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(54) **METHODS OF MAKING OPTOELECTRONIC DEVICES**

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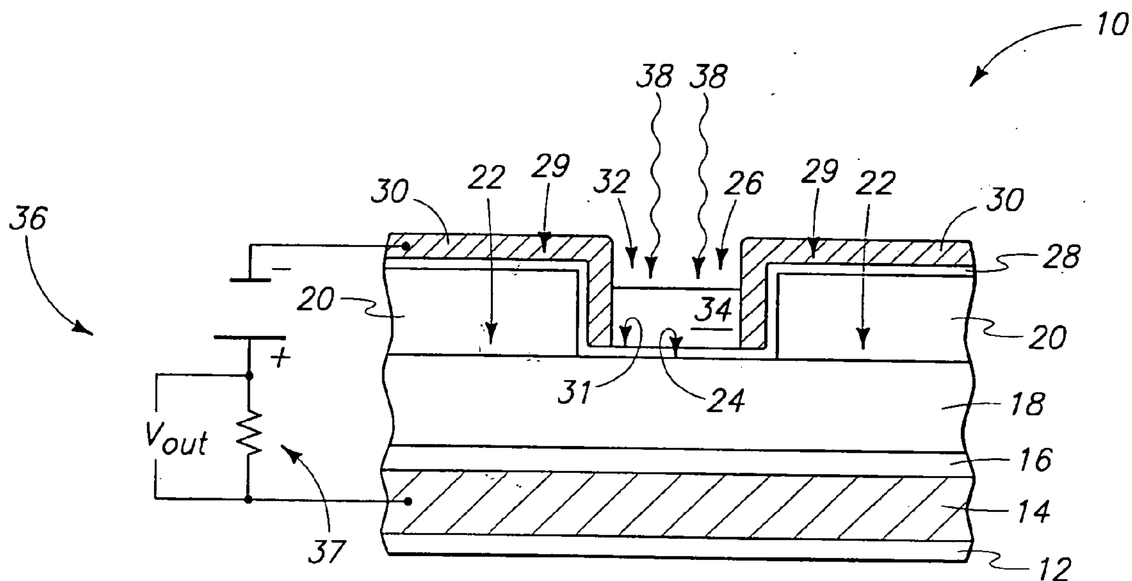
(57) **ABSTRACT**

The invention includes optoelectronic devices containing one or more layers of semiconductor-enriched insulator (with exemplary semiconductor-enriched insulator being silicon-enriched silicon oxide and silicon-enriched silicon nitride), and includes solar cells containing one or more layers of semiconductor-enriched insulator. The invention also includes methods of forming optoelectronic devices and solar cells.



