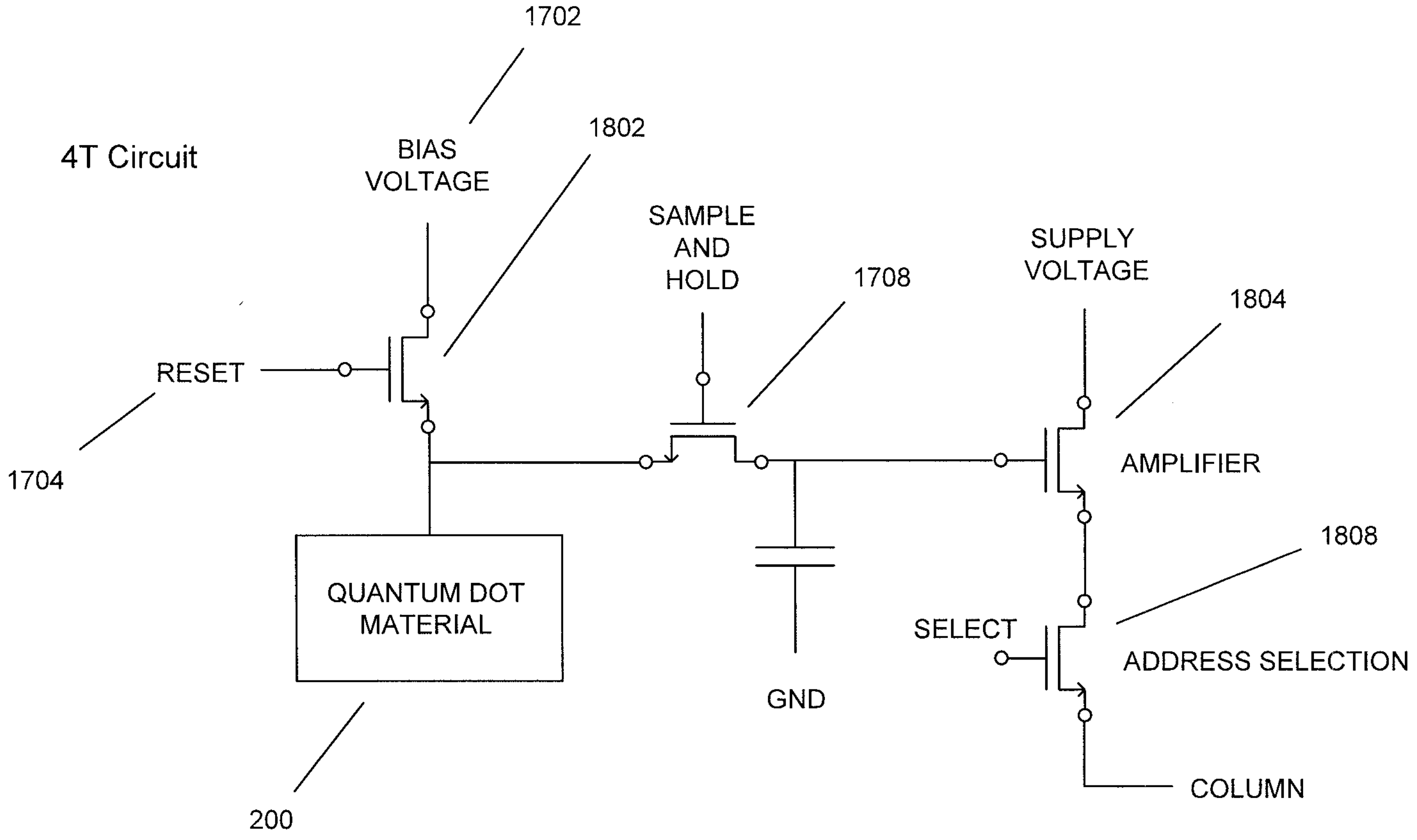

4T Circuit
1702
BIAS VOLTAGE
1802
RESET
1704
SAMPLE AND HOLD
1708
SUPPLY VOLTAGE
1804
AMPLIFIER
1808
SELECT
ADDRESS SELECTION
COLUMN
QUANTUM DOT MATERIAL
200
GND

Fig. 6b

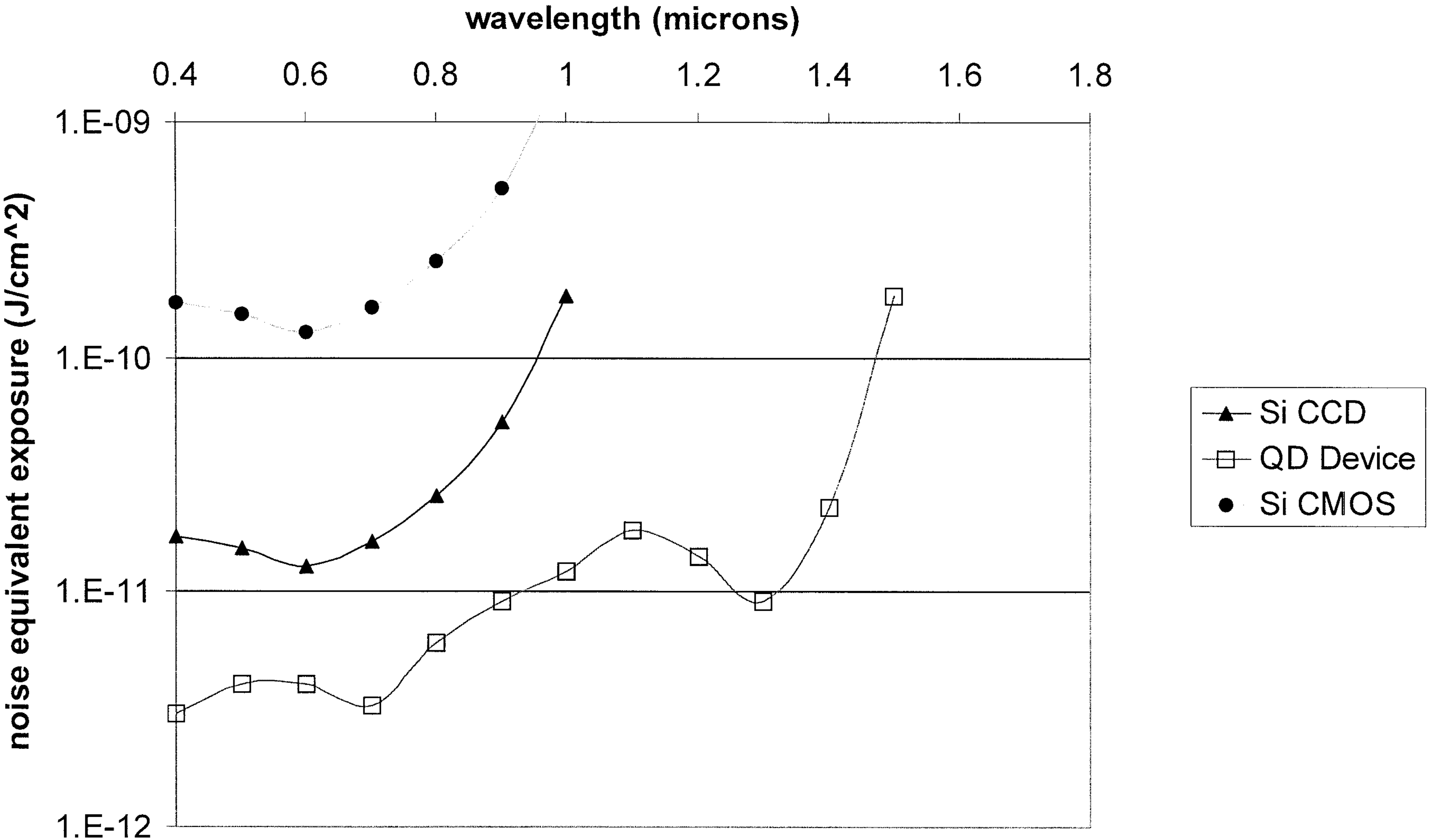

wavelength (microns)
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
noise equivalent exposure (J/cm^2)
1.E-09
1.E-10
1.E-11
1.E-12
Si CCD
QD Device
Si CMOS

Fig. 6c

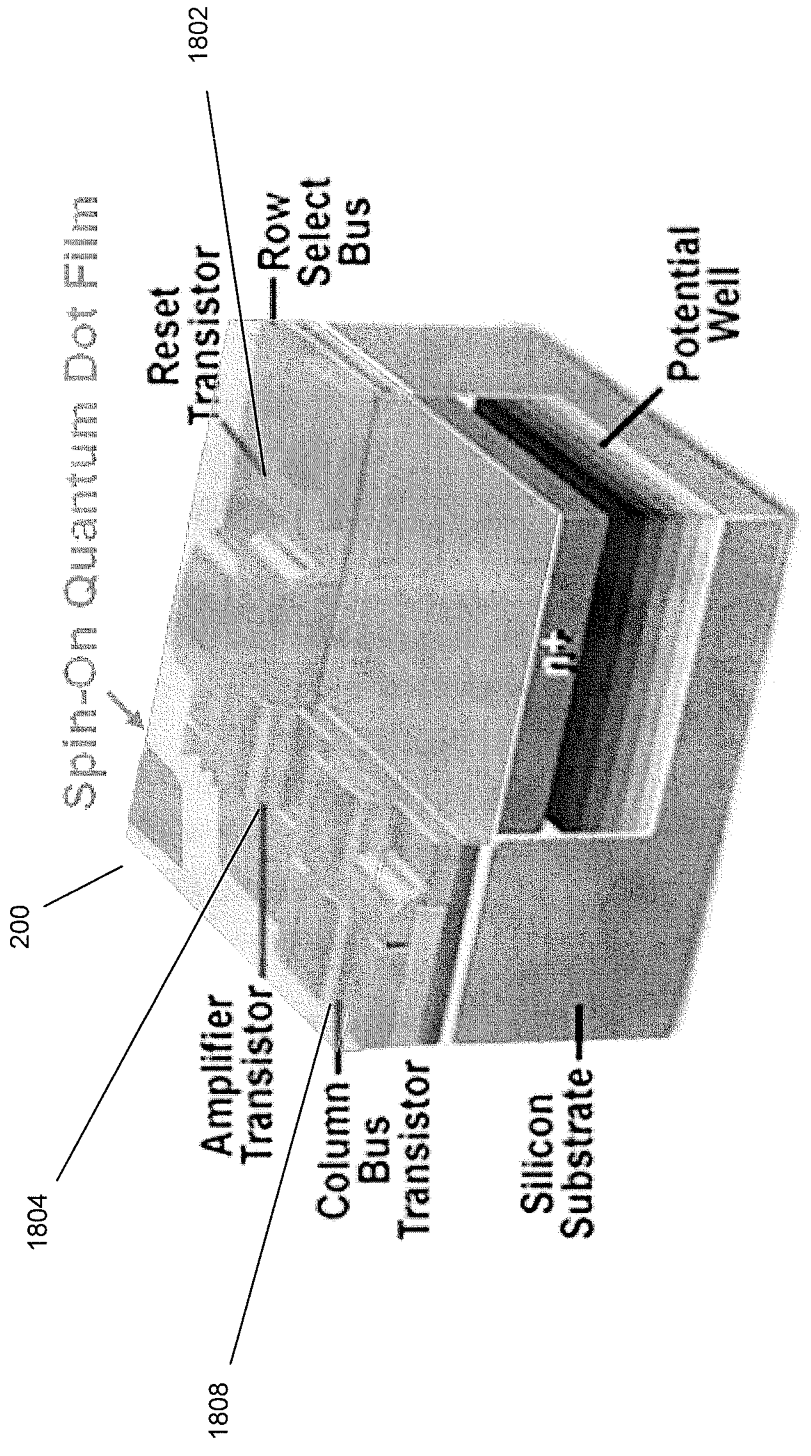

1802
Spin-On Quantum Dot Film
Reset Transistor
Row Select Bus
Potential Well
n+
200
1804
Amplifier Transistor
Column Bus Transistor
Silicon Substrate
1808

Fig. 7a

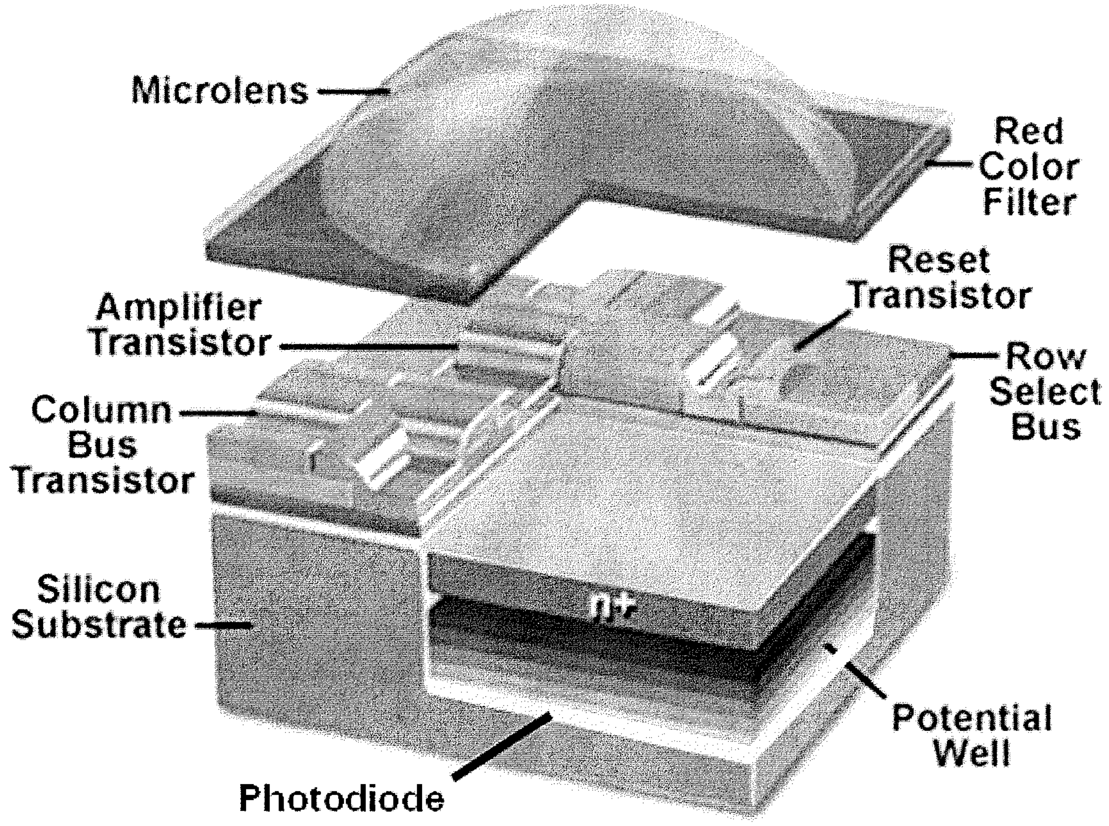

Microlens
Red Color Filter
Reset Transistor
Amplifier Transistor
Row Select Bus
Column Bus Transistor
Silicon Substrate
n+
Potential Well
Photodiode

Fig. 7b

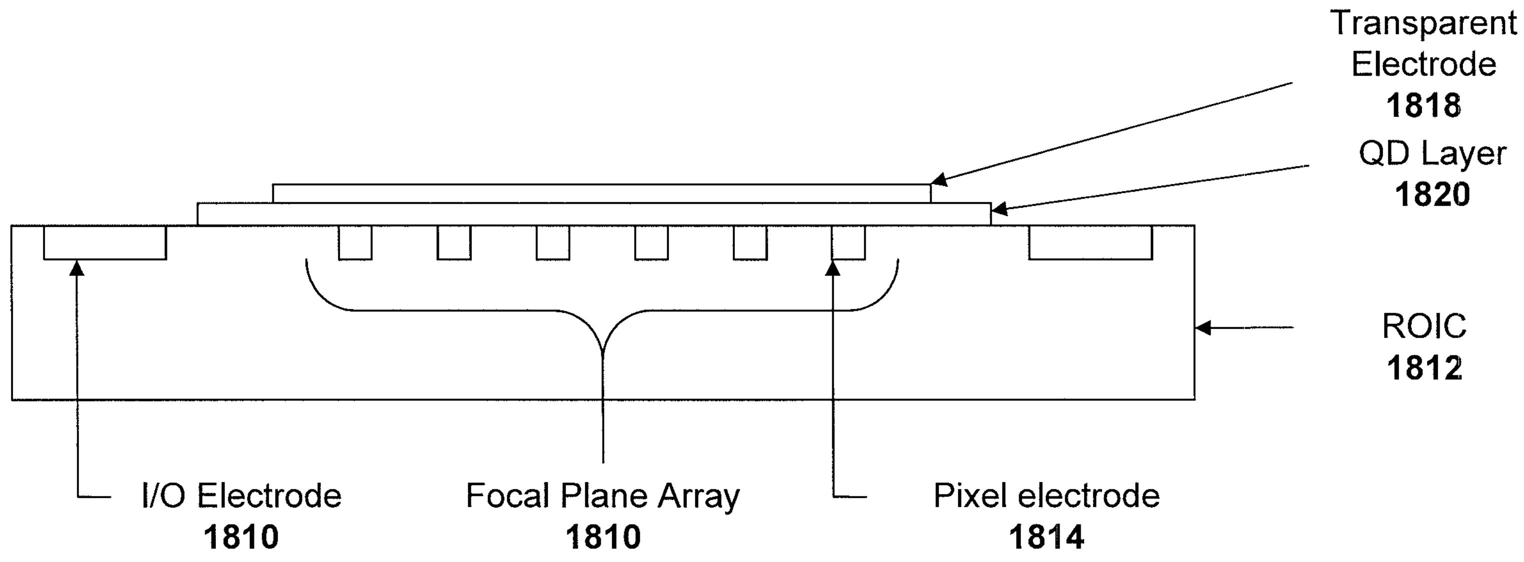

Transparent
Electrode
1818
QD Layer
1820
ROIC
1812
I/O Electrode
1810
Focal Plane Array
1810
Pixel electrode
1814