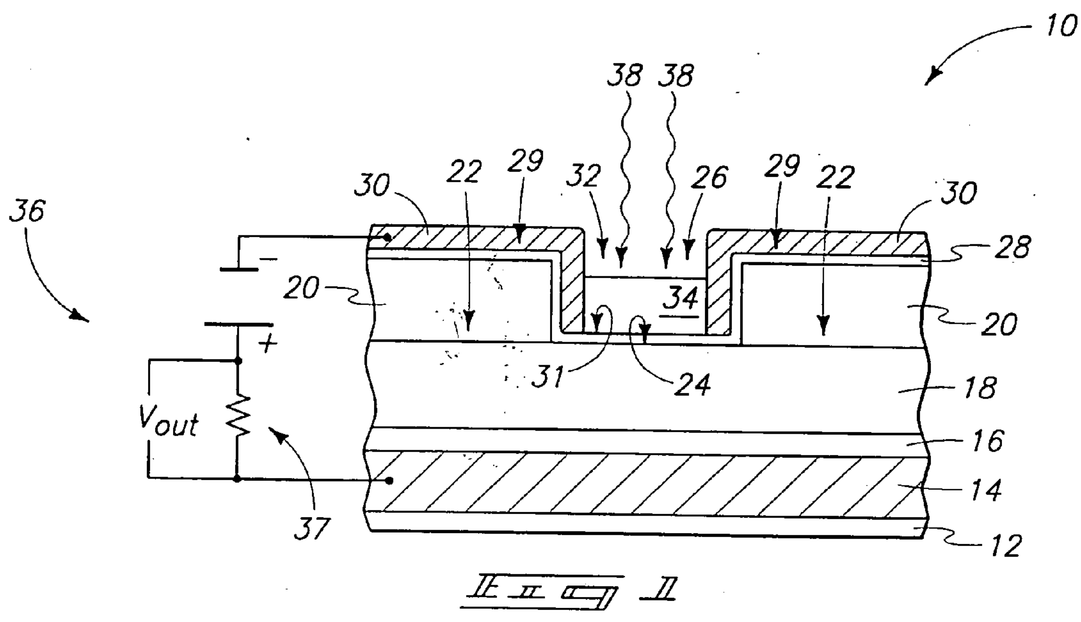


Fig 1

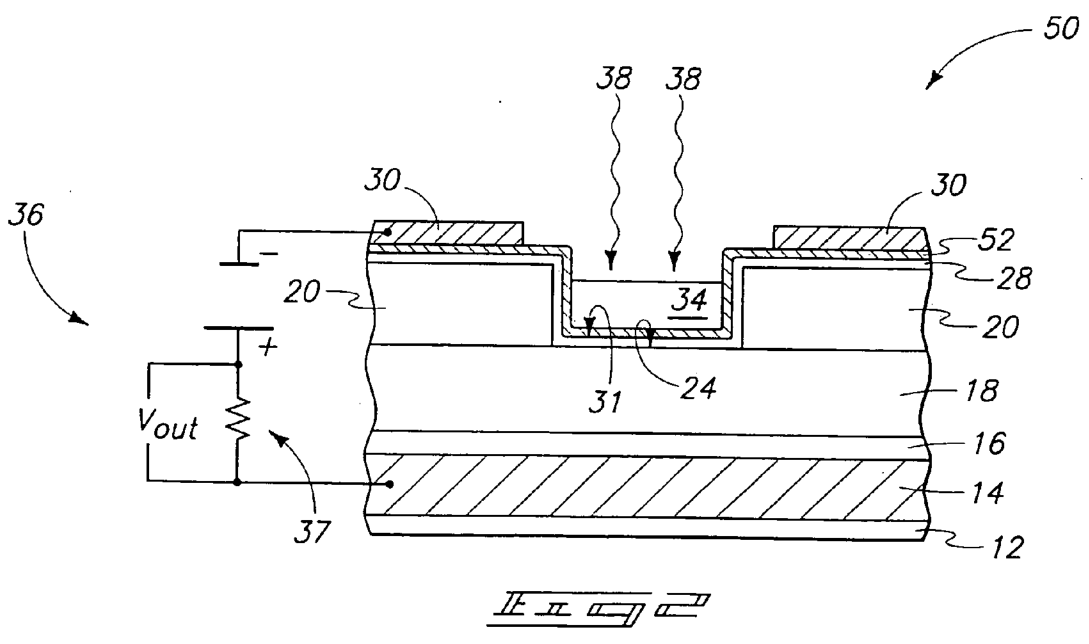


Fig 2

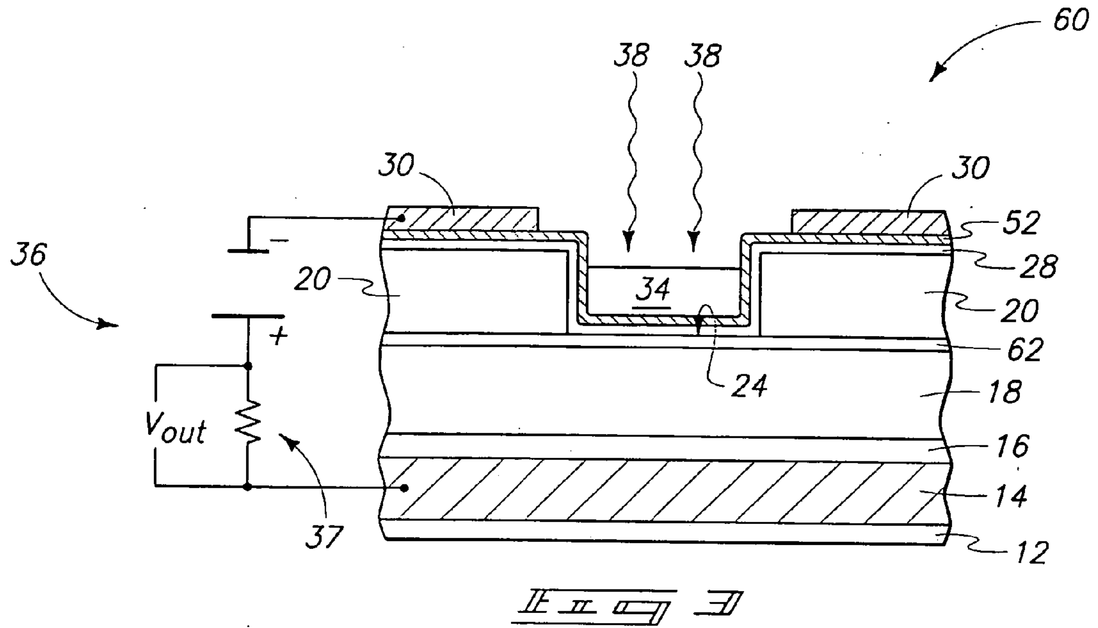


Fig 3

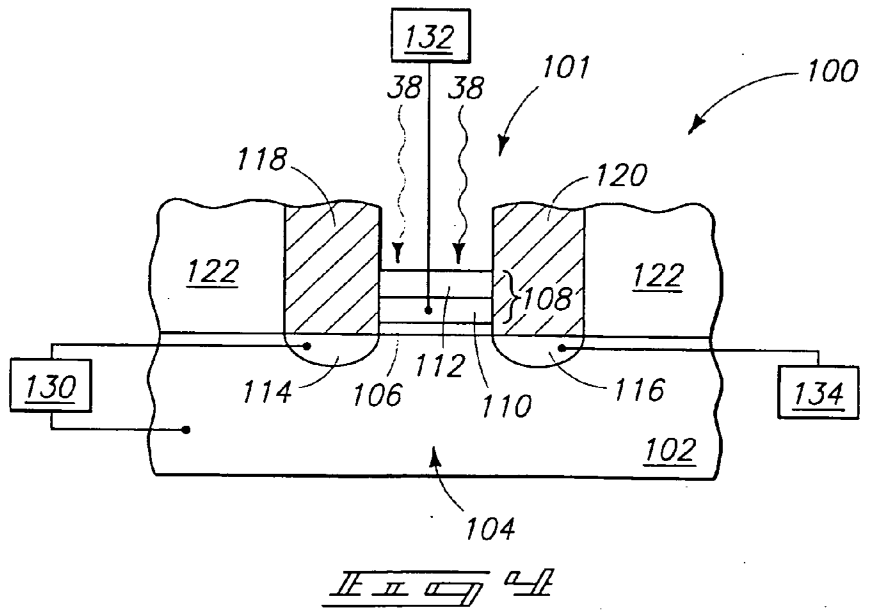


Fig 4

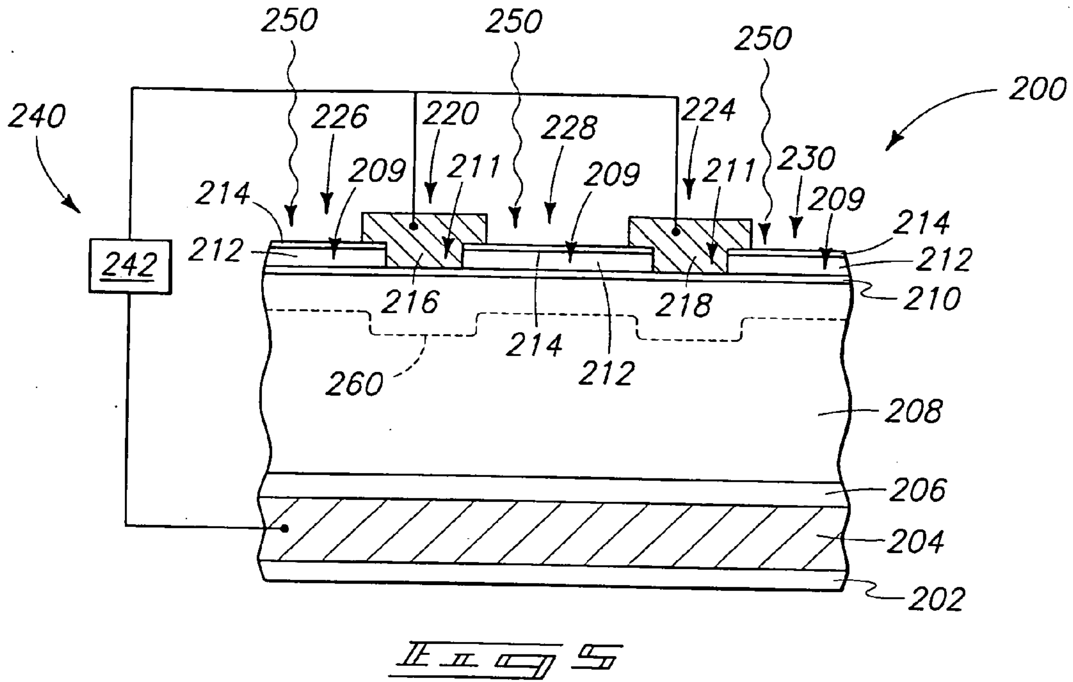


Fig 5

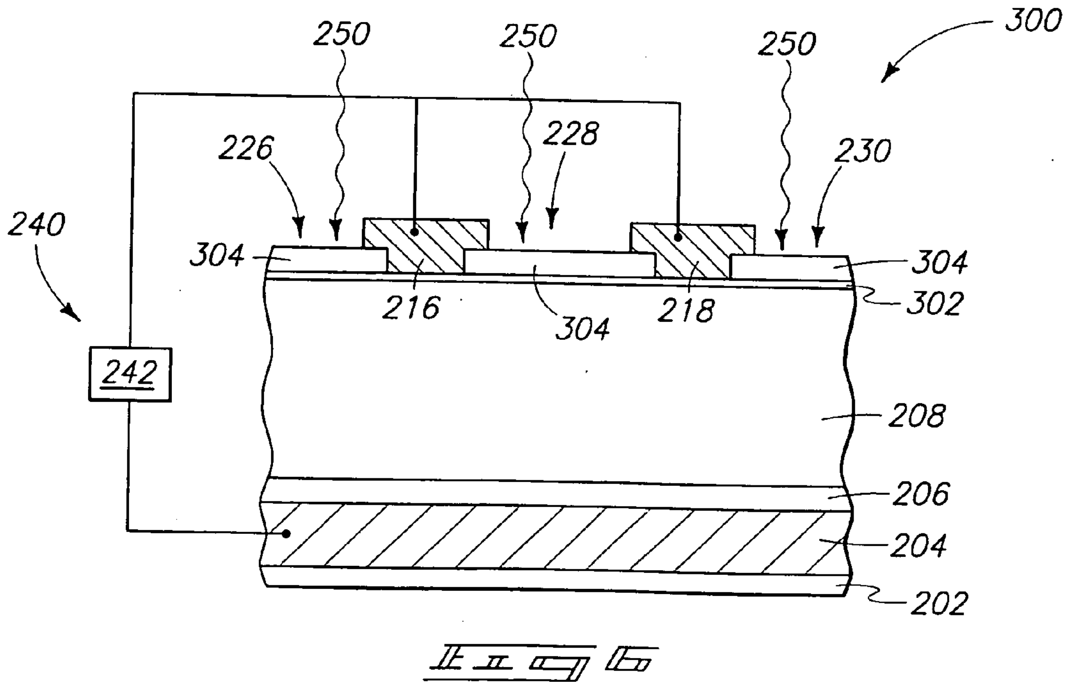


Fig 6

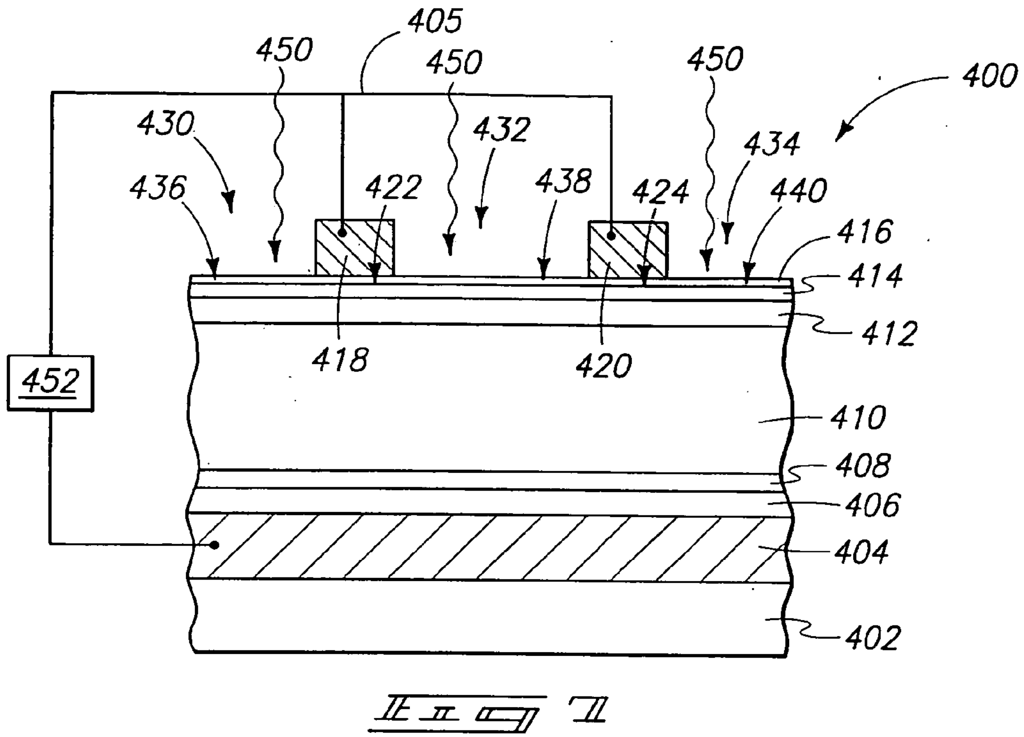


Fig 7

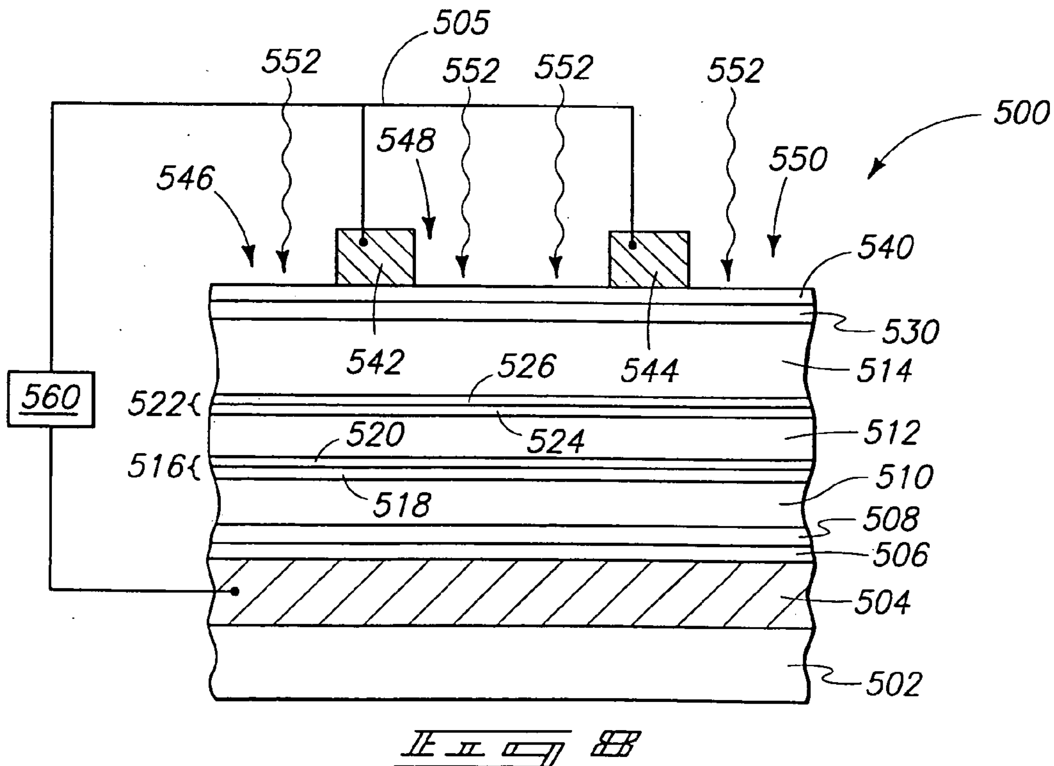


Fig 8

METHODS OF MAKING OPTOELECTRONIC DEVICES

TECHNICAL FIELD

[0001] The invention pertains to optoelectronic devices and solar cells, and pertains to methods of making optoelectronic devices and solar cells.

BACKGROUND OF THE INVENTION

[0002] Optoelectronic devices (i.e., devices which detect electromagnetic radiation) have numerous applications. For instance, optoelectronic devices can be utilized as photodetectors in cameras and other imaging equipment. A continuing goal is to decrease the size and complexity of optoelectronic devices, while increasing robustness of the devices. Accordingly, it is desired to develop improved optoelectronic devices.

[0003] Solar cells (i.e., cells which convert electromagnetic radiation into electrical energy) also have numerous applications. For instance, solar cells can be utilized for providing energy in remote locations, and/or can be utilized to alleviate dependence on other power sources (such as, for example, batteries, petroleum, etc.). A continuing goal is to reduce the cost, size and/or complexity of solar devices, while maintaining, and preferably improving, robustness of the devices. Accordingly, it is desired to develop improved solar cells. Although the term "solar cell" refers to "solar" and thus implies that it is configured to work with sunlight, the term "solar cell" is utilized in the art to refer generically to devices which convert electromagnetic radiation from any source (sunlight or otherwise) to electrical energy. The term "solar cell" is utilized herein to refer to devices which convert electromagnetic radiation from any source (sunlight or otherwise) into electrical energy, and is to be understood to be broad enough to include devices which convert light from regions of the electromagnetic spectrum outside of the wavelengths primarily associated with sunlight.

SUMMARY OF THE INVENTION

[0004] In one aspect, the invention includes an optoelectronic device. The device comprises a first electrode, a first layer of semiconductor material over the first electrode, a second layer of semiconductor material over the first layer of semiconductor material, a layer of semiconductor-enriched insulator over the second layer of semiconductor material, and a second electrode over the layer of semiconductor-enriched insulator. The second electrode has at least one window extending therethrough to a portion of the layer of semiconductor-enriched insulator. The first layer of semiconductor material is heavily-doped semiconductor material, and the second layer of semiconductor material is either essentially undoped or doped to a lower concentration of dopant than the first layer of semiconductor material.

[0005] In particular aspects, the first layer of semiconductor material of the above-described optoelectronic device can be heavily n-type doped semiconductor material, and the second layer of semiconductor material can be lightly n-type doped semiconductor material. Also, in particular aspects, the semiconductor-enriched insulator can comprise one or both of silicon-enriched silicon oxide and silicon-enriched silicon nitride.