Fig. 7c

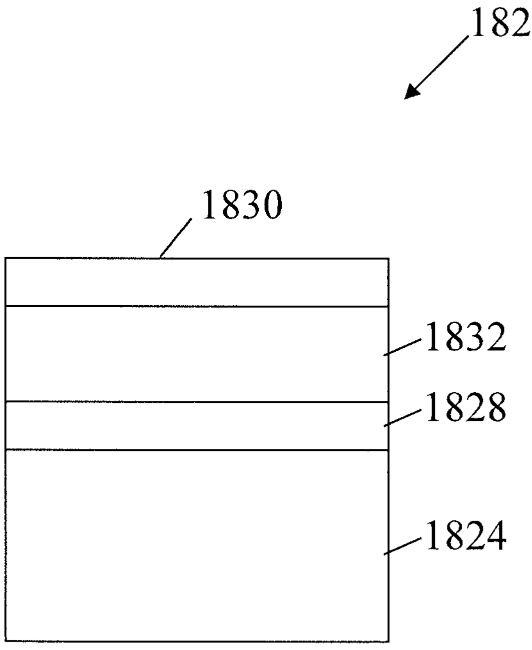


Fig. 7d

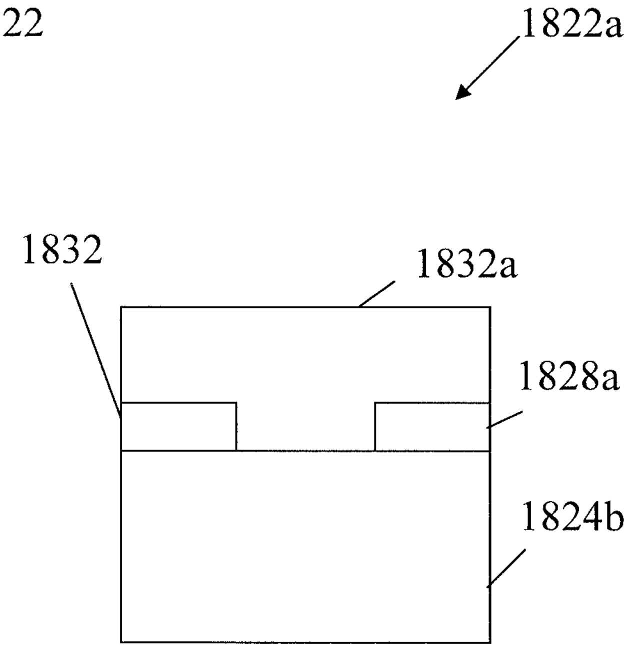


Fig. 7e

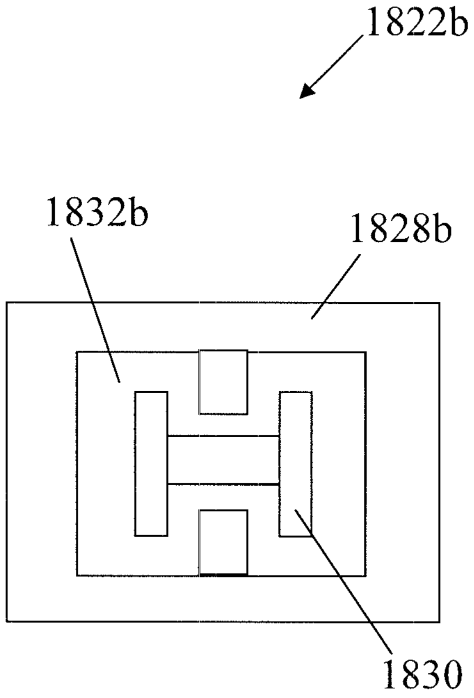


Fig. 7f

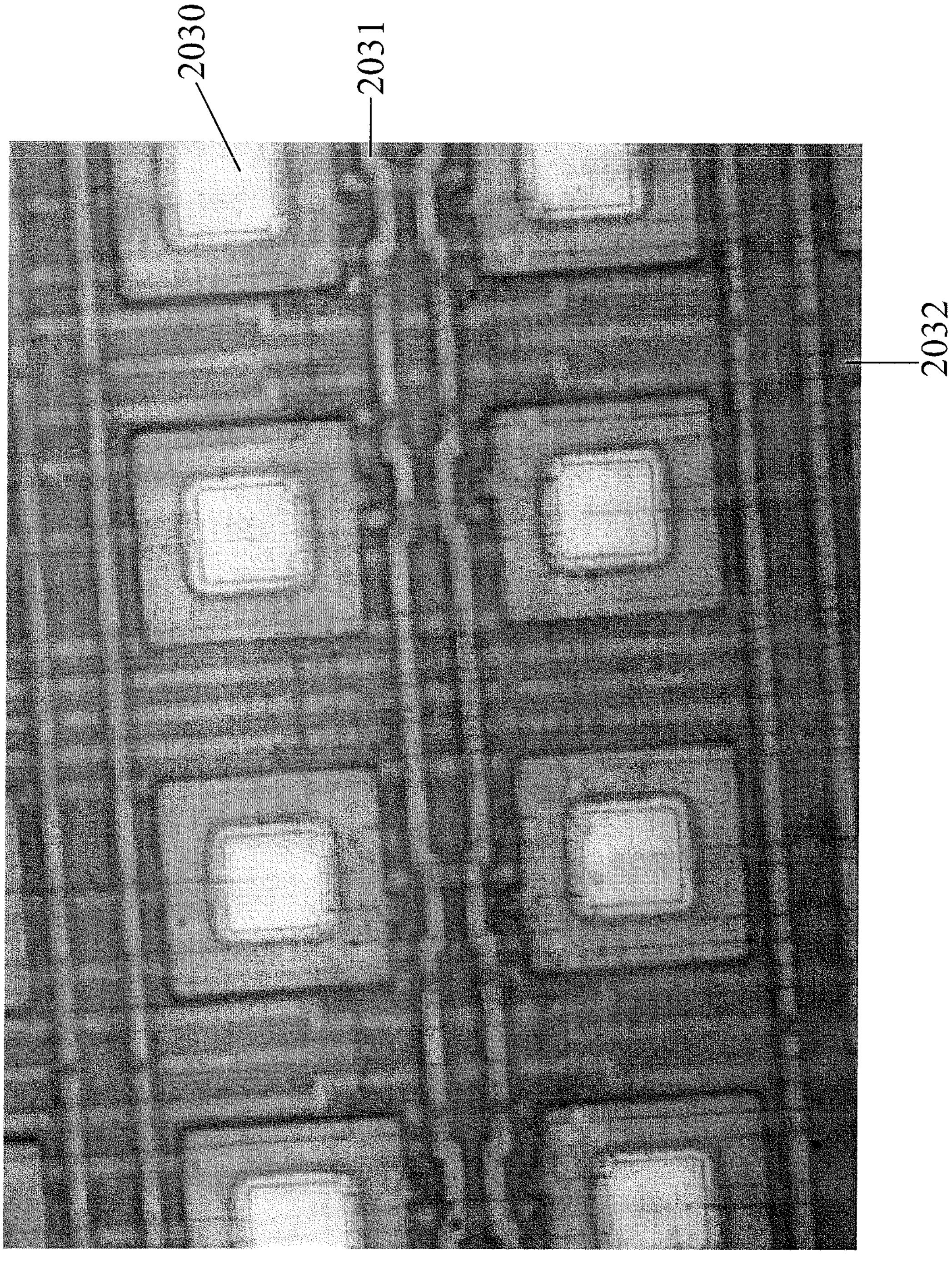


Fig. 8

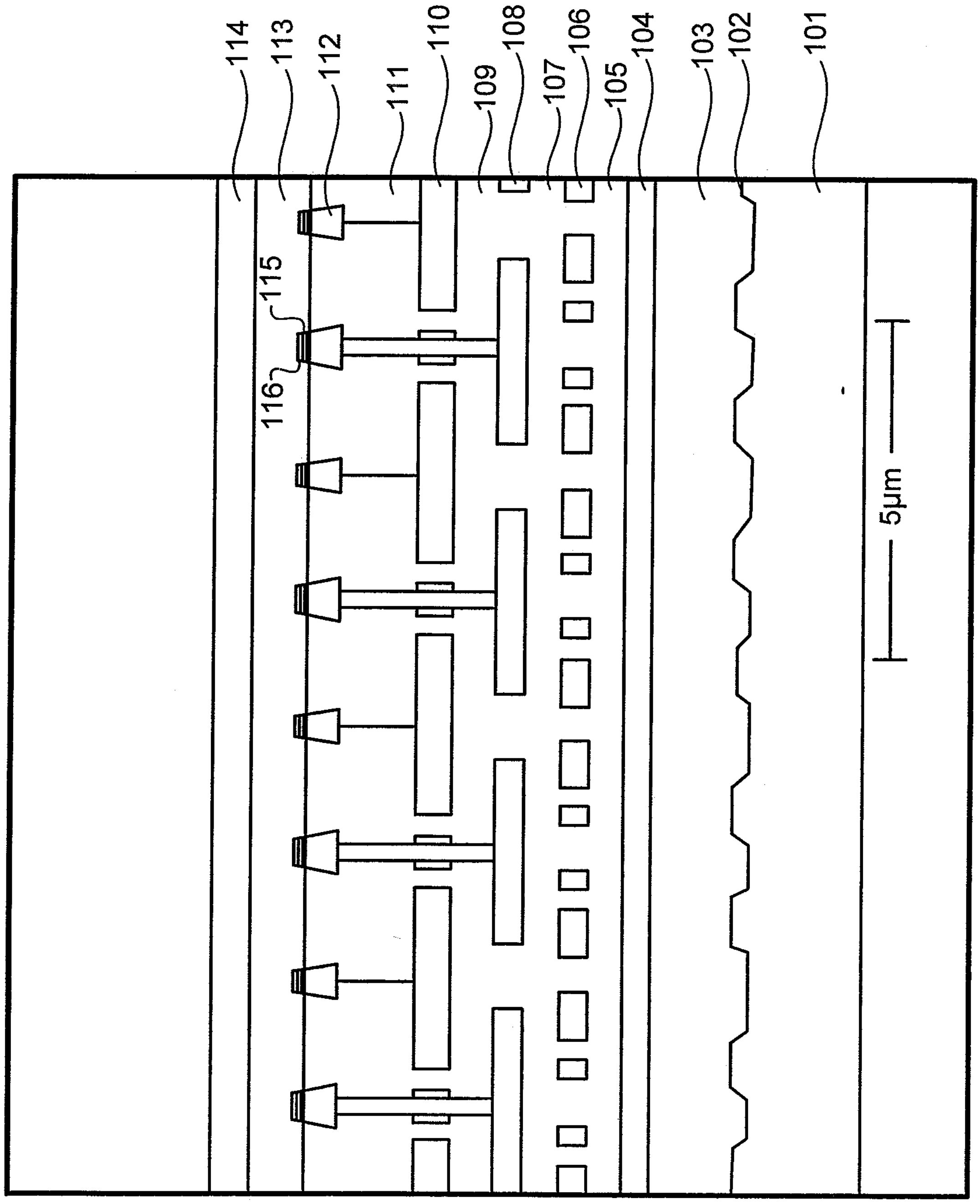

114
113
112
111
110
109
108
107
106
105
104
103
102
101
115
116
5μm

Figure 9

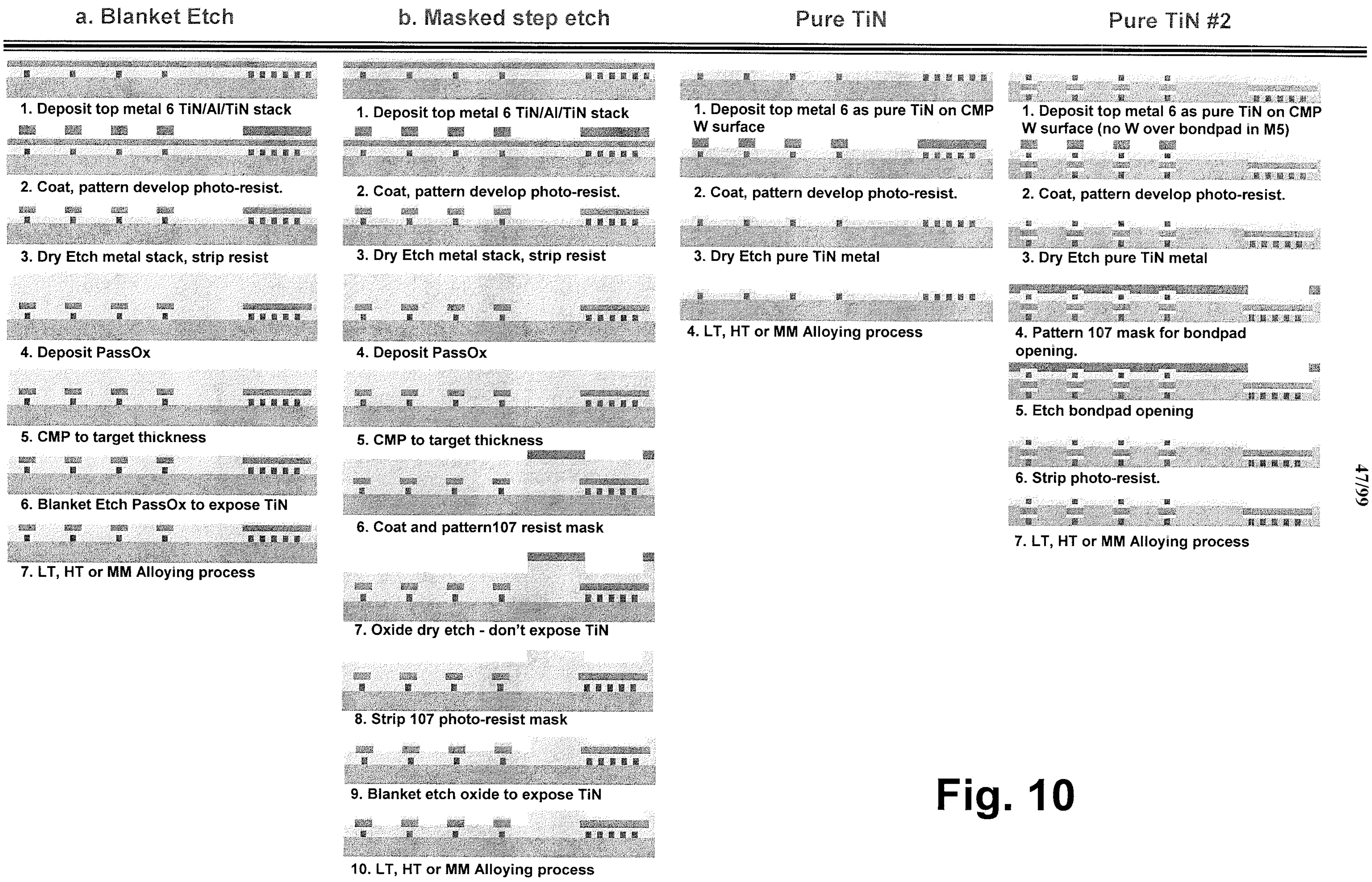

a. Blanket Etch
1. Deposit top metal 6 TiN/Al/TiN stack
2. Coat, pattern develop photo-resist.
3. Dry Etch metal stack, strip resist
4. Deposit PassOx
5. CMP to target thickness
6. Blanket Etch PassOx to expose TiN
7. LT, HT or MM Alloying process
b. Masked step etch
1. Deposit top metal 6 TiN/Al/TiN stack
2. Coat, pattern develop photo-resist.
3. Dry Etch metal stack, strip resist
4. Deposit PassOx
5. CMP to target thickness
6. Coat and pattern107 resist mask
7. Oxide dry etch - don't expose TiN
8. Strip 107 photo-resist mask
9. Blanket etch oxide to expose TiN
10. LT, HT or MM Alloying process
Pure TiN
1. Deposit top metal 6 as pure TiN on CMP W surface
2. Coat, pattern develop photo-resist.
3. Dry Etch pure TiN metal
4. LT, HT or MM Alloying process
Pure TiN #2
1. Deposit top metal 6 as pure TiN on CMP W surface (no W over bondpad in M5)
2. Coat, pattern develop photo-resist.
3. Dry Etch pure TiN metal
4. Pattern 107 mask for bondpad opening.
5. Etch bondpad opening
6. Strip photo-resist.
7. LT, HT or MM Alloying process

Fig. 10

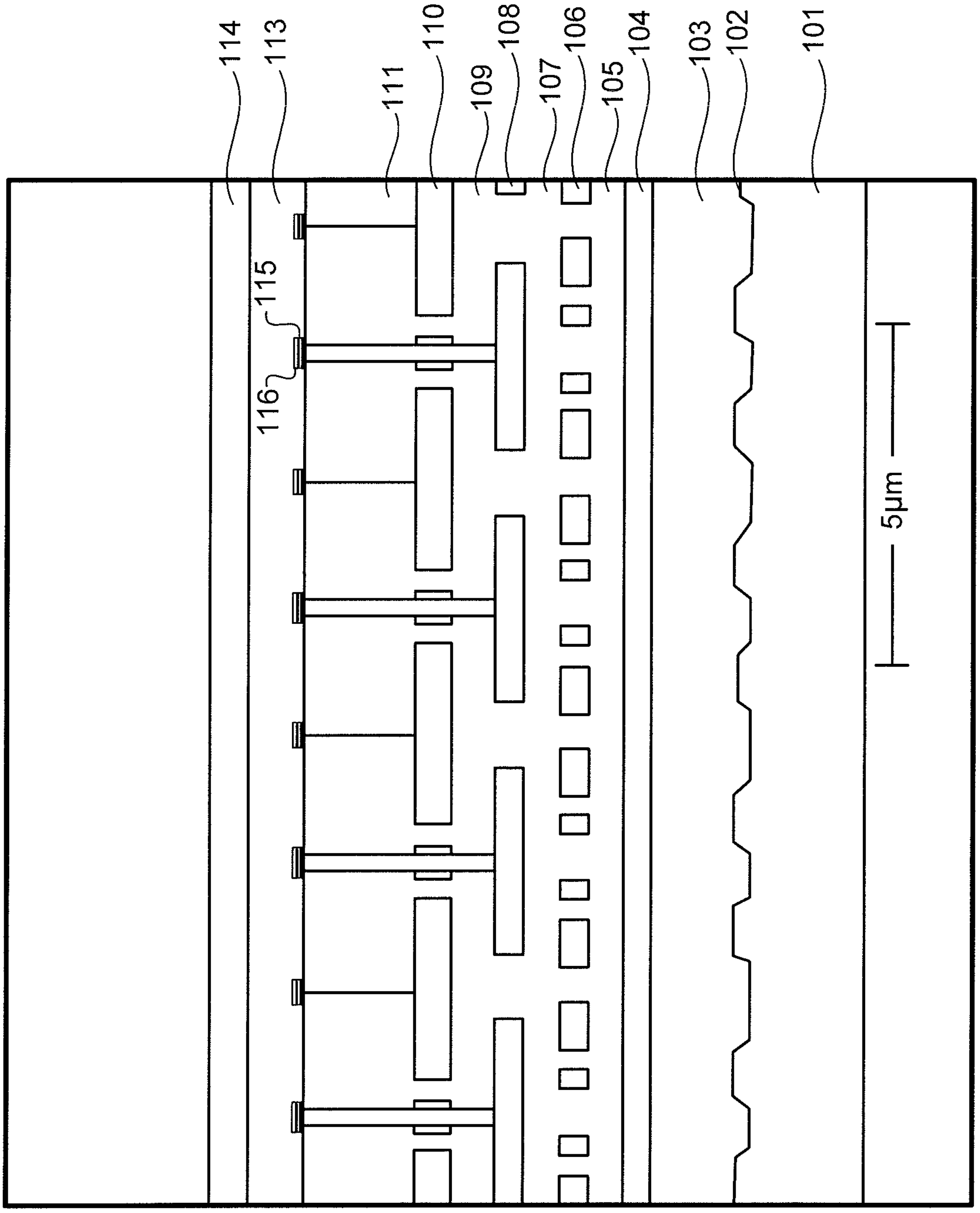


Figure 11

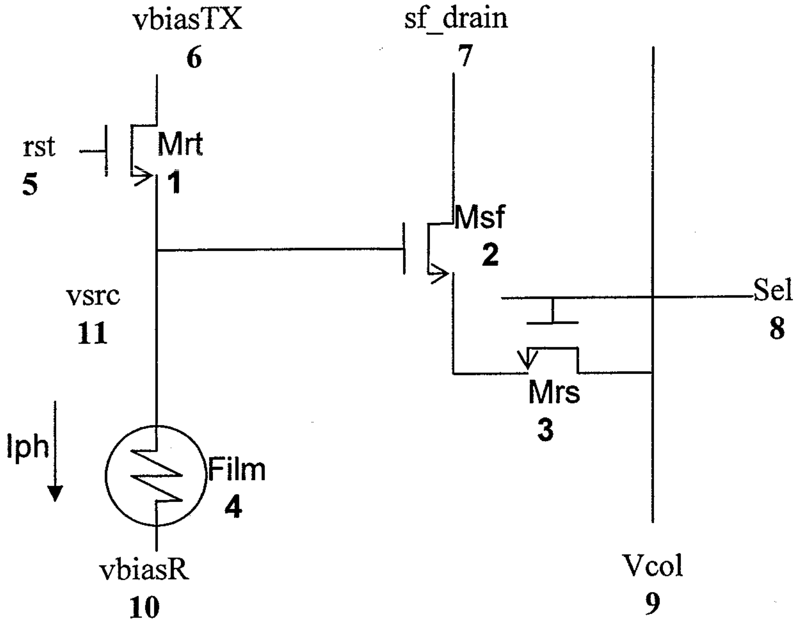


FIG.12

Schematic for 3T 2.4um Pixel

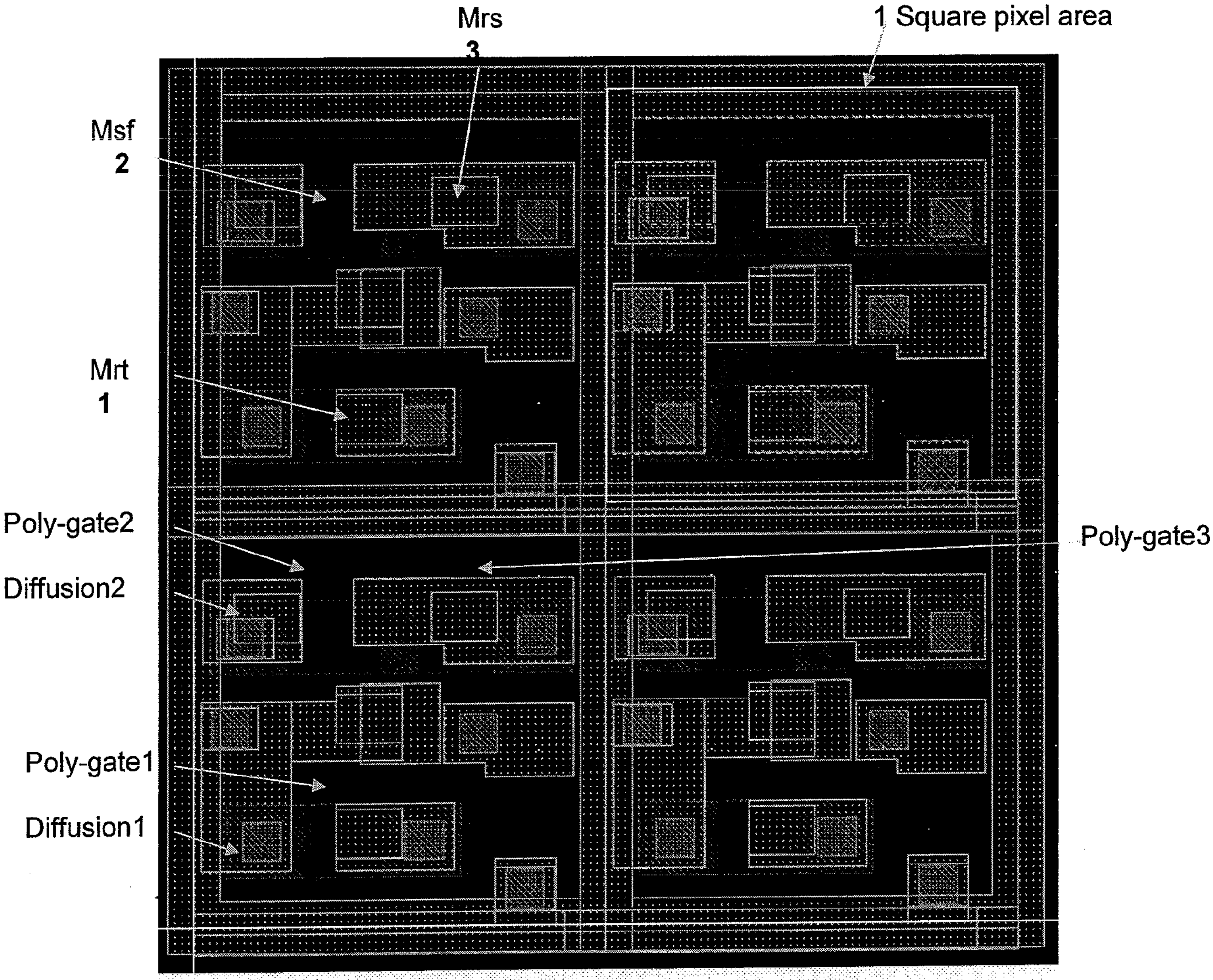
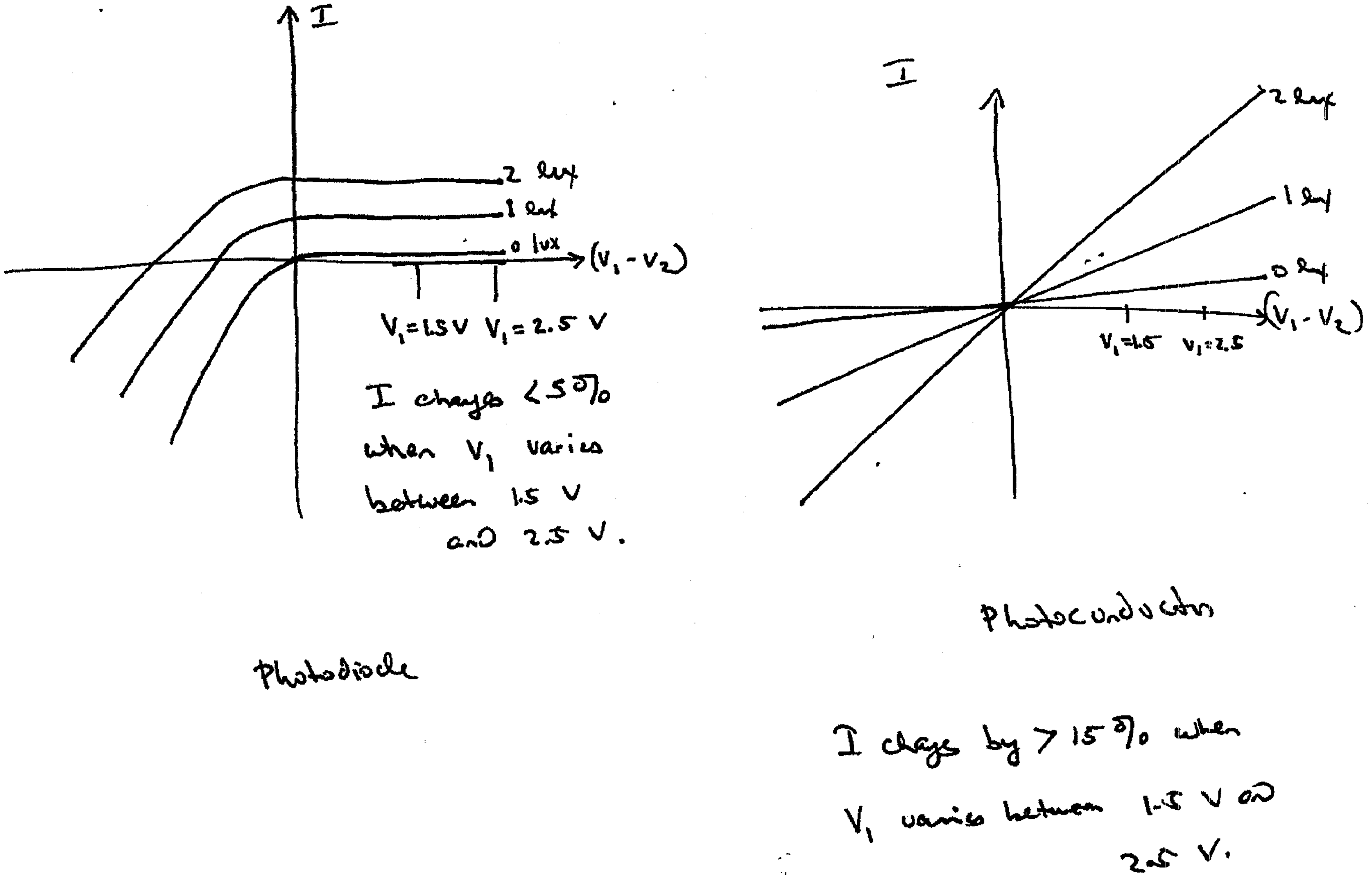


FIG. 13

3T Pixel layout 4x4 array – no sharing, no mirroring (2.4um)



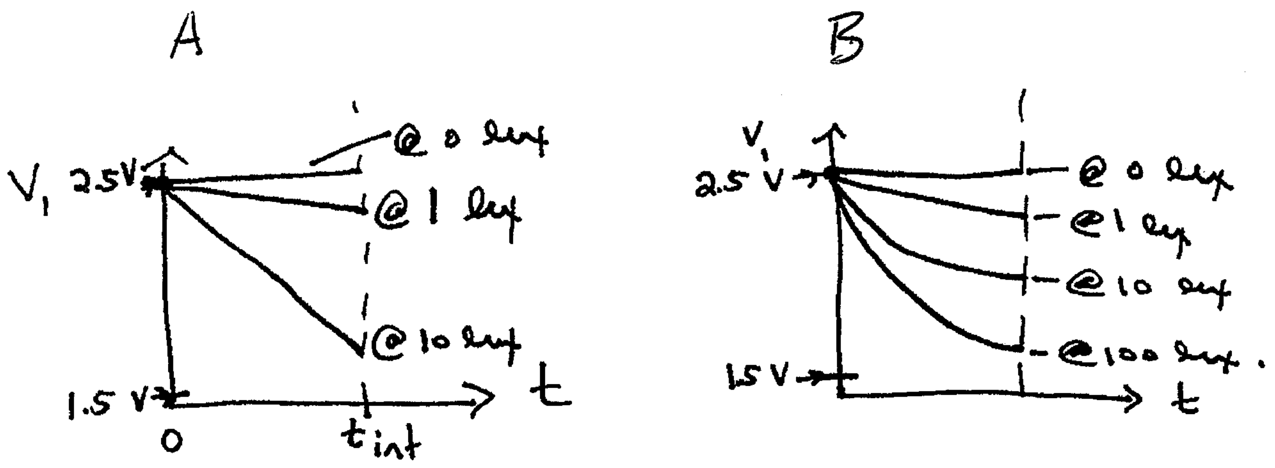
I changes < 5% when V_1 varies between 1.5 V and 2.5 V.

Photodiode

Photoconductor

I changes by > 15% when V_1 varies between 1.5 V and 2.5 V.

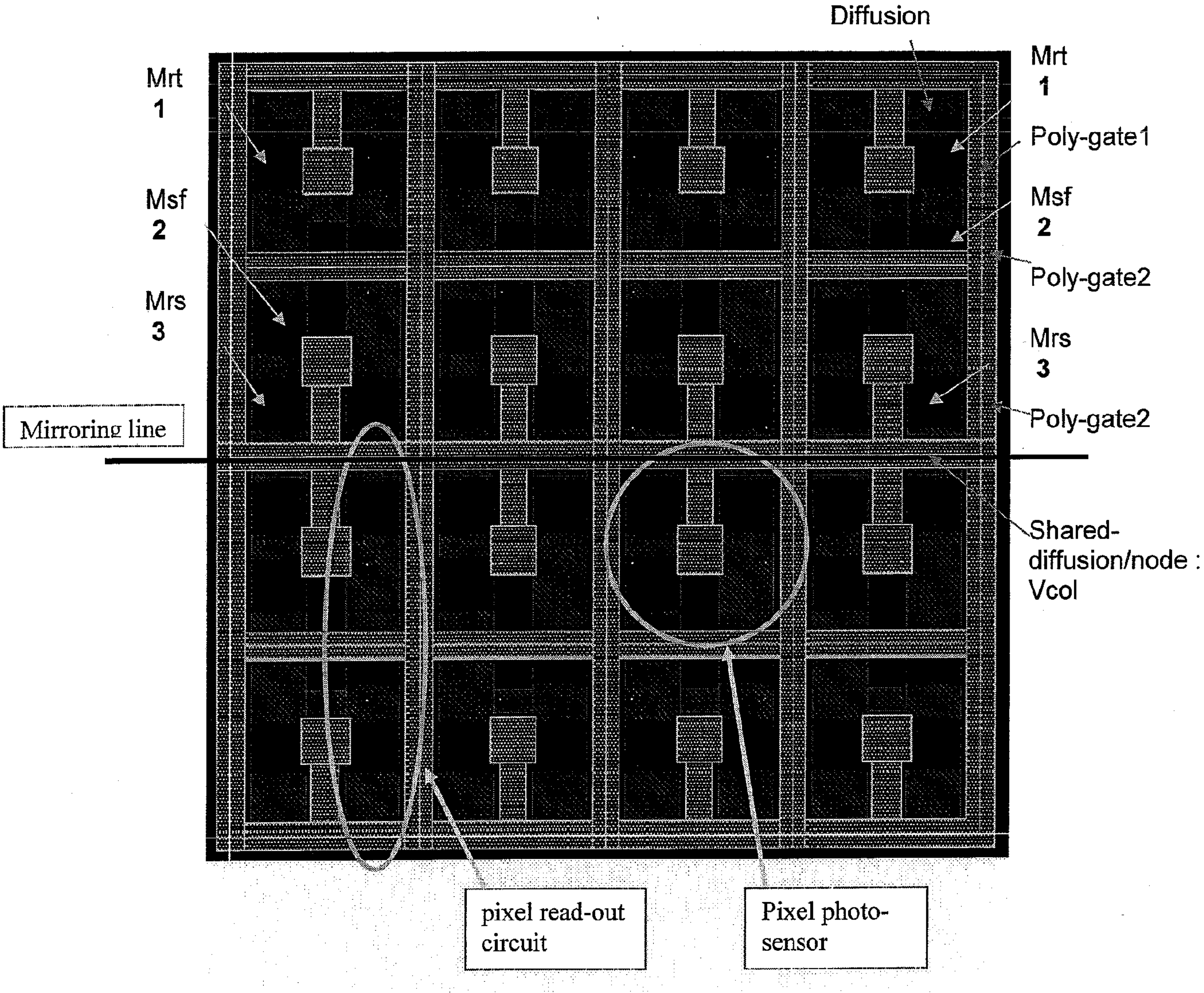
FIG. 14.



Photodiode
(I independent of
V for

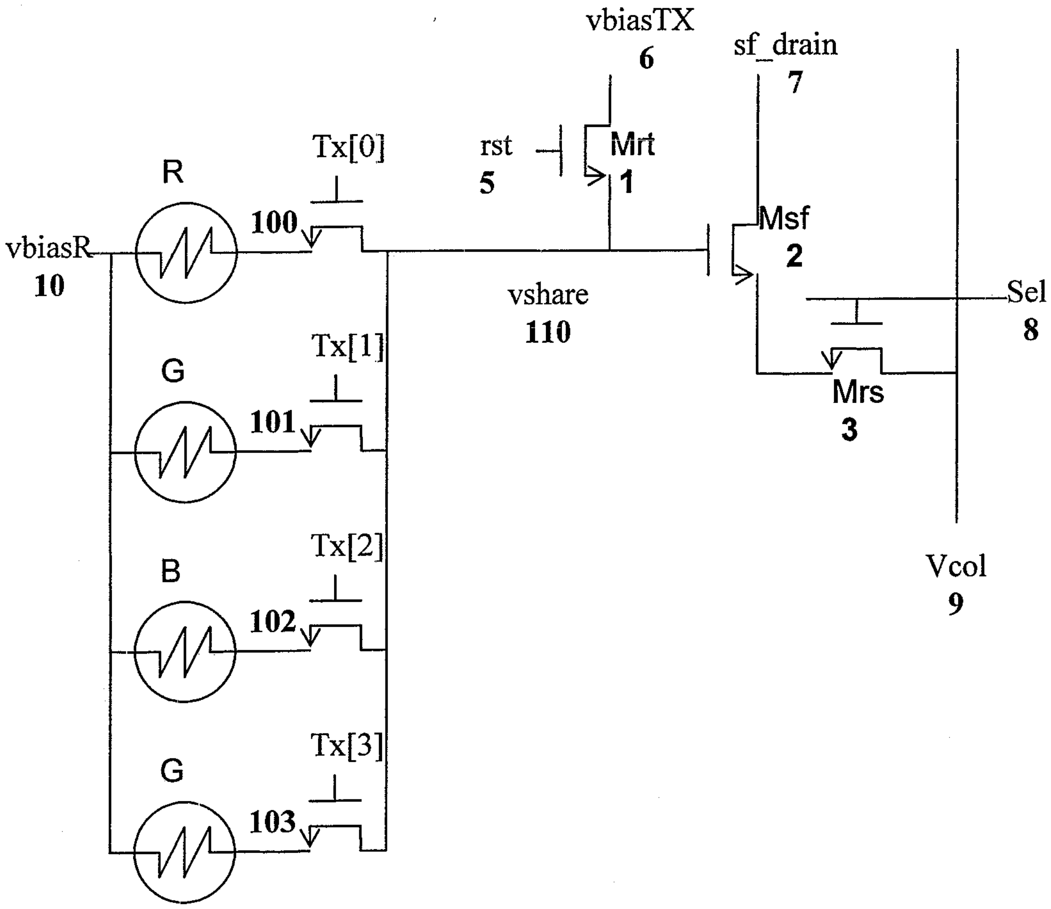
Photoconductor

FIG. 15



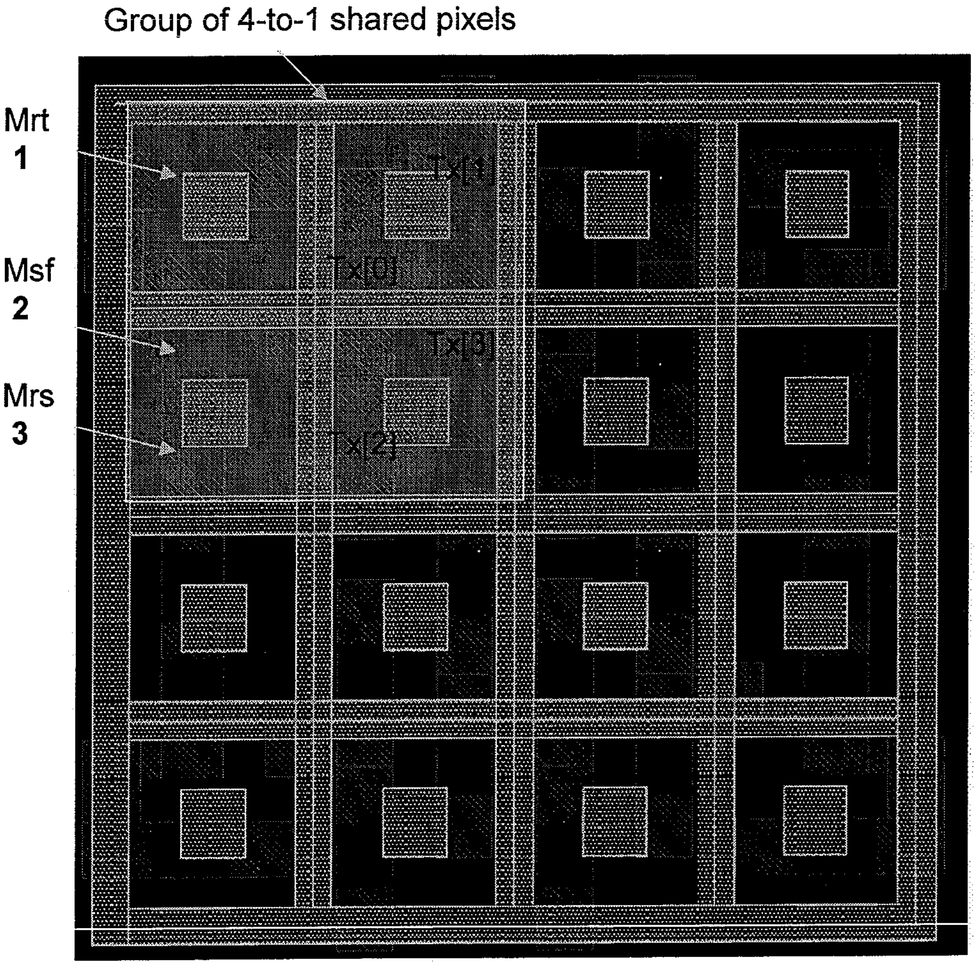
Layout for 3T 1.4um Rectangular Pixel, with mirroring. 4x4 pixels shown.

FIG. 16



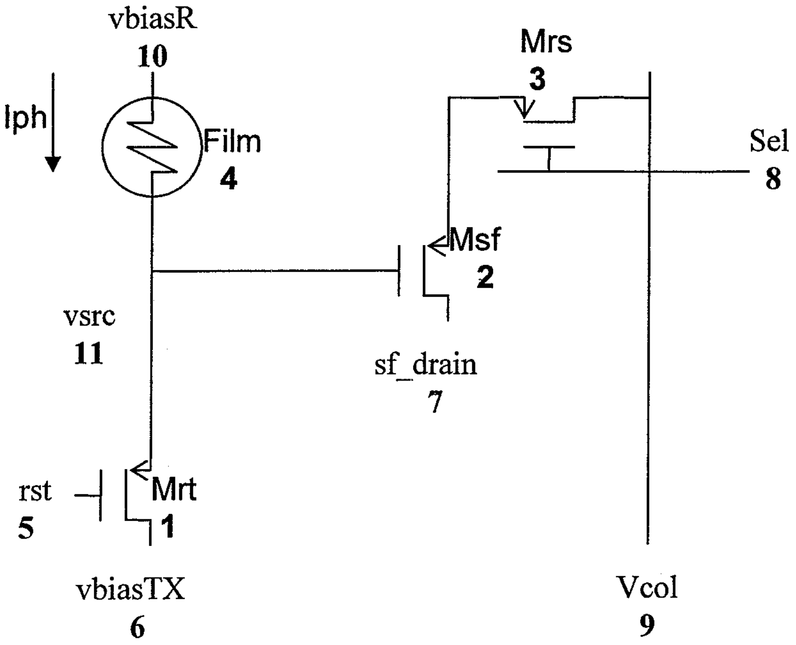
Schematic for 3T 1.1um Pixel with 4-to-1 sharing

Fig. 17



Layout for 3T 1.1um pixel with 4 to 1 sharing; 4x4 pixels shown.