[0006] In one aspect, the invention encompasses an optoelectronic device comprising a semiconductor substrate lightly doped with a first type of dopant and comprising a defined body region of the device. The device includes a gate stack over the body region, with the gate stack containing a layer of semiconductor-enriched insulator and containing a covering material over the semiconductor-enriched insulator. The covering material is at least partially transparent to one or more wavelengths of light that are to be detected by the device. The optoelectronic device further comprises a pair of source/drain regions within the semiconductor substrate and operatively proximate the gate stack and body region. The source/drain regions are heavily doped with a second type of dopant. One of the first and second types of dopant is n-type and the other is p-type.

[0007] In one aspect, the invention includes a solar cell. The solar cell comprises a first electrode, a first layer of semiconductor material over the first electrode, a second layer of semiconductor material over the first layer of semiconductor material, a layer of semiconductor-enriched insulator over the second layer of semiconductor material, a second electrode extending over one or more segments of the layer of semiconductor-enriched insulator, and one or more windows over one or more segments of the layer of semiconductor-enriched insulator. The one or more windows permit one or more wavelengths of electromagnetic radiation to reach segments of the layer of semiconductor-enriched insulator beneath the windows. The first layer of semiconductor material is heavily-doped with a first dopant type, and the second layer of semiconductor material is lightly-doped with the first dopant type.