FIG. 18



Schematic for 3T 2.4um Pixel - PMOS

FIG. 19

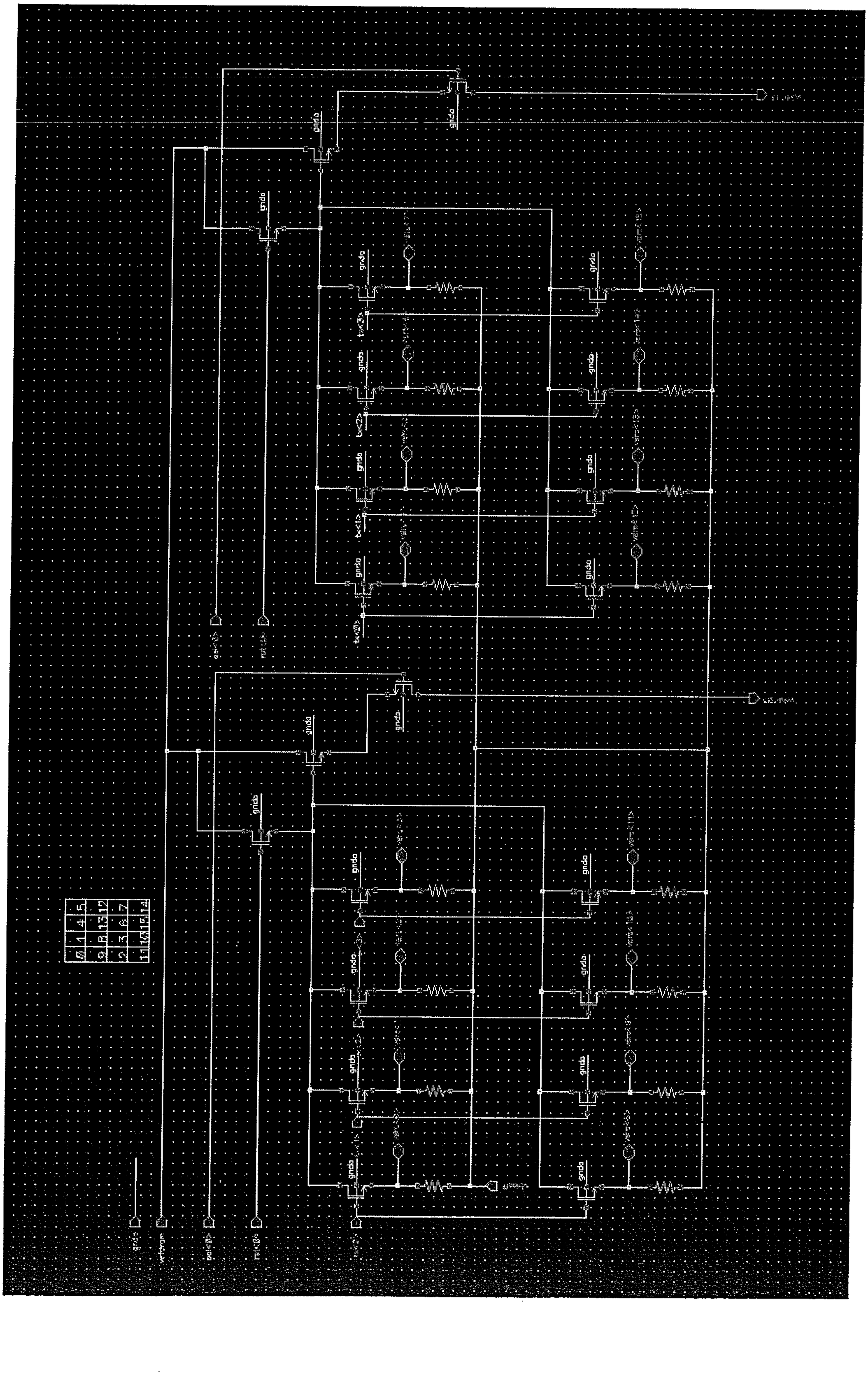


FIG. 20a

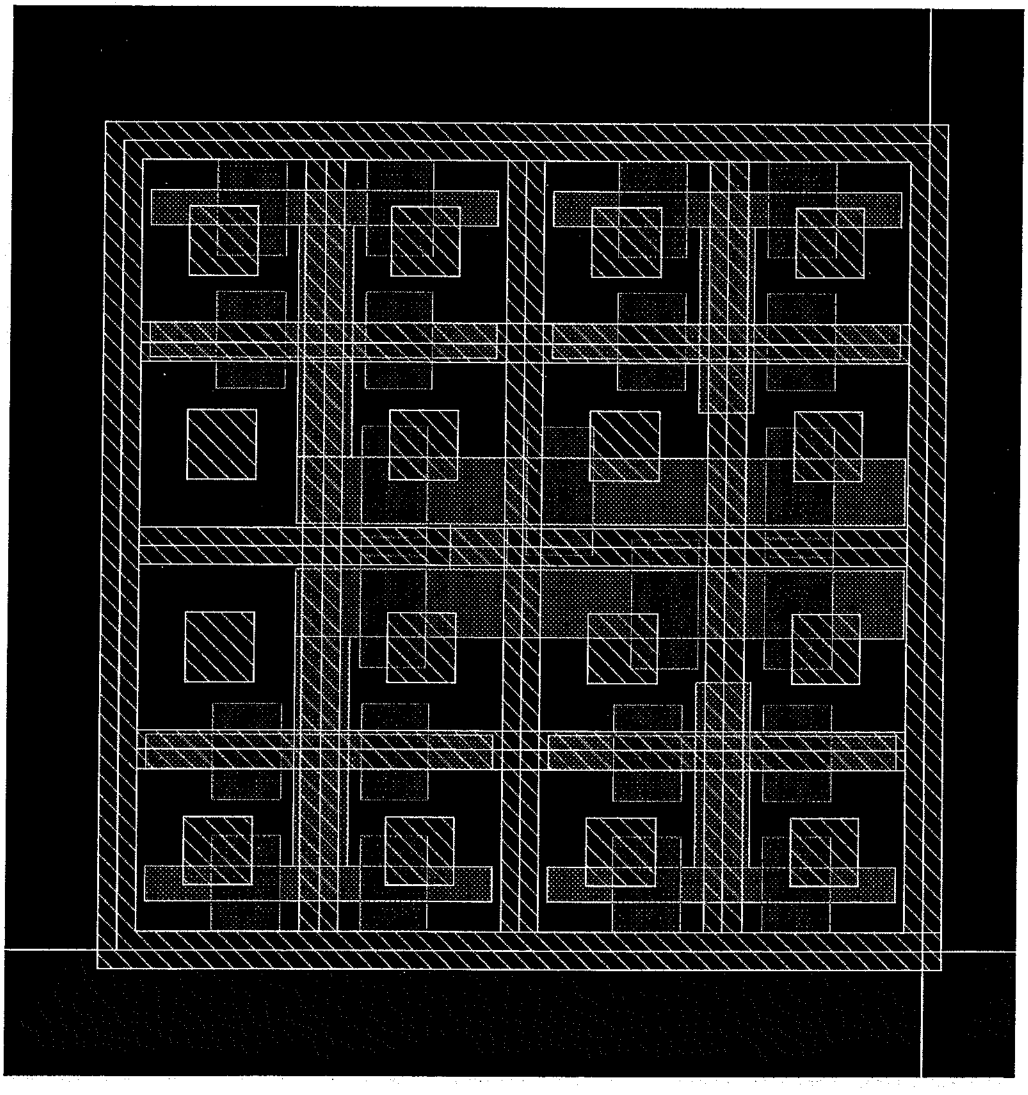
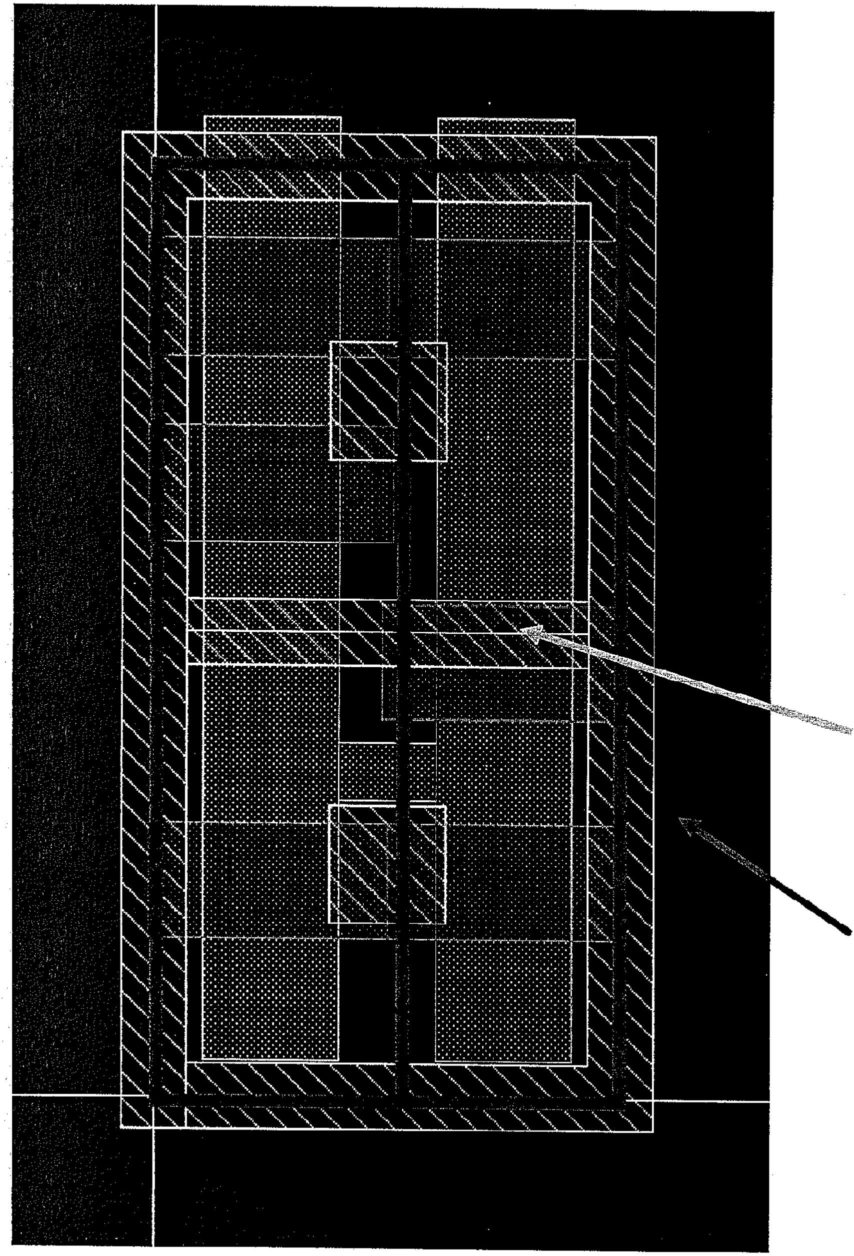


FIG. 20b



At film layer (yellow)
Pixel is square shape

At silicon layer (red-poly, blue-diffusion)
Pixel is rectangular shape

FIG. 20c

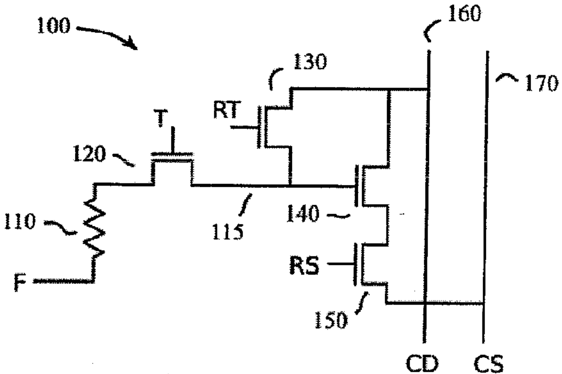


Fig. 21a

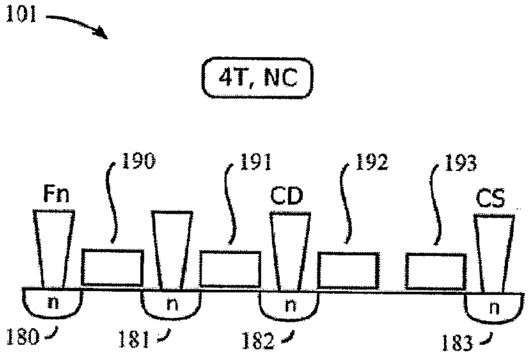


Fig. 21b

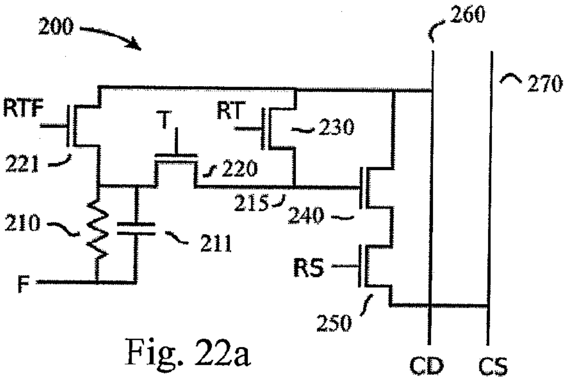


Fig. 22a

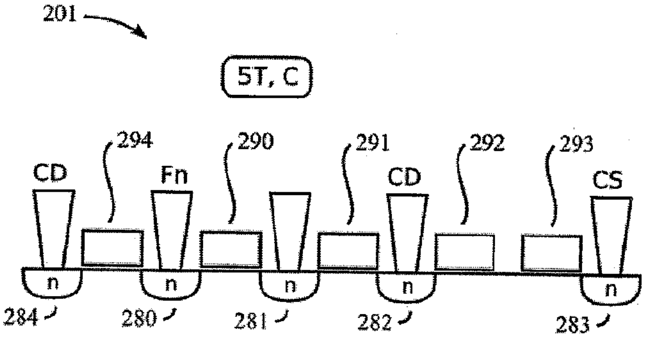


Fig. 22b

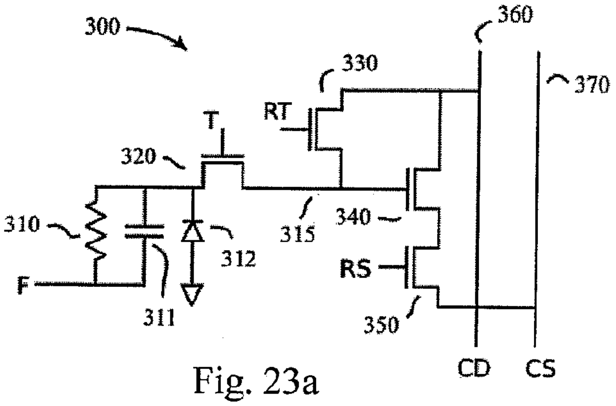


Fig. 23a

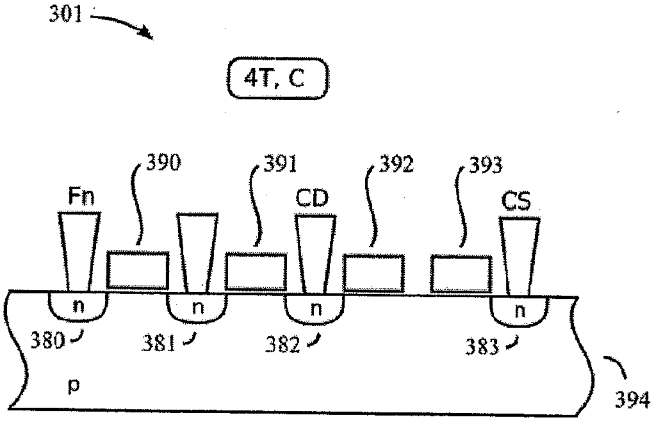


Fig. 23b

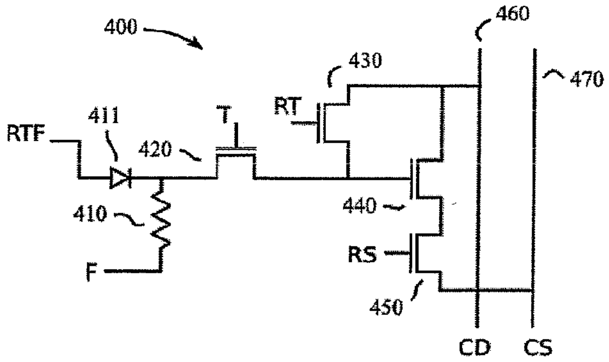


Fig. 24a

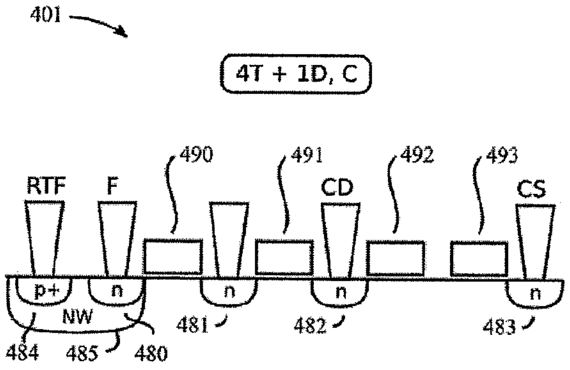


Fig. 24b

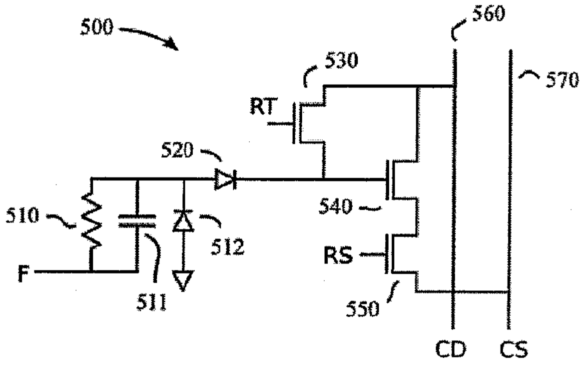


Fig. 25a

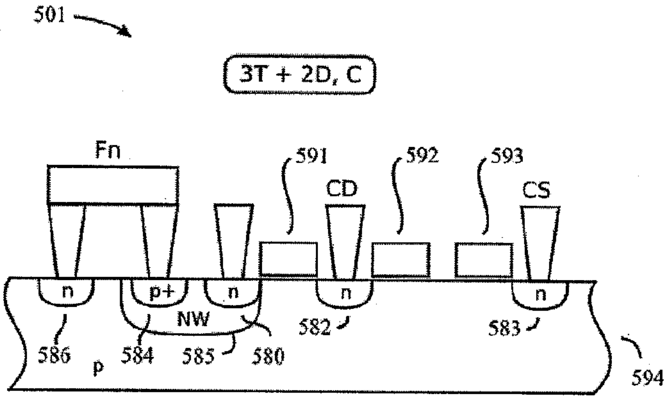


Fig. 25b

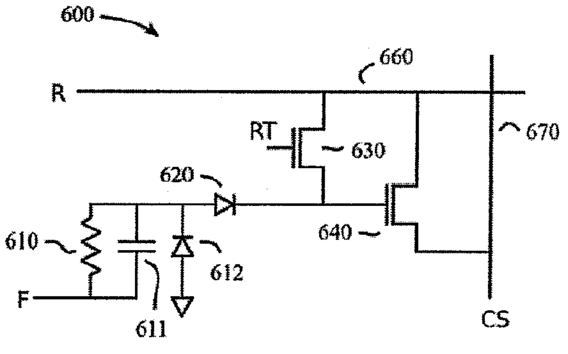


Fig. 26a

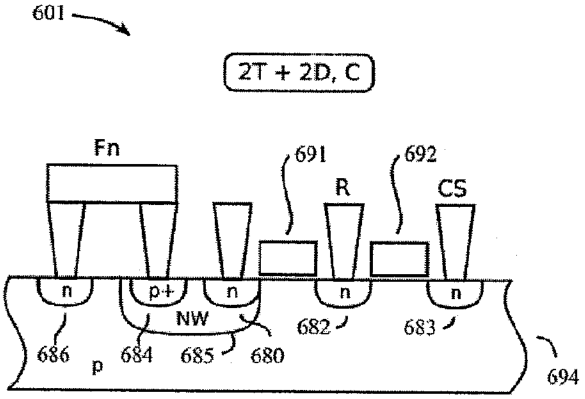


Fig. 26b

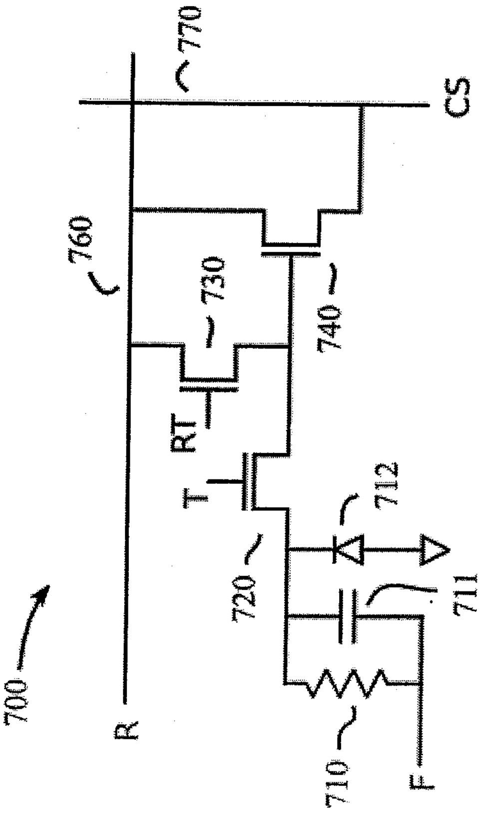


Fig. 27a

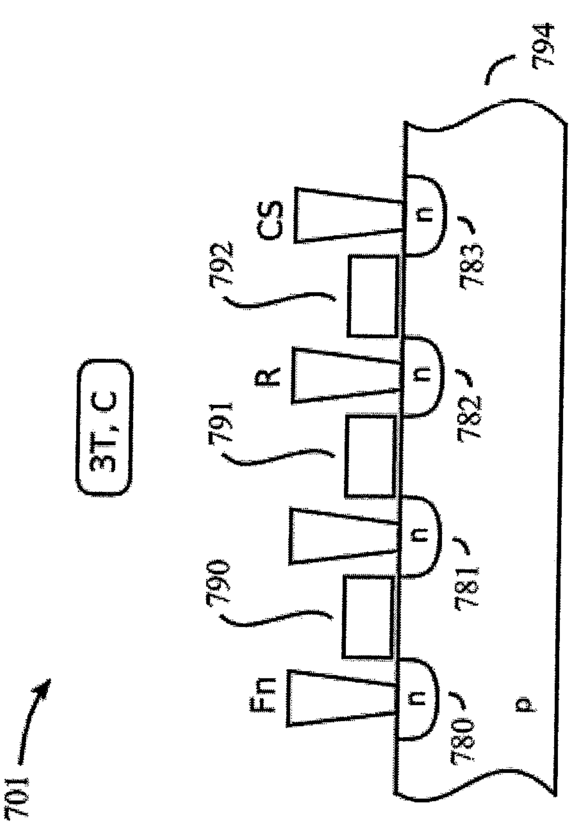


Fig. 27b

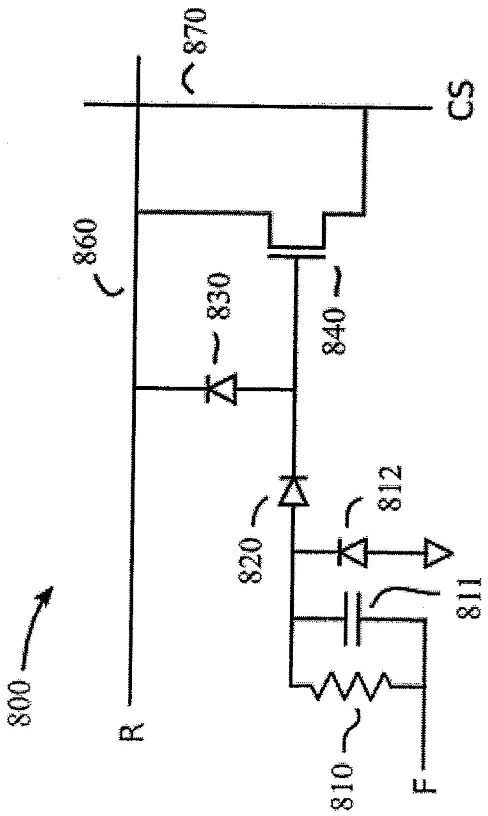


Fig. 28a

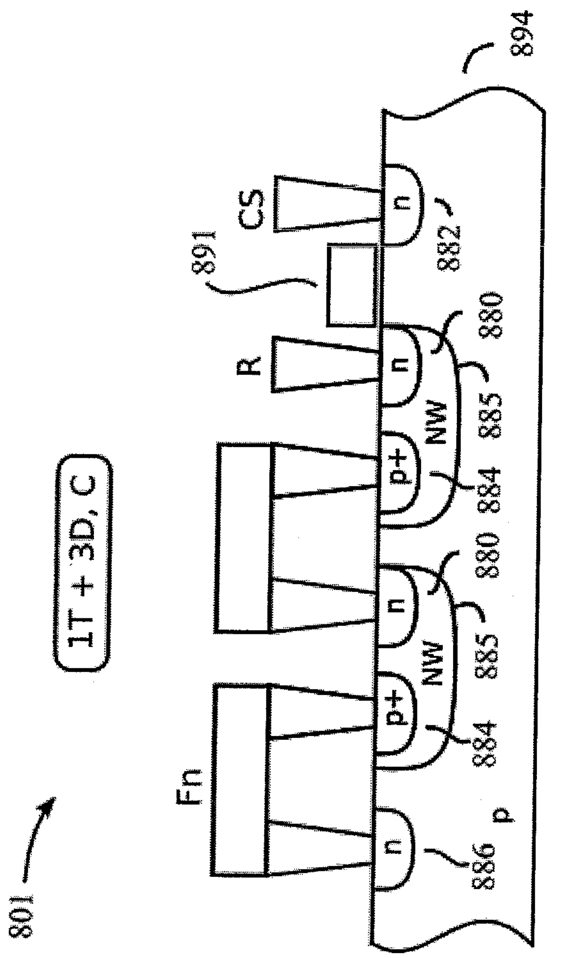


Fig. 28b

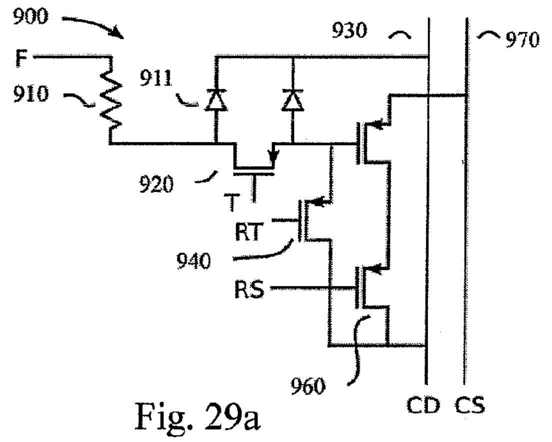


Fig. 29a

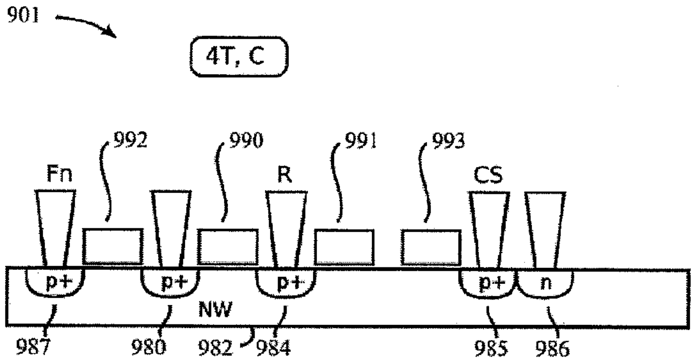


Fig. 29b

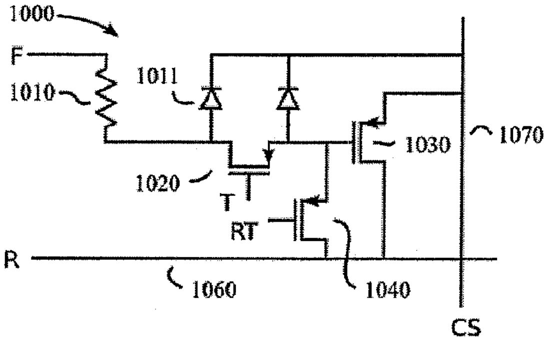


Fig. 30a

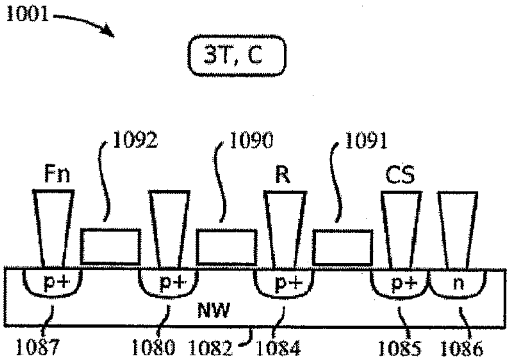


Fig. 30b

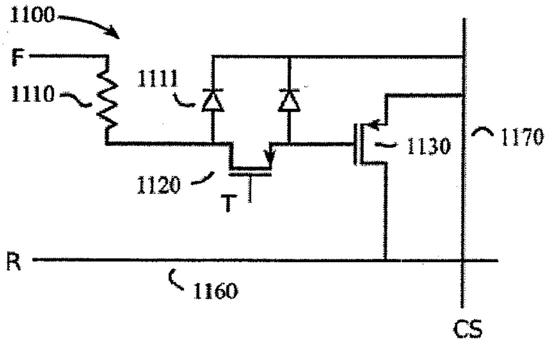


Fig. 31a

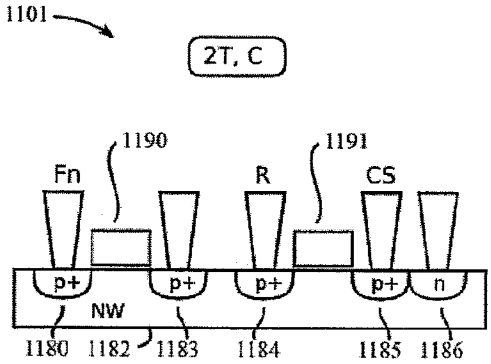


Fig. 31b

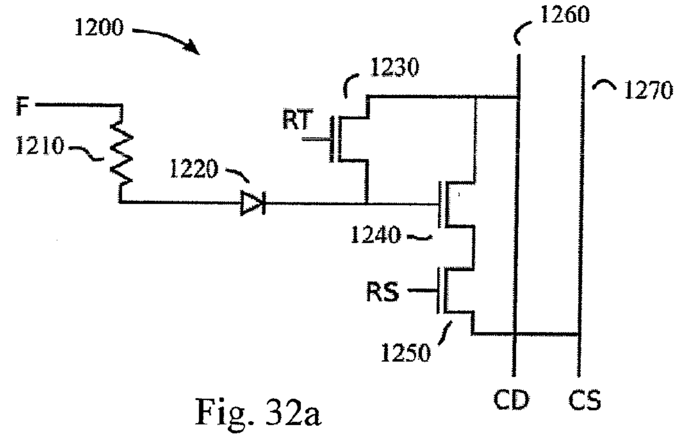


Fig. 32a

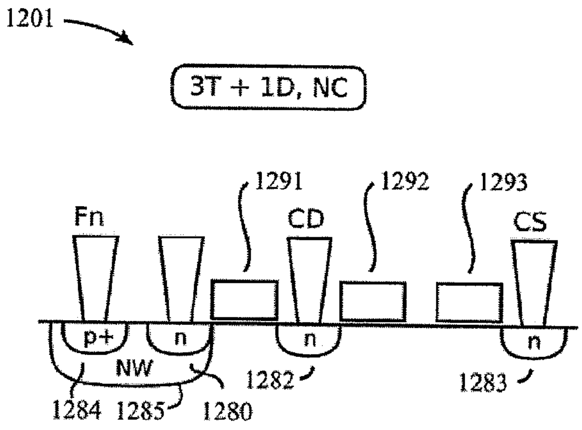


Fig. 32b

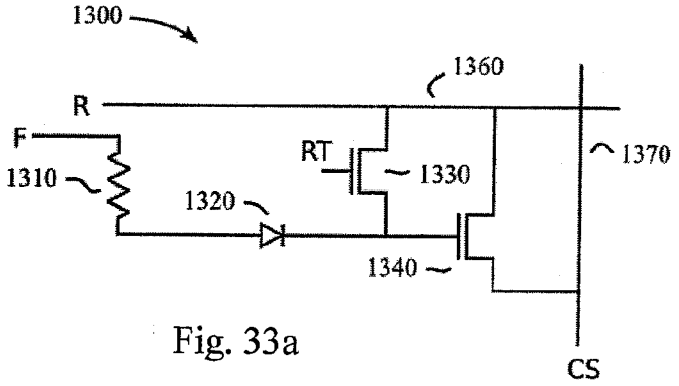


Fig. 33a

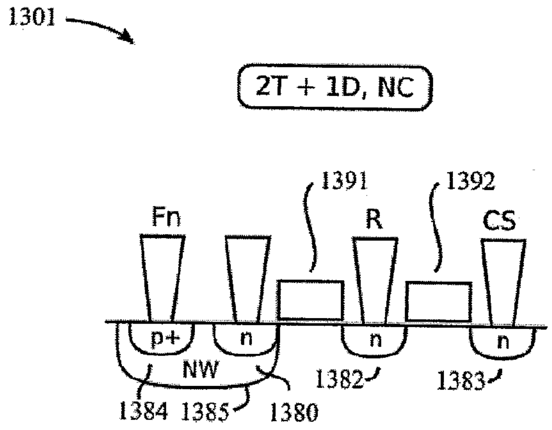


Fig. 33b

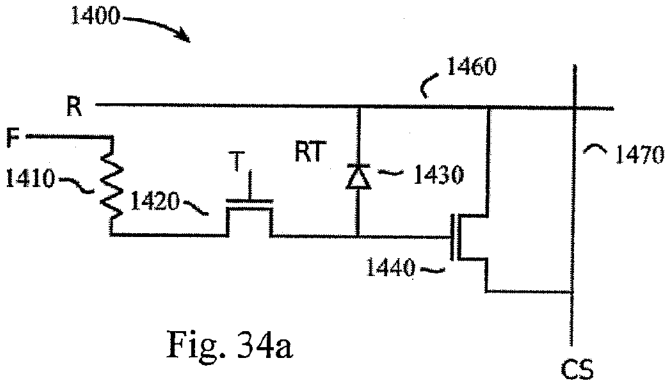


Fig. 34a

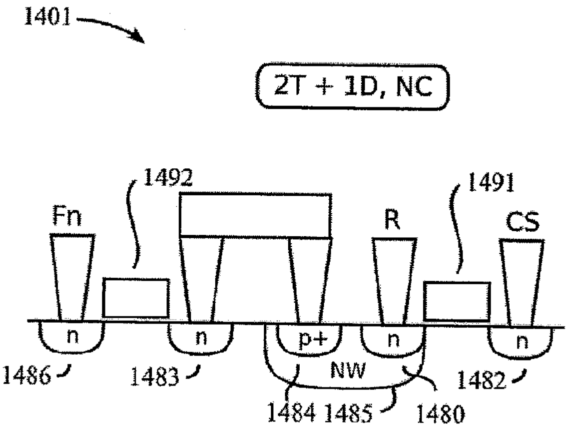


Fig. 34b

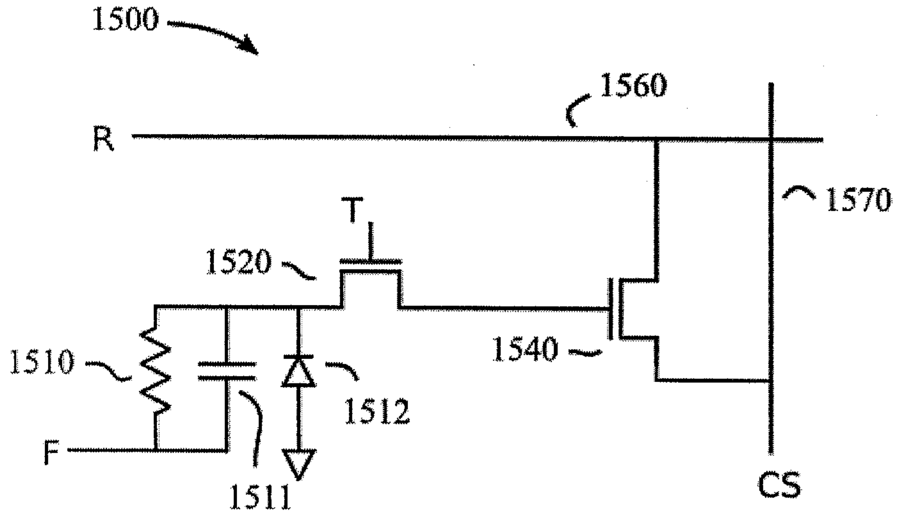


Fig. 35a

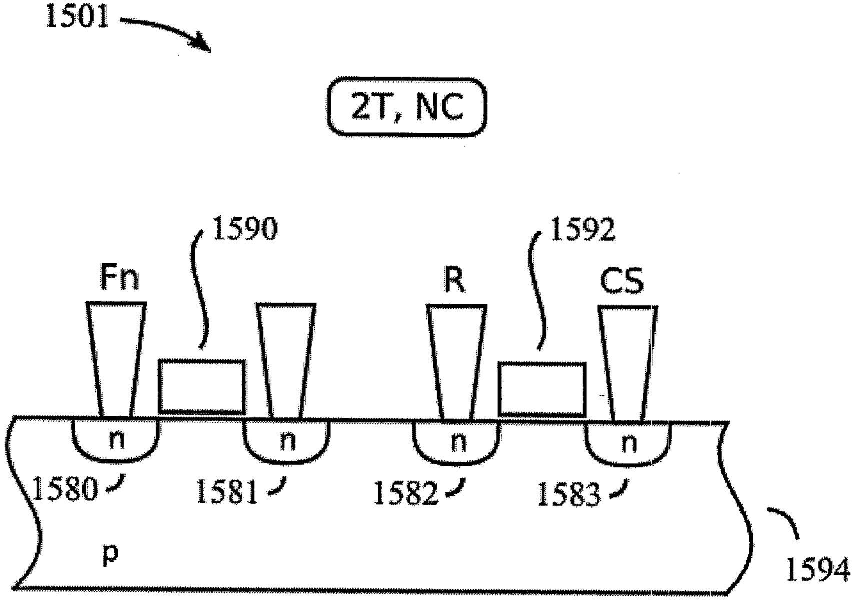


Fig. 35b

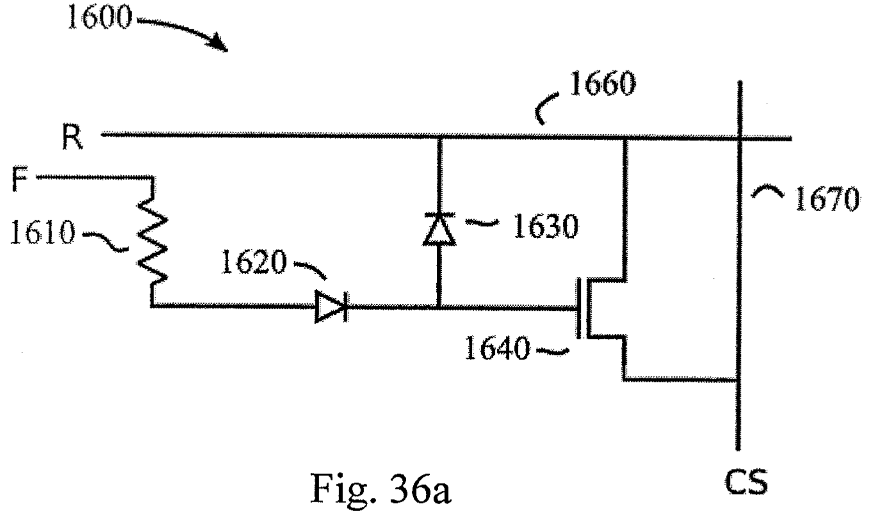


Fig. 36a

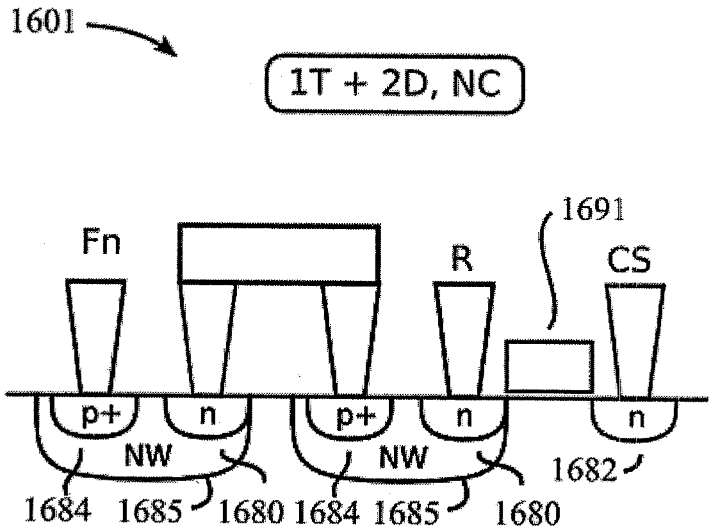


Fig. 36b

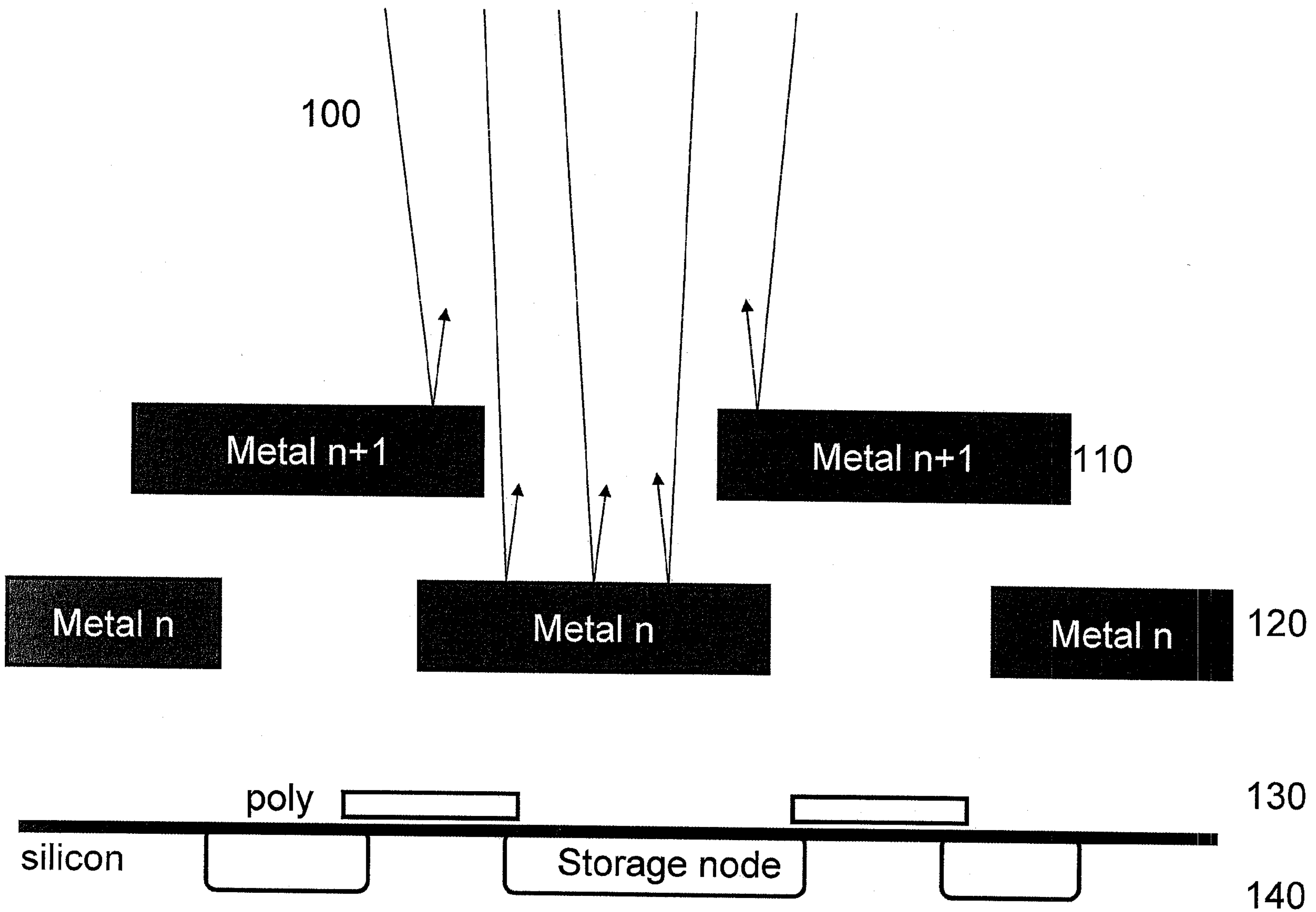

100
Metal n+1
Metal n+1
110
Metal n
Metal n
Metal n
120
poly
130
silicon
Storage node
140

Fig. 37

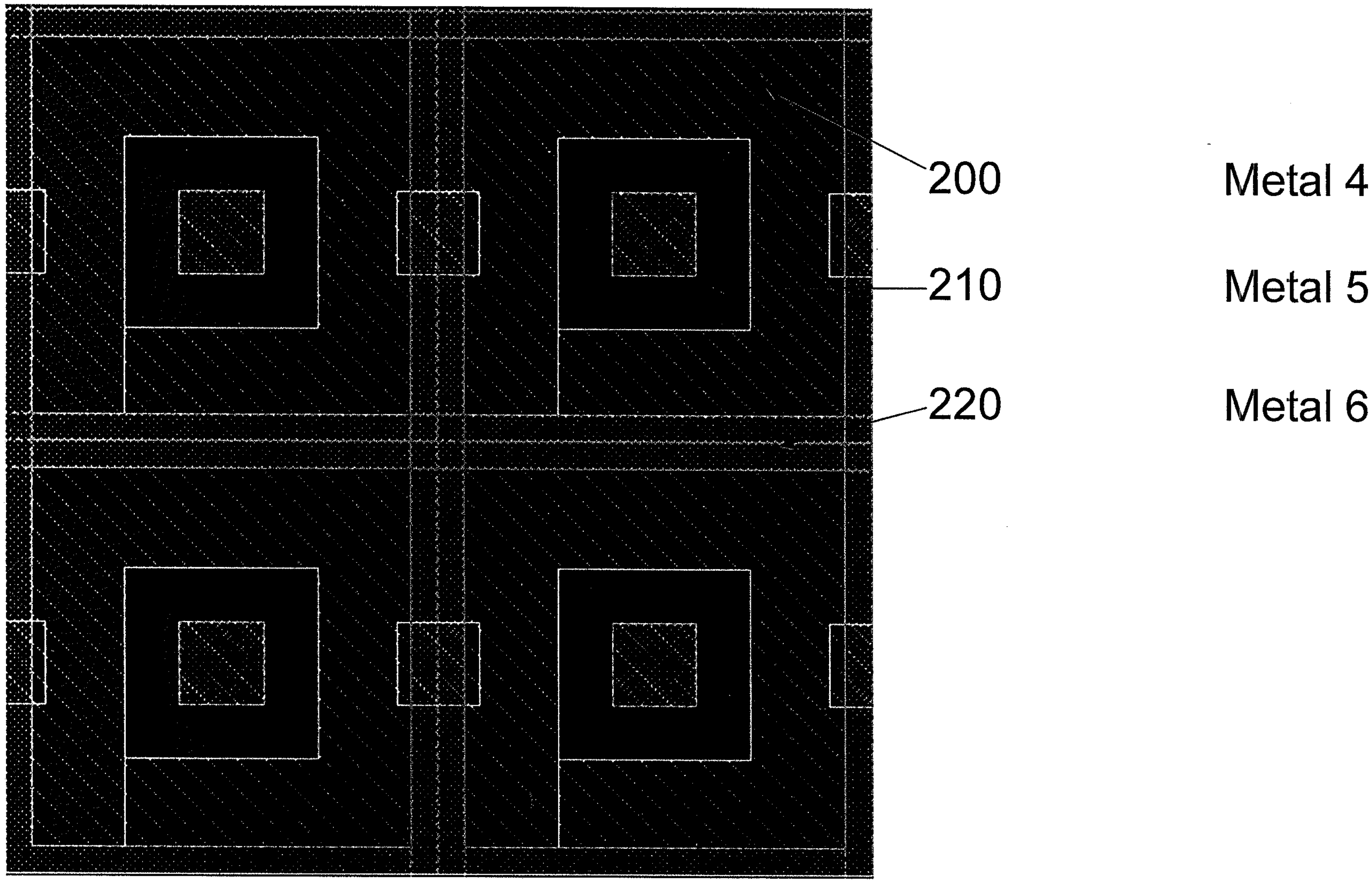


Fig. 38

FIG. 39

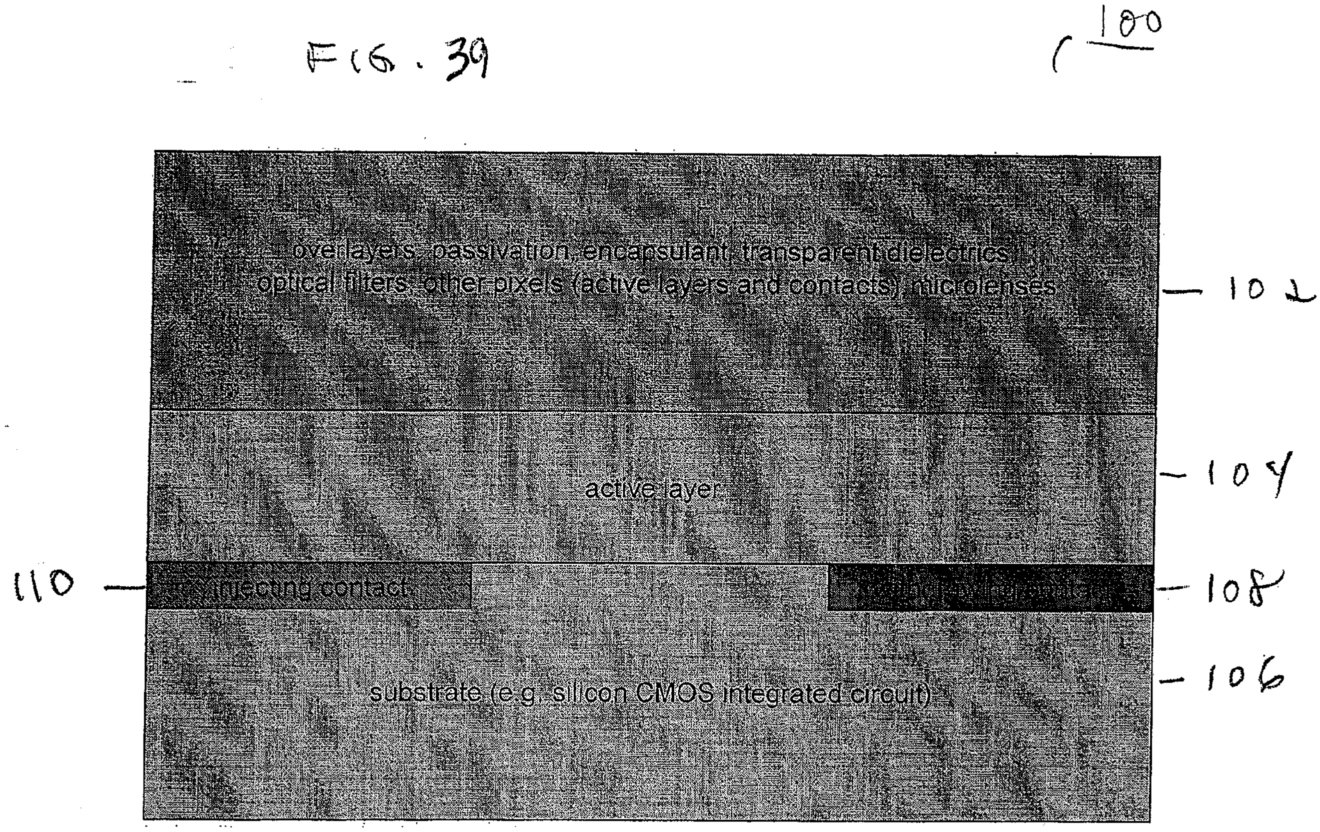
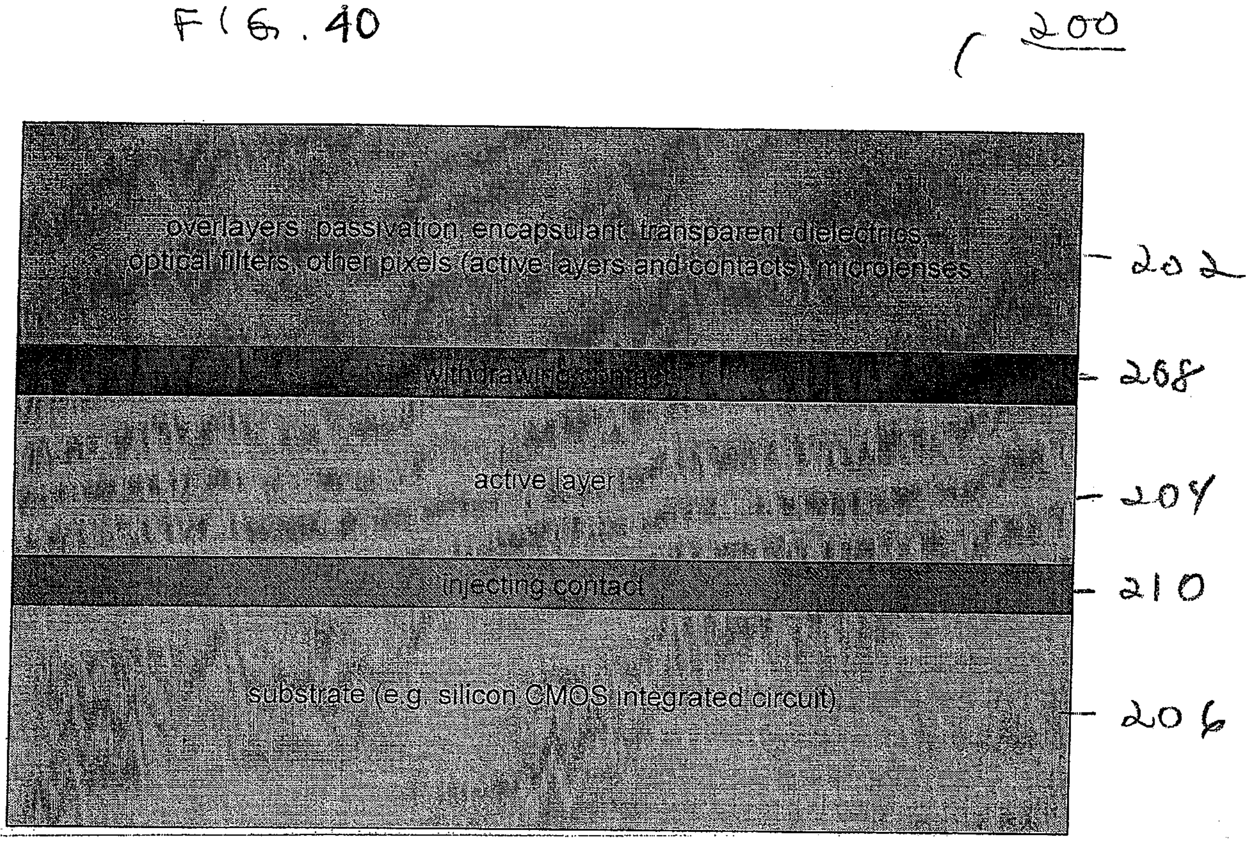

100
overlayers, passivation, encapsulant, transparent dielectrics, optical filters, other pixels (active layers and contacts), microlenses
102
active layer
104
110
injecting contact
108
substrate (e.g. silicon CMOS integrated circuit)
106

FIG. 40


200
overlayers, passivation, encapsulant, transparent dielectrics, optical filters, other pixels (active layers and contacts), microlenses
202
withdrawing contact
208
active layer
204
injecting contact
210
substrate (e.g. silicon CMOS integrated circuit)
206

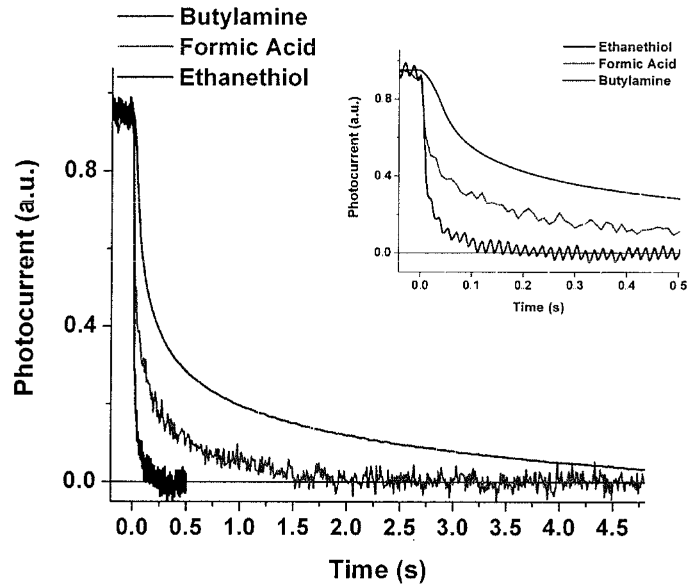