[0008] In one aspect, the invention encompasses a solar cell which includes a first electrode, a first layer of semiconductor material over the first electrode, a plurality of light-detecting regions over the first layer of semiconductor material (for example, three light-detecting regions can be provided in exemplary aspects of the invention), a layer of semiconductor-enriched insulator over the plurality of light-detecting regions, a second electrode extending over segments of the layer of semiconductor-enriched insulator, and one or more windows which permit electromagnetic radiation to reach the semiconductor-enriched insulator. In exemplary aspects in which three light-detecting regions are utilized, a first of the three light-detecting regions can be a stack of amorphous silicon and amorphous silicon-germanium, a second of the light-detecting regions can be another stack of amorphous silicon and amorphous silicon-germanium, and a third of the light-detecting regions can be amorphous silicon without any substantial concentration of germanium. The amorphous silicon-germanium of the first stack can have a different atomic concentration of germanium than the amorphous silicon-germanium of the second stack. The first layer of semiconductor material can be either heavily n-type doped or heavily p-type doped, and the layer of semiconductor-enriched insulator can comprise one or both of silicon-enriched silicon oxide and silicon-enriched silicon nitride.

[0009] The invention also includes methods of forming optoelectronic devices, and methods of forming solar cells.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

[0011] **FIG. 1** is a diagrammatic, fragmentary, cross-sectional view of an optoelectronic device in accordance with one aspect of the present invention.

[0012] **FIG. 2** is a diagrammatic, fragmentary, cross-sectional view of an optoelectronic device in accordance with another aspect of the present invention.

[0013] **FIG. 3** is a diagrammatic, cross-sectional view of an optoelectronic device in accordance with yet another aspect of the present invention.

[0014] **FIG. 4** is a diagrammatic, fragmentary, cross-sectional view of an optoelectronic device in accordance with yet another aspect of the present invention.

[0015] **FIG. 5** is a diagrammatic, cross-sectional, fragmentary view of a solar cell in accordance with an aspect of the present invention.

[0016] **FIG. 6** is a diagrammatic, cross-sectional, fragmentary view of a solar cell in accordance with another aspect of the present invention.

[0017] **FIG. 7** is a diagrammatic, fragmentary, cross-sectional view of a solar cell in accordance with yet another aspect of the present invention.

[0018] **FIG. 8** is a diagrammatic, cross-sectional, fragmentary view of a solar cell in accordance with yet another aspect of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

[0020] Structures containing stacks of metal/semiconductor-enriched insulator/semiconductor can behave like semiconductor junction diodes if appropriate compositions of semiconductor-enriched insulator are employed. Such characteristics of semiconductor-enriched insulators can be exploited in combination with various electrical and optical properties of the materials to form optoelectronic devices and solar cells.

[0021] The semiconductor-enriched insulator family of materials includes silicon-enriched insulator materials, such as silicon-enriched silicon oxide and silicon-enriched silicon nitride. A silicon-enriched silicon nitride can, for example, comprise from about 1 atomic percent excess silicon to about 20 atomic percent excess silicon as measured relative to Si_3N_4; and a silicon-enriched silicon oxide can, for example, comprise from about 1 atomic percent excess silicon to about 20 atomic percent excess silicon, as measured relative to SiO_2. The amount of excess silicon can be measured by direct measurement of the silicon concentration, or alternatively can be measured by determining the refractive index of a silicon-enriched material. For instance, Si_3N_4 will have a refractive index of about 2, and silicon enrichment of the silicon nitride will increase the refractive index quantitatively, as is known to persons of ordinary skill in the art. Similarly, silicon dioxide (SiO_2) has a refractive index of about 1.5, and silicon enrichment of the silicon dioxide will alter the refractive index in a quantitative manner, as is known to persons of ordinary skill in the art. The semiconductor-enriched insulator family of materials also includes germanium-enriched insulator materials, such as, for example, germanium-enriched germanium nitride.

[0022] Semiconductor-enriched insulator materials tend to be multiphase materials, with the excess semiconductor material being present in a matrix of the dominate material. For instance, silicon-enriched silicon nitride will generally have a phase of silicon within a matrix of silicon nitride, and silicon-enriched silicon oxide will generally have a phase of silicon present within matrix of silicon dioxide. The physical properties of semiconductor-enriched insulator materials can enable the materials to be utilized for charge trapping, with silicon-enriched materials having from about 1 atomic % to about 20 atomic % excess silicon frequently being capable of a charge trapping density of from about 1% to about 10%.

[0023] In some aspects of the invention, the semiconductor layer of a stack of metal/semiconductor-enriched insulator/semiconductor (such as a stack of meta/silicon-enriched insulator/silicon) can be essentially undoped (i.e., can contain less than 1×10^{17} atoms/cm^3 of dopant; in other aspects the semiconductor layer can be lightly doped (i.e., can contain from about 1×10^{17} atoms/cm^3 to about 1×10^{20} atoms/cm^3 of dopant); and in yet other aspects the semiconductor layer can be heavily doped (i.e., can contain greater than about 1×10^{20} atoms/cm^3 of dopant).

[0024] The semiconductor-enriched insulators utilized in the various aspects of the invention described herein can be formed by any suitable methodology. In some aspects, such insulators can be formed utilizing low pressure chemical vapor deposition (LPCVD) technology, or plasma enhanced chemical vapor deposition (PECVD) technology. Deposition temperatures are typically from about 700° C. to about 800° C. for LPCVD, and from about 200° C. to about 400° C. for PECVD. In alternative aspects, electron-cyclotron-resonance plasma enhanced CVD processes (ECR-PECVD) can be utilized for forming semiconductor-enriched insulators. Such technology can enable the semiconductor-enriched insulators to be formed with excellent physical/electrical properties during deposition at room temperature, or near room temperature, followed by a rapid thermal anneal. The ECR-PECVD process can be particularly useful for forming optoelectronics and/or solar cells when low temperature processing is desired.

[0025] Appropriate control of the deposition conditions utilized to form semiconductor-enriched insulators can enable control of various physical properties of the insulator composition. For instance, appropriate control of the deposition conditions utilized to form silicon-enriched insulators can enable the concentration, size and distribution of excess silicon to be controlled. Various properties of silicon-enriched insulators, such as, for example, refractive index, dielectric permittivity, optical absorption, electrical conductivity, charge trapping characteristics (trap density/trap depth) can be reproducibly and widely altered by controlling the composition (i.e., the amount of silicon enrichment) within the films.