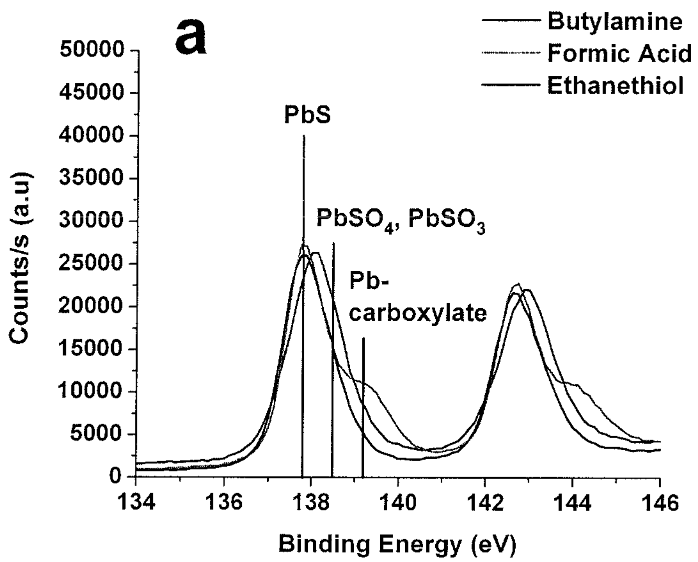


Fig. 41: Temporal response of photocurrent in butylamine, formic acid and ethanethiol treated nanocrystal films, BA treated films exhibit a photocurrent decay with multiple time constants of approximately 60, 300 and 2000 ms. FA treated devices yield a main photocurrent decay time constant of ~420 ms. ET treated devices show a faster photocurrent decay with a time constant of ~27 ms, the photocurrent decays to the dark current state within less than 200 ms (shown in the inset).



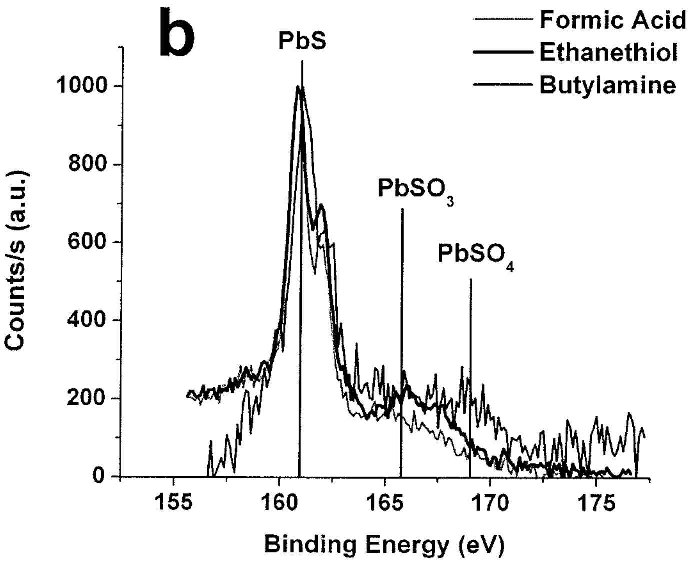


Fig. 42: XPS spectra of Pb4f (a) and S2p (b) signal from butylamine, formic acid and ethanethiol treated nanocrystal films used as photodetectors.

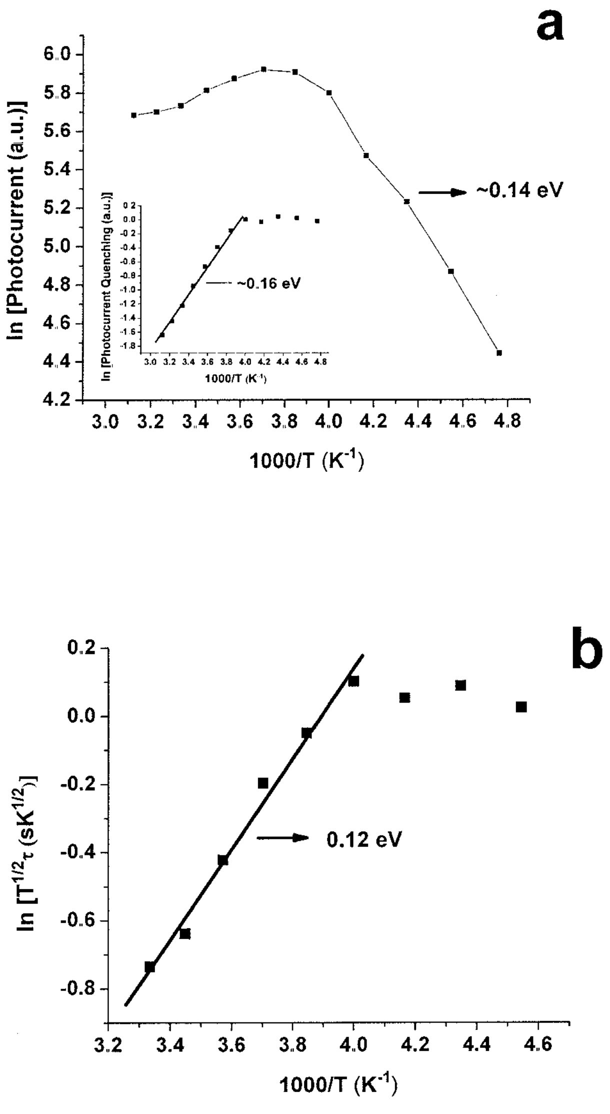


Fig. 43: Photocurrent temperature spectroscopy results. (a) Photocurrent vs temperature and photocurrent quenching vs temperature (shown in inset) reveal a single sensitization center 0.16 eV below the conduction band. (b) Photocurrent temporal response as a function of temperature reveals an activation energy of the sensitizing center of 0.12 eV below the conduction band, in good agreement with the value extracted via photocurrent quenching.

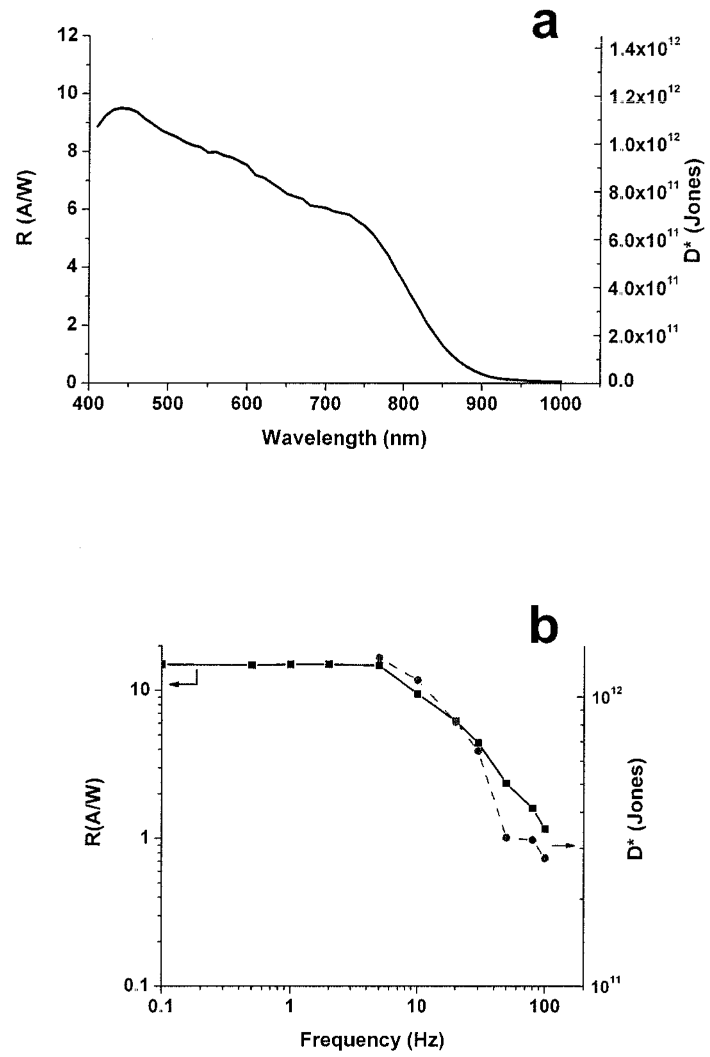


Fig. 44: (a) Spectral responsivity and detectivity of the ethane-thiol treated device considered a modulation frequency of 10 Hz. (b) Responsivity and specific detectivity as function of modulation frequency at 450 nm wavelength.

Treatments	**Oxides**	**Time constants**
Original	$PbSO_3$ Pb-carboxylate $PbSO_4$	-
Butylamine	$PbSO_3$ Pb-carboxylate $PbSO_4$	~60 ms ~300 ms ~2 s
Ethanethiol	$PbSO_3$	~27 ms
ET + aging in ambient	$PbSO_3$ $PbSO_4$	~38 ms ~3 s
Formic acid	$PbSO_3$ Pb-carboxylate	~33 ms ~420 ms

Fig. 45: Summary of the correlation between oxide species and photocurrent time constants observed in variously treated PbS nanocrystal films.

XPS Analysis of variously treated PbS Nanocrystal films.

For XPS analysis PbS nanocrystals were spincoated on a Au-overcoated silicon substrate and underwent the exact same treatments as the films used for photodetectors reported in the manuscript.

As-synthesized oleic acid capped nanocrystals.

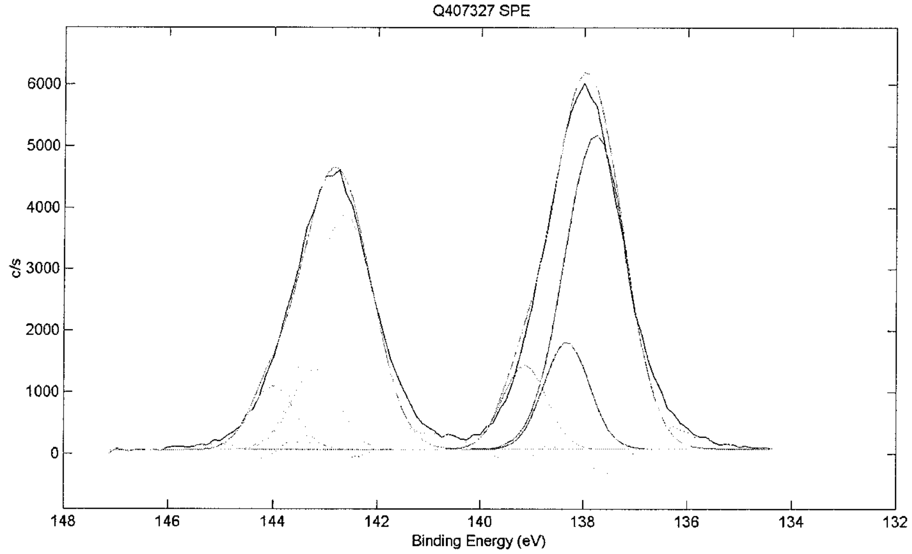


Fig. 46a: Pb4f signal of oleate-capped PbS nanocrystals. Three components can be distinguished: PbS (~137.7 eV), $PbSO_4$ and $PbSO_3$ (~138.4 eV) and Pb-carboxylate (~139.1 eV).

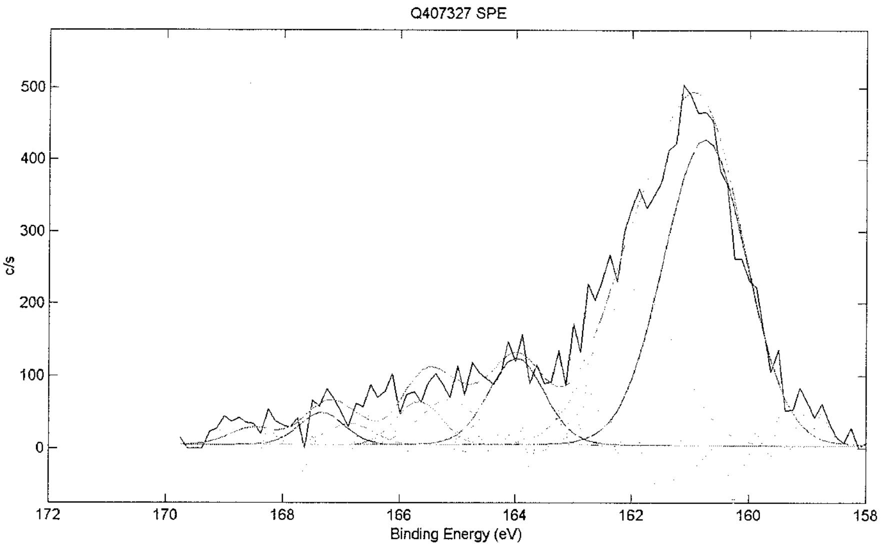


Fig. 46b: S2p signal of oleate-capped PbS nanocrystals. The s2p signal exhibits a PbS peak (160.8 eV) a poly-sulfide peak (163.9 eV), a $PbSO_3$ peak (165.6 eV) and a $PbSO_4$ peak (167.9 eV)

Pb-oleate.