[0026] Frequently, silicon-enriched silicon nitride films are found to have superior characteristics in terms of interface control, thermal stability, device reproducibility, and radiation hardness as compared to silicon-enriched silicon oxide films. Accordingly, it can be preferable that the

devices described herein be formed utilizing silicon-enriched silicon nitride films. It is to be understood, however, that silicon-enriched oxide films can also be utilized in the devices, and further that other semiconductor-enriched insulator materials can be utilized, including, for example, germanium-rich materials and silicon-germanium rich materials. In some aspects, it can be advantageous to utilize a material comprising, consisting essentially of, or consisting of germanium-enriched germanium nitride for detecting infrared radiation.

[0027] Electrical conductivity of silicon-enriched silicon nitride films can be varied by several orders of magnitude by controlling the concentration of excess silicon (and accordingly the refractive index) of such films. At low excess silicon concentration, the conductivity approaches that of silicon nitride (Si_3N_4), whereas at high silicon concentrations the materials behave like semiconductors. Similarly, optical properties (for example a refractive index) are also altered by the concentration of excess silicon. The relationship between refractive index and silicon/nitrogen ratio of silicon rich nitride films is published, as is the relationship between current density (J) versus electric field (E) for different silicon/nitrogen ratios of silicon nitride films. Other semiconductor-enriched materials, including, for example, silicon-enriched silicon oxide, also have physical properties which can be varied by controlling the concentration of excess semiconductor within the materials.

[0028] In particular aspects, the invention pertains to optoelectronic devices and methods of forming such devices. Such aspects are discussed with reference to **FIGS. 1-4**. In other aspects, the invention pertains to solar cells and methods of forming solar cells. Such aspects are discussed with reference to **FIGS. 5-8**.

[0029] Referring initially to **FIG. 1**, an exemplary optoelectronic device **10** is illustrated. Device **10** comprises a support structure, or base, **12**. Such support structure can comprise any suitable material or combination of materials, including, for example, various polymers (such as plastic), glass, metal, etc.

[0030] A first electrode **14** is supported by base **12**. First electrode **14** can comprise any suitable electrically conductive composition, or combination of compositions. In particular aspects, first electrode **14** will comprise, consist essentially of, or consist of one or both of silver and aluminum.

[0031] A layer **16** is over electrode **14**, and in the shown aspect is in direct physical contact with a surface of electrode **14**. Layer **16** comprises semiconductor material, and in particular aspects will be heavily doped. For instance, layer **16** can comprise, consist essentially of, or consist of heavily-doped silicon, heavily-doped germanium, or heavily-doped silicon-germanium. The heavy dopant concentration within layer **16** will typically correspond to n-type dopant (such as, for example, phosphorous), but it is to be understood that the invention encompasses other aspects (discussed below) in which the dopant type can be p-type.

[0032] Construction **10** comprises a layer **18** over layer **16**. Layer **18** corresponds to a layer of semiconductor material, and in some aspects layers **16** and **18** can be referred to as a first layer of semiconductor material and a second layer of semiconductor material, respectively, to distinguish the layers from one another. Layer **18** is shown to be thicker than layer **16**, but it is to be understood that the relative thicknesses of layers **16** and **18** can vary so that layers **16** and **18** are about the same thicknesses as one another, or so that layer **16** is thicker than layer **18**.

[0033] Second layer **18** can comprise essentially undoped semiconductor material, or can comprise doped semiconductor material. Typically, to the extent that layer **18** comprises any dopant, the layer will have a lower concentration of dopant than first layer **16**. If layer **18** is doped, the dopant type within layer **18** can match that within layer **16**. Accordingly, layer **16** can correspond to heavily n-type doped semiconductor material and layer **18** can correspond to lightly n-type doped semiconductor material. In particular aspects, layer **16** can comprise, consist essentially of, or consist of heavily n-type doped silicon and layer **18** can comprise, consist essentially of, or consist of lightly n-type doped silicon; and in other aspects, layer **16** can comprise, consist essentially of, or consist of heavily n-type doped germanium and layer **18** can comprise, consist essentially of, or consist of lightly n-type doped germanium; and in yet other aspects layer **16** can comprise, consist essentially of, or consist of heavily n-type doped silicon-germanium and layer **18** can comprise, consist essentially of, or consist of lightly n-type doped silicon-germanium.

[0034] An electrically insulative material **20** is over second semiconductor layer **18** and patterned to cover a portion **22** of layer **18** while not covering a portion **24** of layer **18**. More specifically, insulative material **20** is patterned to have an opening **26** extending therethrough and to an upper surface of layer **18**.

[0035] Insulative material **20** can comprise, consist essentially of, or consist of any suitable material or combination of materials, including, for example, silicon dioxide.

[0036] A layer **28** of semiconductor-enriched insulator is provided over insulative material **20** and within opening **26**. The layer **28** of semiconductor-enriched insulator is shown to be in direct physical contact with an upper surface of second semiconductor layer **18** within the opening **26**. Layer **28** can, in particular aspects, correspond to a silicon-enriched insulator. In some aspects, layer **28** can comprise, consist essentially of, or consist of silicon-enriched silicon nitride, and can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon relative to Si_3N_4. Alternatively, layer **28** can comprise, consist essentially of, or consist of silicon-enriched silicon oxide, and can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon relative to SiO_2. In yet other aspects, layer **28** can correspond to a mixture of silicon-enriched silicon nitride and silicon-enriched silicon oxide. Layer **28** can have any suitable thickness, and in particular aspects will have a thickness of from about **10** nanometers to about **50** nanometers. In the shown aspect, layer **28** can be considered to have a portion over insulative material **20** and spaced from layer **18** by the insulative material **20**, and to have another portion directly against layer **18**.

[0037] A second electrode **30** is over semiconductor-enriched insulator **28**. Second electrode **30** is patterned so that the second electrode is over a first portion of semiconductor-enriched insulator **28**, and has a window **32** extending therethrough to a second portion of semiconductor-enriched insulator **28**. The first portion of semiconductor-

enriched insulator **28** is diagrammatically labeled as **29**, and the second portion of semiconductor-enriched insulator **28** is diagrammatically labeled as **31**.

[**0038**] Second electrode **30** can comprise any suitable electrically conductive composition or combination of compositions. In particular aspects, second electrode **30** will comprise the same composition as first electrode **14**, and in other aspects second electrode **30** will comprise a different composition than first electrode **14**. In exemplary aspects, second electrode **30** can comprise one or both of silver and aluminum.

[**0039**] An antireflective material **34** is provided within window **32** and over the second portion **31** of semiconductor-rich insulator **28**. Antireflective material **34** can, for example, comprise, consist essentially of, or consist of indium tin oxide (ITO). The antireflective coating can be utilized to enhance the absorption efficiency of incident photon flux.

[**0040**] Circuitry **36** is shown provided to electrically bias second electrode **30** relative to first electrode **14**. Specifically, the circuitry is shown biasing the second electrode to a negative potential relative to the first electrode. Such bias assumes that the conductively-doped material of layers **16** and **18** is n-type doped. If the semiconductor material of layers **16** and **18** is p-type doped, the shown bias of circuitry **36** will typically be reversed so that second electrode **30** would have a positive potential relative to first electrode **14**. However, it is generally preferred that n-type doping be utilized in devices of the type diagrammatically illustrated as device **10**, and accordingly it is generally preferred that circuit **36** be provided to negatively bias second electrode **30** relative to first electrode **14**.

[**0041**] Electromagnetic radiation **38** is diagrammatically illustrated as being directed toward device **10**, and specifically as entering window **32**. The electromagnetic radiation can interact with semiconductor-enriched material **18** to cause charge separation to occur, which can be detected as a change in electrical properties by circuit **36**. Accordingly, device **10** can be utilized to detect electromagnetic radiation. More specifically, when light having an energy greater than the E_g of the semiconductor material of layer **28** impacts the diode comprising layer **28**, the light gets absorbed into the depletion layer of silicon below the silicon-semiconductor rich semiconductor interface, and electron-hole pairs are generated. Electrons get collected at the positively-biased bottom electrode, and holes get collected at the negatively-biased top electrode. Thus, a photocurrent is generated which flows externally through the load resistor of circuit **36** (labeled as **37**) to generate an output voltage (V_{out})).

[**0042**] The particular wavelengths of radiation detected by device **10** can be influenced by, among other things, the composition of material **34**, the composition of material **28**, the semiconductor material utilized for layer **18** and/or layer **16**, and the dopant type and concentration utilized in layer **18** and/or layer **16**. For instance, material **34** can be chosen to be relatively transparent to particular wavelengths of light, and non-transparent to other wavelengths of light so that the material **34** functions as a filter to determine which wavelengths of light will be detected by device **10**. Alternatively, or additionally, the compositions of layers **16**, **18** and **28** can be chosen so that device **10** is more sensitive to particular wavelengths of light than to others. Accordingly, device **10** can be configured as an optoelectronic device having sensitivity for particular desired wavelengths of electromagnetic radiation.

[**0043**] The discussion above assumes that second electrode **30** is relatively opaque to the wavelength of radiation detected by device **10**. It is to be understood, however, that material **30** can, in some aspects, be at least partially transparent to such radiation. In such aspects, window **32** is defined by the location where semiconductor-enriched layer **28** is closely proximate layer **18** (and in the shown aspect directly physically contacts layer **18**) as opposed to regions where layer **28** is spaced from layer **18** by the relatively thick intervening material **20**.

[**0044**] **FIG. 2** shows an optoelectronic device **50** illustrating another embodiment of the present invention. In referring to device **50**, similar numbering will be used as was utilized above in describing the device **10** of **FIG. 1**, where appropriate.

[**0045**] Device **50** comprises the base **12**, first electrode **14**, first and second semiconductor layers **16** and **18**, insulative material **20** and semiconductor-enriched material **28** described previously. Device **50** also comprises the circuitry **36** described above with reference to **FIG. 1**.

[**0046**] Device **50** comprises the second electrode **30** and antireflective material **34** discussed above with reference to device **10** of **FIG. 1**. The second electrode **30** of **FIG. 2** is shown patterned differently than that of **FIG. 1**, and specifically is shown not extending into the opening within insulative material **20** of the **FIG. 2** embodiment of the invention.

[**0047**] Device **50** comprises a thin electrically conductive layer **52** over semiconductor-enriched material **28**. Layer **52** can correspond to a metal-containing material, and in particular aspects can be considered a film of metal-containing material. Layer **52** can have a thickness of, for example, approximately 10 nanometers, and can be optically transparent to the particular wavelengths of electromagnetic radiation desired to be detected with device **50**. In particular aspects, film **52** can comprise, consist essentially of, or consist of one or both of gold and aluminum. Layer **52** is shown extending over portions of semiconductor-enriched layer **28** within a window exposed to electromagnetic radiation **38**, as well as over portions of layer **28** which are not within such window (i.e., portions covered by second electrode **30**).

[**0048**] Antireflective material **34** of the **FIG. 2** embodiment of the invention can comprise silicon nitride, zinc sulfide (ZnS) and/or zirconium oxide (ZrO_2) either in addition to ITO, or in place of ITO. In operation, the thin layer of optically transparent metal film **52** can be used as a conducting element for the top electrode **30**.

[**0049**] **FIG. 3** shows an optoelectronic device **60** in accordance with yet another aspect of the invention. The device **60** of **FIG. 3** is identical to the device **50** described with reference to **FIG. 2** in all respects except that a layer **62** is provided between semiconductor-enriched insulator **28** and the second semiconductor layer **18**. In the shown aspect of the invention, layer **62** is in direct physical contact with both layer **28** and layer **18**, with layers **18** and **28** being on opposing sides of layer **62** relative to one another. Layer **62** can comprise semiconductor material, and can be referred to

as a third layer of semiconductor material to distinguish layer **62** from the layers **16** and **18** described previously.

[**0050**] In particular aspects, device **60** is configured for detecting infrared radiation. In such aspects, layer **16** comprises, consists essentially of, or consists of heavily n-type doped germanium; and layer **18** comprises, consists essentially of, or consists of undoped germanium or n-type doped germanium. If layer **18** is n-type doped germanium, the dopant concentration within layer **18** will typically be less than that within layer **16**. Layer **62** comprises, consists essentially of, or consists of either undoped silicon or n-type doped silicon. The silicon of layer **62** is relaxed, in the sense that the silicon has a crystallographic orientation compatible with that of the underlying germanium material, as opposed to a strained configuration in which the silicon would have a crystallographic orientation less compatible with the underlying germanium material. Although the dopant described as being utilized with layer **16**, **18** and **62** is n-type dopant, it is to be understood that p-type dopant can be utilized in other aspects of the invention.