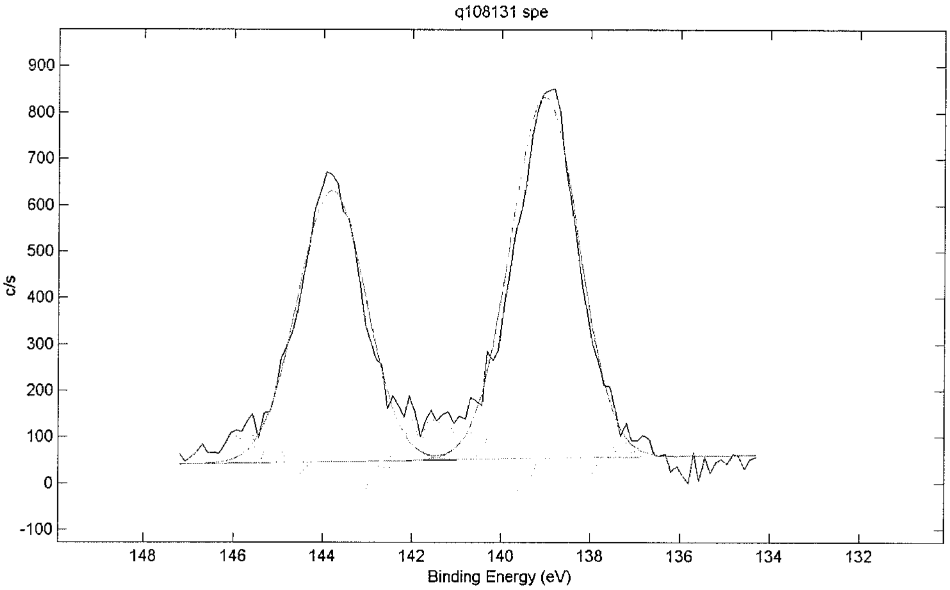


Fig. 47: Pb4f signal of Pb-oleate. There is a single peak at 139.1 eV attributable to Pb-carboxylate bond of Pb-oleate.

Butylamine treated nanocrystals.

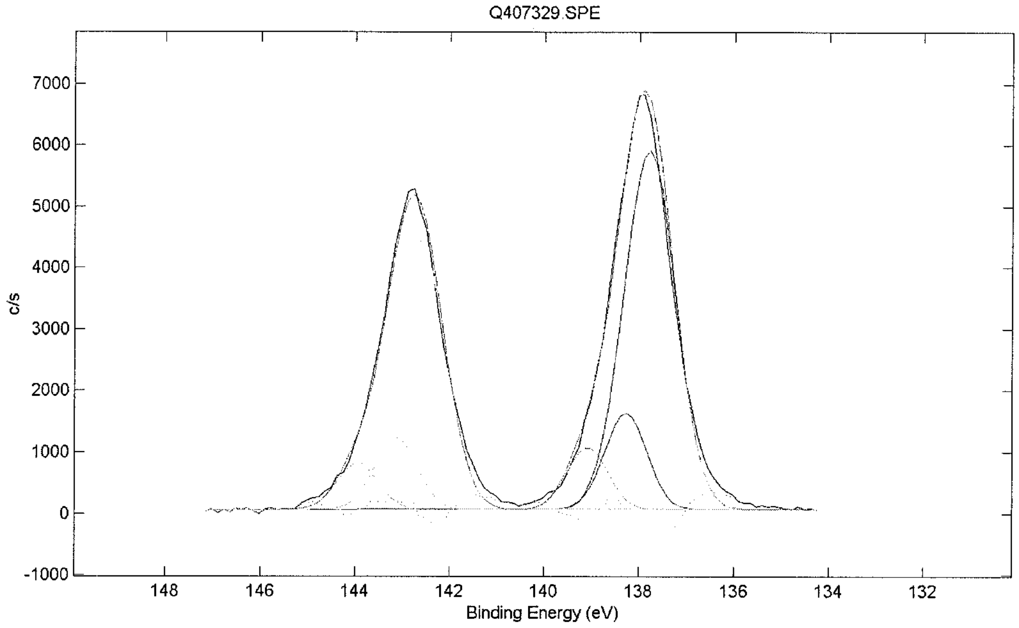


Fig. 48a: Pb4f peak of butylamine treated nanocrystals. The identified species are: PbS (137.7 eV), $PbSO_3$ and $PbSO_4$ (~138.4 eV) and Pb-carboxylate (~139.1 eV).

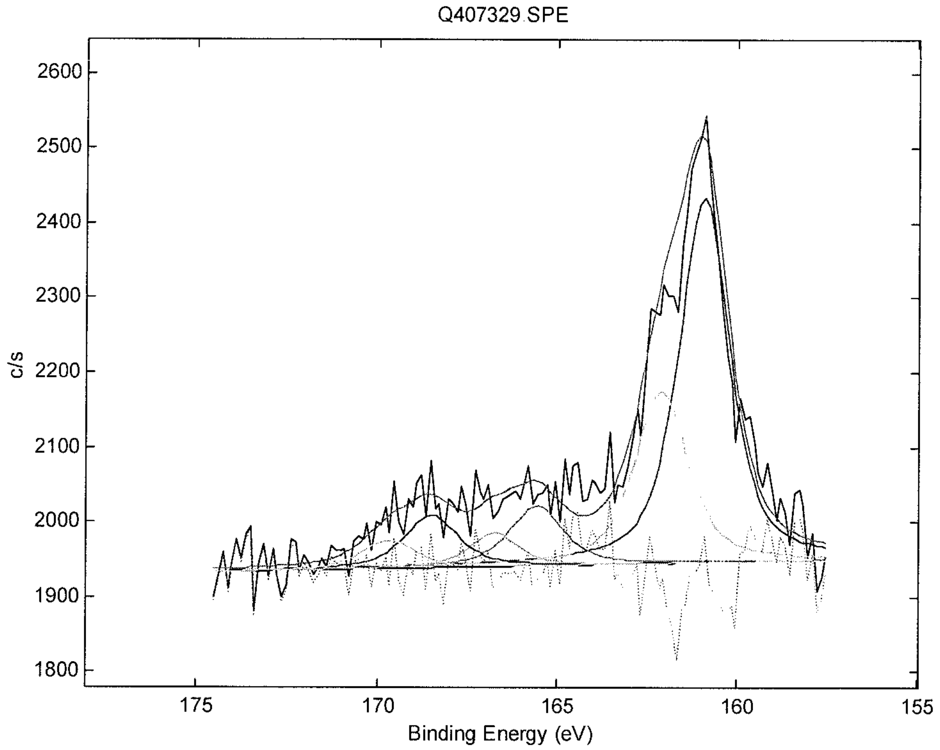


Fig. 48b: S2p signal of butylamine treated nanocrystals: The identified species are: PbS (160.9 eV), $PbSO_3$ (~165.6 eV) and PbSO4 (167.8 eV).

Formic Acid treated nanocrystals.

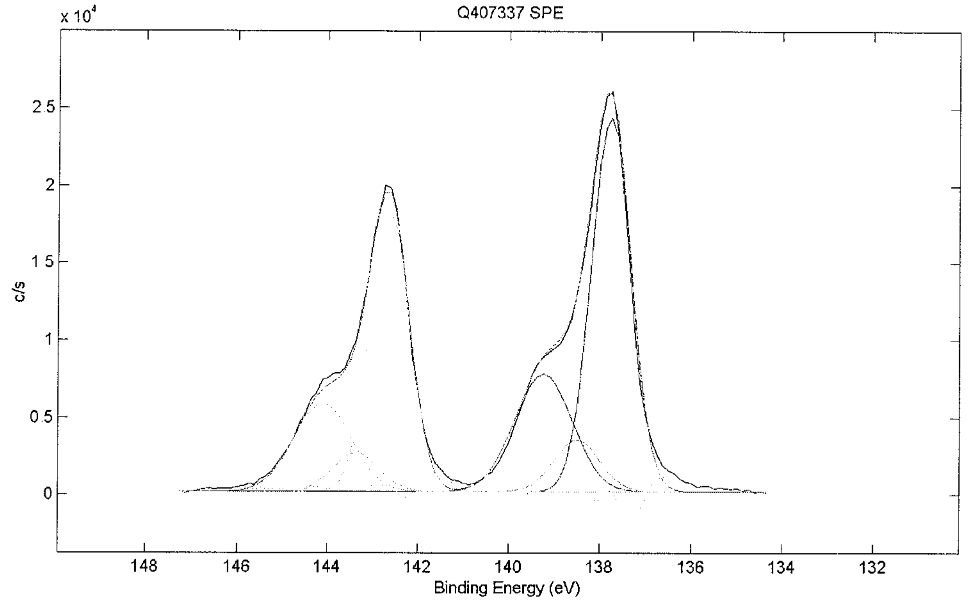


Fig. 49a: Pb4f signal of PbS nanocrystals treated with formic acid. 3 species are identified: PbS (137.7 eV), $PbSO_3$ (138.5 eV) and Pb-carboxylate (139.2 eV).

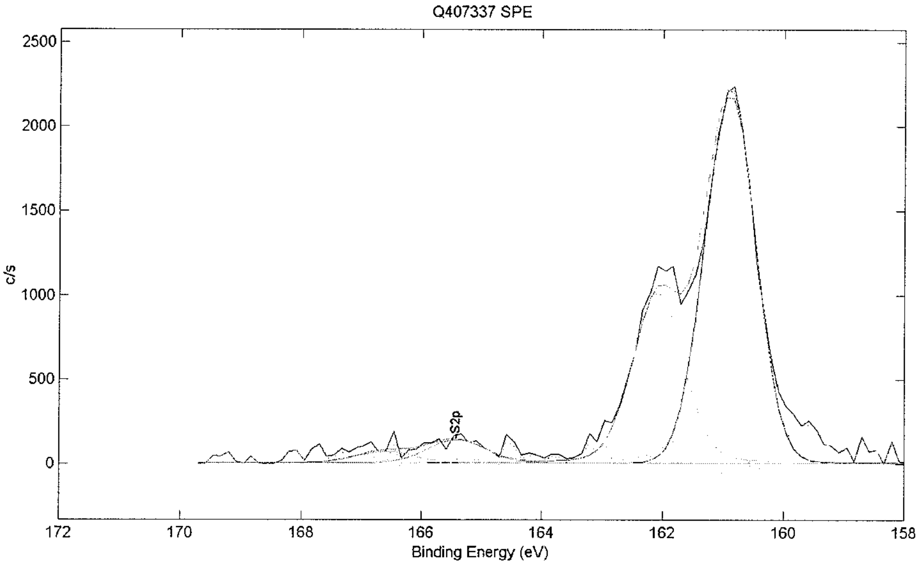


Fig. 49b: S2p signal of PbS nanocrystals treated with formic acid. Two species are found: PbS (160.9 eV) and $PbSO_3$ (165.6 eV).

Ethanethiol treated nanocrystals.

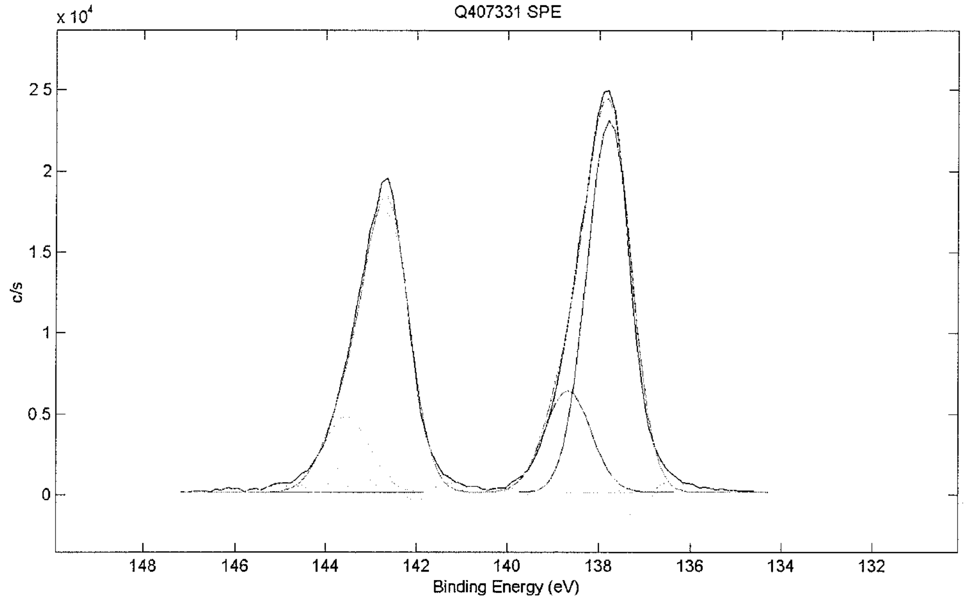


Fig. 50a: Pb4f signal of ethanethiol treated nanocrystals. Two species are found: PbS (137.7 eV) and $PbSO_3$ (~138.6 eV).

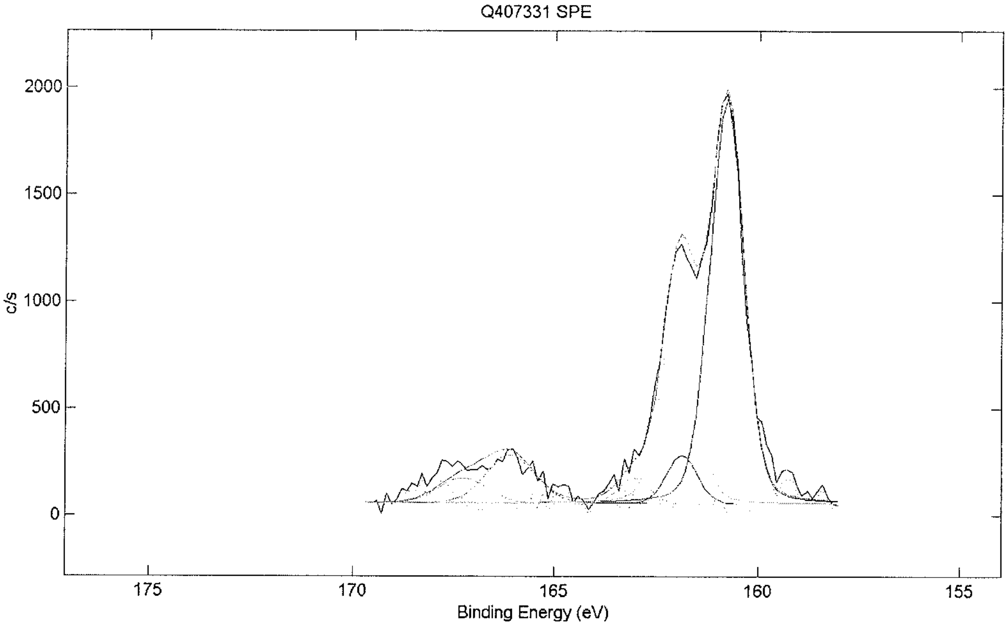


Fig. 50b: S2p peak of ethanethiol treated nanocrystals. The 3 existent species can be identified as: PbS (160.8 eV), $PbSO_3$ (165.8 eV) and thiol signature of S-C bond (161.9 eV).

Ethanethiol treated nanocrystals aged in ambient.

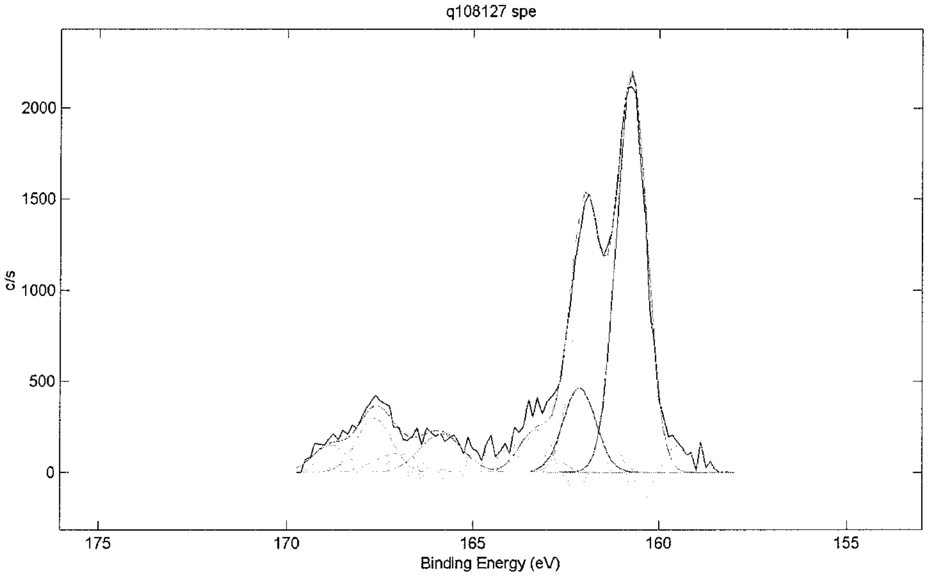


Fig. 51: S2p signal of ethanethiol treated nanocrystals followed by ageing in ambient conditions. There exist 4 species: PbS (160.9 eV), $PbSO_3$ (165.8 eV), $PbSO_4$ (167.8 eV) and the thiol signature from the S-C bond (162 eV)

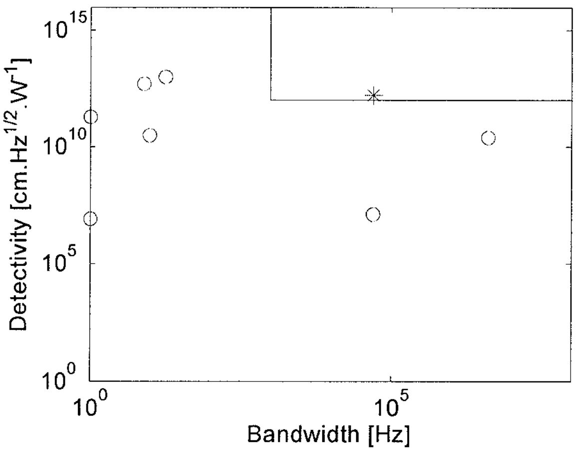


Figure 52. Detectivity and bandwidth of previously reported solution-processed photodetectors (circles), and the photodetector presented in our submission (star).

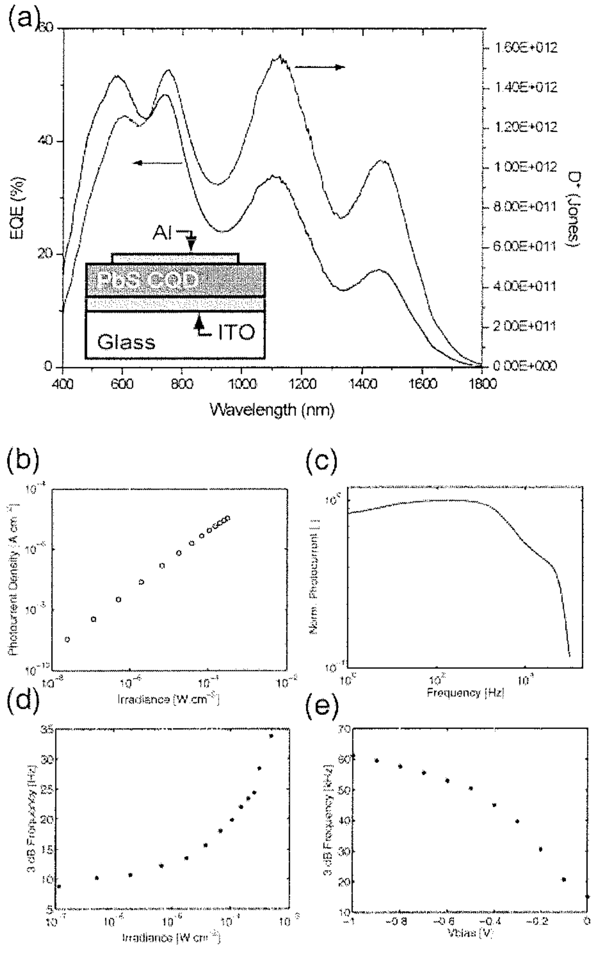


Figure 53. (a) External quantum efficiency (at 295 K) and normalized detectivity (at 250 K) as a function of wavelength. The inset shows a schematic representation of the photodiode device architecture. (b) Photocurrent density as a function of irradiance at 1550 nm. (c) Frequency dependence of photocurrent at zero bias and 17.9 μW.cm^{-2} irradiance and 3dB frequency dependence on irradiance (d) and bias (e).

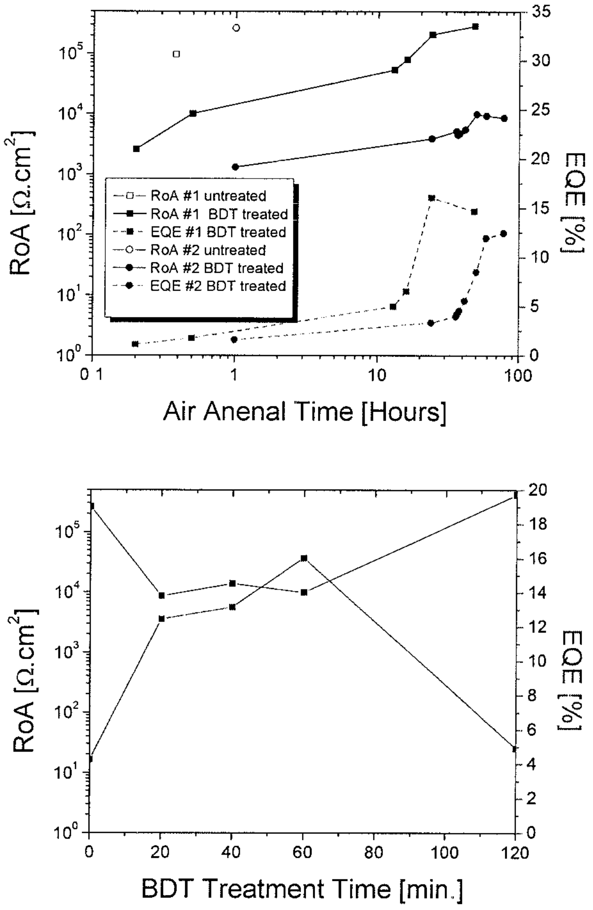


Figure 54. (a) Normalized zero-bias shunt resistance (*RoA*) and external quantum efficiency (EQE) as a function of air anneal time after BDT treatment for photodiodes fabricated with CQDs exchanged **25** days previously (Batch 1) and **5** days previously (Batch 2). Accelerated annealing was introduced after 16 and 44 hours of air-annealing in Batches 1 and 2, respectively. *RoA* for untreated CQD photodiodes for the same CQD batches is also shown. (b) *RoA* and EQE as a function of BDT treatment time, following air annealing.

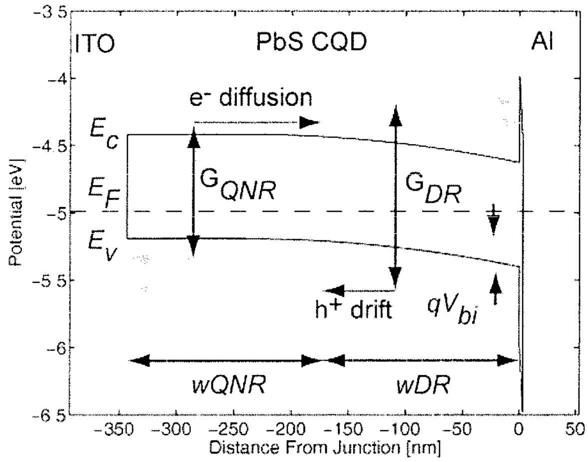


Figure 55. Energy bands and photocurrent components in the quasi-neutral and depletion regions of photodiode.

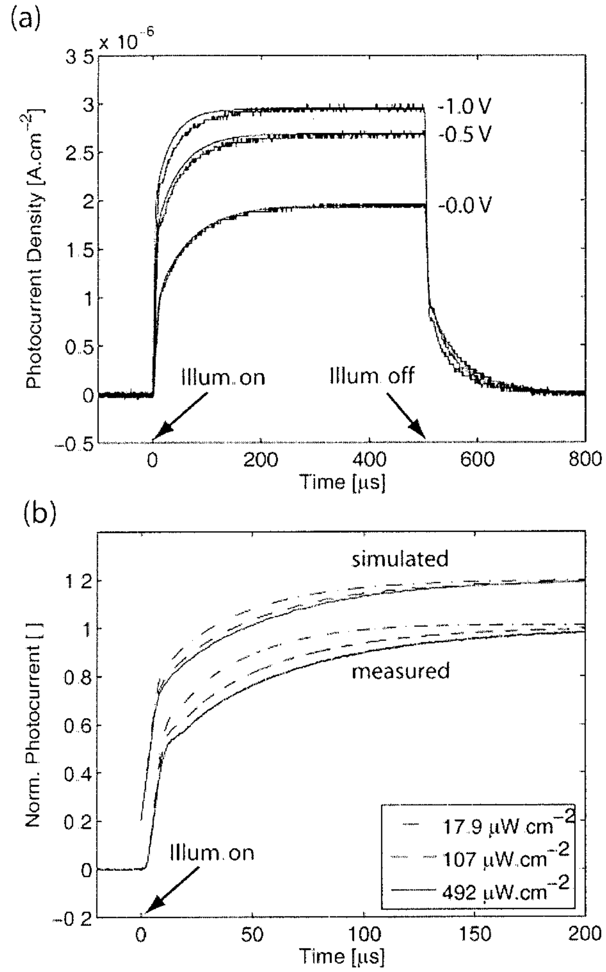


Figure 56. (a) Measured (noisy line) and simulated (smooth line) photocurrent transient response as a function of bias to a square illumination pulse at 17.9 μW.cm^{-2}. Note that the measured and simulated lines are co-incident for 0.0V. (b) Measured and simulated photocurrent transient response (normalized) as a function of irradiance at zero bias. The simulated response is shifted for clarity.

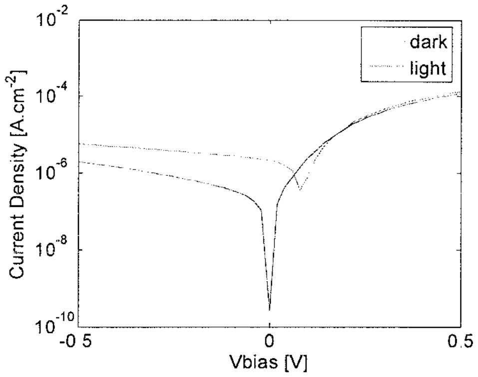


Figure 57. Steady-state *I-V* characteristics in the dark and at 17.9 μW.cm^{-2} illumination at 1550 nm.

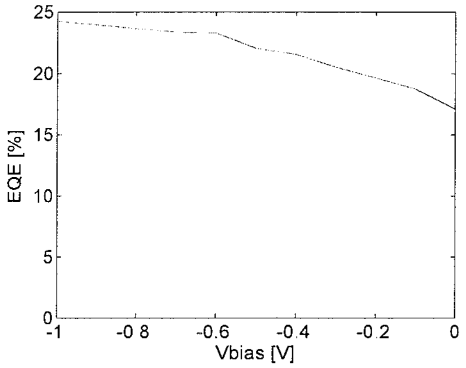


Figure 58. EQE at 1450 nm (100 Hz modulation) as a function of reverse bias.

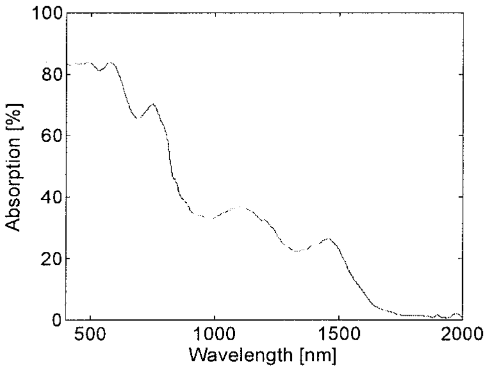


Figure 59. Net absorption in the CQD film of the CQD photodiode.

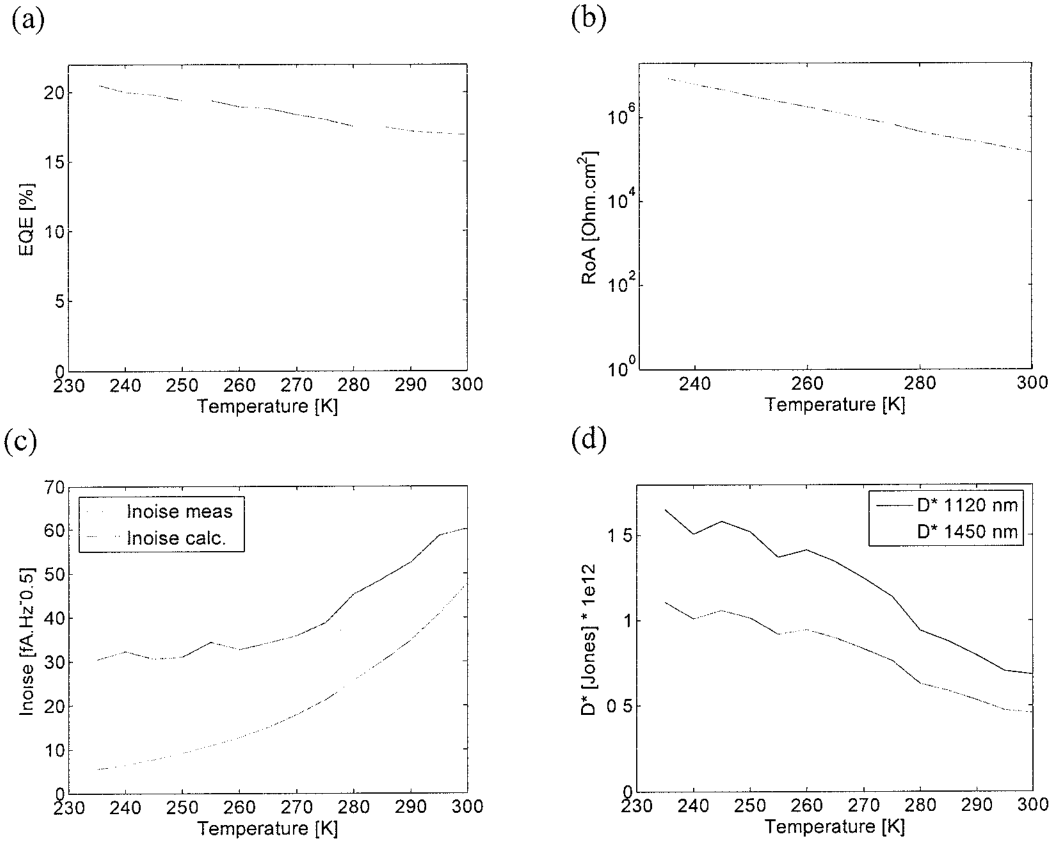


Figure 60. (a) EQE at 1450 nm as a function of temperature. (b) Measured *RoA* as function of temperature. (c) Measured i_{noise} and i_{noise} calculated from measured *RoA*, as a function of temperature. (d) D* at 1450 nm and 1120 nm, as a function of temperature.

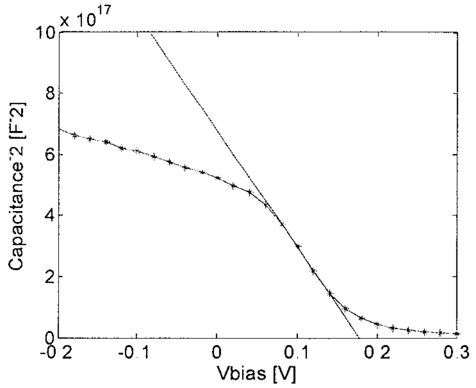


Figure 61. Measured capacitance, as a function of bias, and best-fit using the abrupt junction approximation.

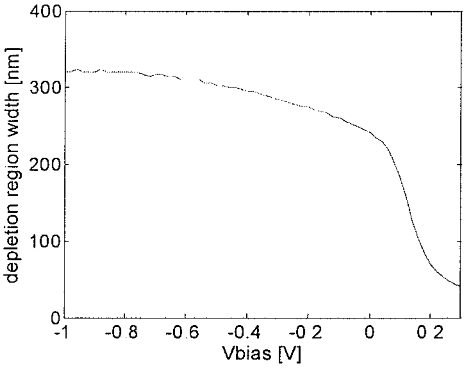


Figure 62. Depletion region width, as a function of bias, calculated from the measured capacitance.

Measurement details

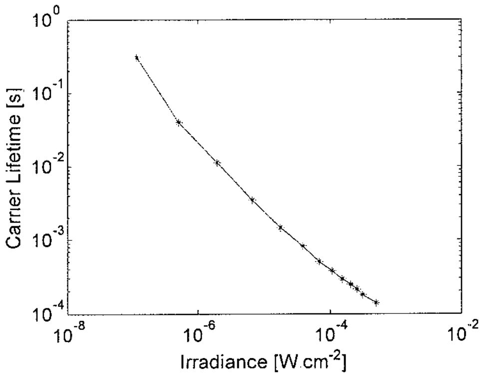


Figure 63 Carrier lifetime as a function of irradiance at 1550 nm.

Parameter	Symbol	Measurement Method	Measured Value	Value used in model
CQD Film Thickness [nm]	d	profilometer	340	340
Depletion Region Thickness [nm]	w_{DR}	capacitance-voltage	240 305 320	170 at Vbias = 0.0 200 at Vbias = -0.5 250 at Vbias = -1.0
Quasi-Neutral Region Thickness [nm]	w_{QNR}	calculated from d- w_{DR}	100 35 20	*170 at Vbias = 0.0* *140 at Vbias = -0.5* *90 at Vbias = -1.0*
Built-in Potential [V]	V_{bi}	capacitance-voltage	0.20	0.20
Absorption Coefficient [cm^{-1}]	α	absorption	1.05e4	1.05e4
Internal Quantum Efficiency [ ]	η	absorption		0.30 at Vbias = 0.0 0.41 at Vbias = -0.5 0.44 at Vbias = -1.0
Carrier Lifetime [s]	τ	V_{oc} transient	(see SOM Section 5.0)	(see SOM Section 5.0)
Static Dielectric Permittivity [ ]	ε_r	CELIV	19.2	19.2
Hole Mobility [cm^2.V^{-1}.s^{-1}]	μ_h	CELIV	1.1e-4	1.1e-4
Electron Diffusivity [cm^2.s^{-1}]	D_e	SSPG		3.4e-6

Figure 64. Measured physical parameters of the CQD photodiode and values used in the model.

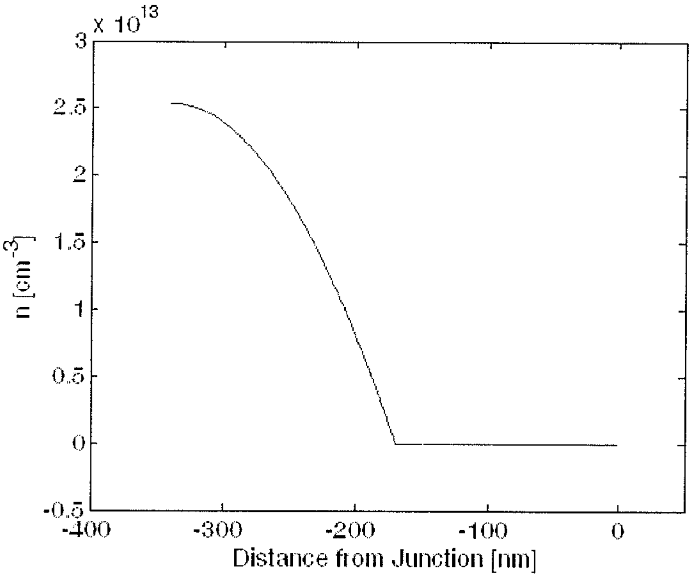


Figure 65. Electron concentration as a function of position in the CQD photodiode under steady-state illumination.

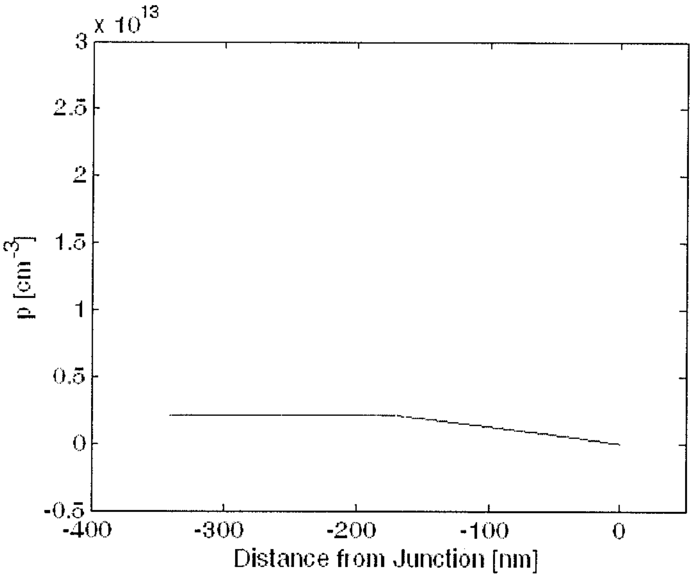
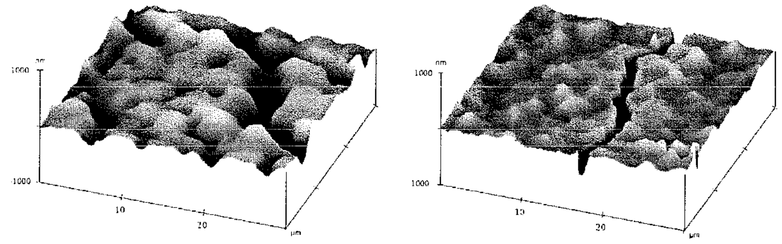
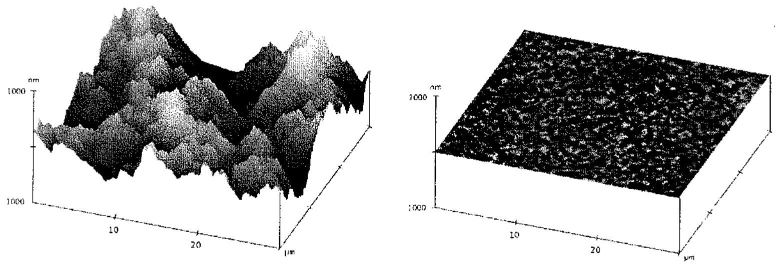


Figure 66. Hole concentration as a function of position in the CQD photodiode under steady-state illumination.



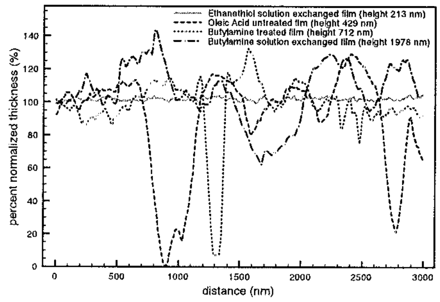
(a) AFM original oleic acid capping, Ra 103 nm

(b) AFM butylamine film treatment, Ra 64 nm



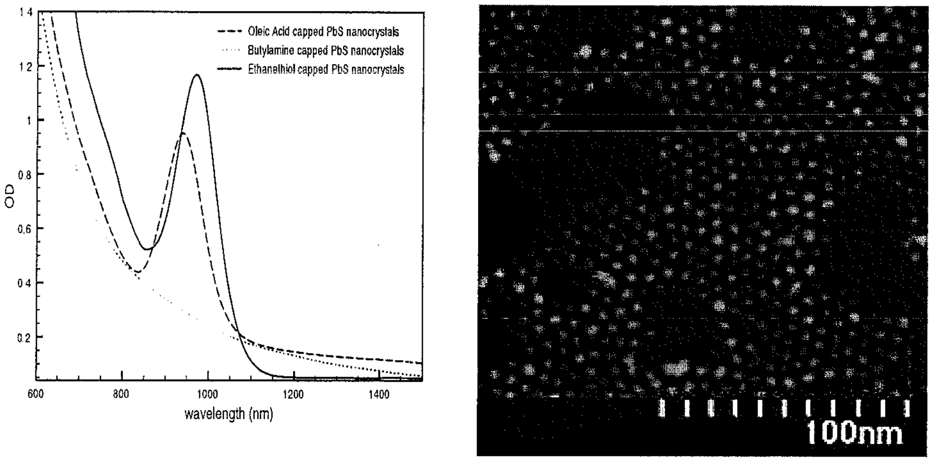
(c) AFM butylamine solution exchanged, Ra 335 nm

(d) AFM ethanethiol solution exchanged, Ra 1.4 nm

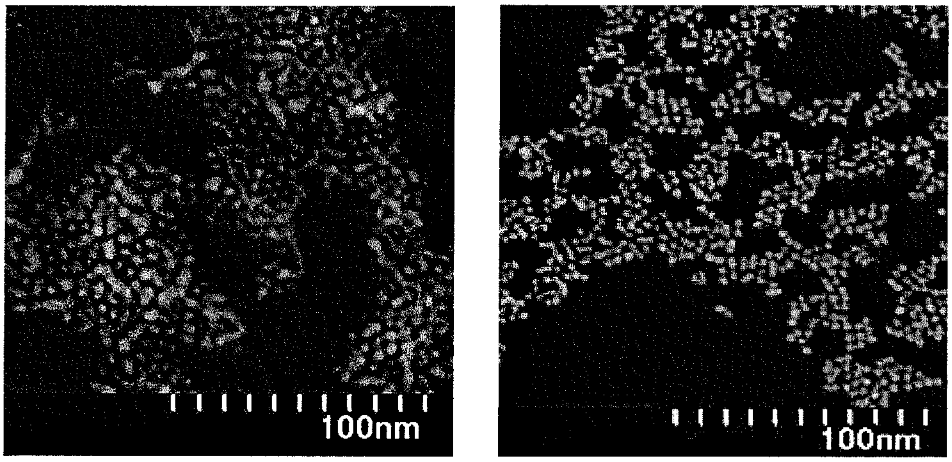


(e) percent average height normalized metrology of above exchanges

Fig. 67

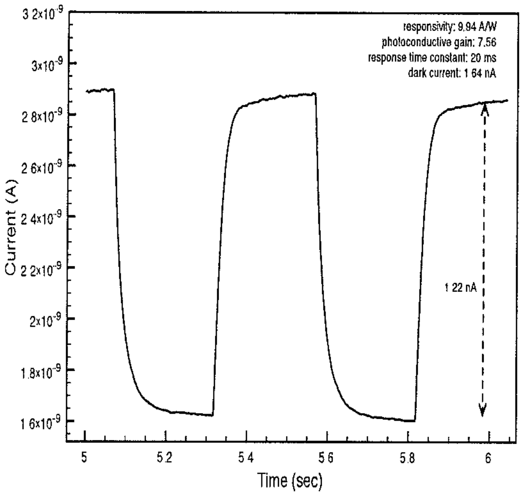


(a) Absorption spectrophotometry (b) TEM original oleic acid capping



(c) TEM butylamine solution exchange (d) TEM ethanethiol solution exchanged

Fig. 68



(a) Typical transient response

Fig. 69

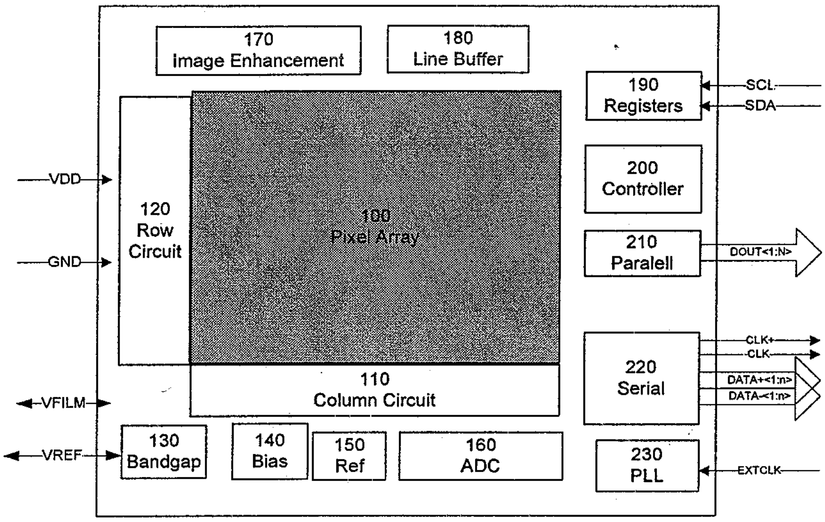

170
Image Enhancement
180
Line Buffer
190
Registers
SCL
SDA
200
Controller
120
Row
Circuit
100
Pixel Array
VDD
GND
210
Paralell
DOUT<1:N>
220
Serial
CLK+
CLK-
DATA+<1:n>
DATA-<1:n>
110
Column Circuit
VFILM
VREF
130
Bandgap
140
Bias
150
Ref
160
ADC
230
PLL
EXTCLK

FIG. 70