[**0051**] The cutoff wavelength for a device having a configuration of device **60** can be extended to about 1.9 micrometers, which can provide efficient infrared photodetection in the wavelength range of light of from about 700 nanometers to about 1700 nanometers, with good response time.

[**0052**] The devices described above with reference to **FIGS. 1-3** are exemplary devices, and it is to be understood that the invention encompasses various modifications which are not shown. For instance, additional semiconductor layers can be provided in addition to the layers **16**, **18** and **62**. Also, additional antireflective materials can be provided in addition to, or alternatively to, the shown material **34**. For instance, material **34** can correspond to a stack of antireflective materials. As another example, an antireflective material can be provided between semiconductor-enriched layer **28** and conductive layer **52** in the embodiments of **FIGS. 2 and 3**.

[**0053**] The semiconductor-enriched insulative material **28** of the above-described optoelectronic devices of **FIGS. 1-3** functions similarly to a p-i-n diode (where "i" is an intrinsic or undoped layer of semiconductor), or a metal-insulator-semiconductor diode, or a metal-semiconductor diode. Since there is no p-n junction, the diode of the present can have several intrinsic advantages relative to prior art diodes. Such advantages can include, for example, scalability, very low leakage and therefore low power, high quantum efficiency, low noise, and fast response time (greater than 10^{-10} seconds) similar to metal-semiconductor diodes. Additionally, high density and low temperature processing can provide potential low costs. Application of the photodiodes of the present invention can be utilized primarily in the ultraviolet and visible ranges, or can be utilized for efficient infrared detection, particularly if the semiconductor material of layers **16** and/or **18** comprises germanium in addition to, or instead of silicon.

[**0054**] **FIG. 4** shows a fragment **100** comprising an optoelectronic device **101** illustrating another aspect of the invention.

[**0055**] Fragment **100** includes a semiconductor substrate **102** lightly doped with a first type of dopant. The lightly-doped semiconductor substrate comprises a body region of the optoelectronic device, with such body region being diagrammatically illustrated as extending generally around the location labeled **104**. Substrate **102** can comprise any suitable semiconductor material, and in particular aspects will comprise, consist essentially of, or consist of lightly-doped silicon. The dopant utilized for the light doping of substrate **102** can be either n-type or p-type, and in typical applications will be p-type. Suitable p-type dopant which can be utilized is one or both of indium and boron. In particular aspects, a substantial entirety of the dopant within the body region will be both indium and boron, with the term "substantial entirety" indicating that the only dopants within the body region are indium and boron within the tolerances of a process utilized to form the body region.

[**0056**] A dielectric material **106** is over the body region. Dielectric material **106** can, for example, comprise, consist essentially of, or consist of silicon dioxide.

[**0057**] A gate stack **108** is over the dielectric material. Gate stack **108** comprises a semiconductor-enriched insulator **110** and a covering material **112** over the semiconductor-enriched insulator. Semiconductor-enriched insulator **110** will typically comprise a silicon-enriched insulator, and specifically will typically comprise one or both of silicon-enriched silicon oxide and silicon-enriched silicon nitride. Covering material **112** will correspond to a material at least partially transparent to one or more wavelengths of light which are to be detected by the optoelectronic device. In particular aspects, device **101** is configured for detecting infrared radiation, and in such aspects covering material **112** can comprise, consist essentially of, or consist of one or both of indium tin oxide and silicon nitride (Si_3N_4).

[**0058**] To the extent that the semiconductor-enriched material **110** comprises silicon-enriched silicon oxide or silicon-enriched silicon nitride, the material can be from about 1 atomic % enriched in silicon to about 20 atomic % enriched in silicon.

[**0059**] A pair of heavily-doped regions **114** and **116** extend within substrate **102**, and are operatively proximate the gate stack **108** and body region **104** of device **101** to enable the device to detect electromagnetic radiation. Heavily-doped regions **114** and **116** will be oppositely doped relative to the lightly-doped body region surrounding regions **114** and **116**. Accordingly, if body region **104** comprises p-type doped semiconductor material, heavily-doped regions **114** and **116** will be n-type doped, and vice versa.

[**0060**] In some aspects, regions **114** and **116** can be referred to as source/drain regions, in that regions **114** and **116**, together with gate stack **108**, form a type of transistor device.

[**0061**] A pair of conductive pedestals **118** and **120** are provided to extend from regions **114** and **116**, respectively, to allow interconnection of regions **114** and **116** to circuitry external of the shown device **101** (such circuitry is not shown).

[**0062**] An insulating material **122** is provided around device **101** to electrically isolate device **101** from other circuitry (not shown) which may be adjacent device **101**. Insulating material **122** can comprise any suitable material, or combination of materials, and in particular aspects will comprise, consist essentially of, or consist of silicon dioxide.

[0063] Heavily-doped region **114** and body region **104** are shown to both be electrically connected to ground **130**. Semiconductor-enriched layer **110** is electrically coupled with a first voltage **132**, and heavily-doped region **116** is electrically coupled with a second voltage **134**. Voltages **132** and **134** are different from ground, and generally will be different from one another.

[0064] The various layers and materials of device **101** can be formed to any suitable thicknesses. Typically, dielectric layer **106** will have a thickness of from about 4 to about 5 nanometers, semiconductor-enriched insulator **110** will have a thickness of from about 10 to about 30 nanometers, and the light-transmissive overcoat **112** will have a thickness of greater than about 30 nanometers.

[0065] Optoelectronic device **101** can be referred to as a phototransistor. The transistor action can enable device **101** to achieve a significantly higher gain than can photodiodes, although the response time for the phototransistor will typically be slower than the response time of photodiodes.

[0066] In operation, infrared radiation **38** (i.e., radiation having a wavelength of from about 2 micrometers to about 7 micrometers) photo-ionizes indium centers and generates excess holes in the body region **104** of substrate **102**. Such lowers the threshold of the phototransistor **101**, and accordingly alters channel conductance. The change in the channel conductance can be detected through circuitry coupled to device **101** to indicate the presence of infrared radiation, and in particular aspects to quantitate the amount of infrared radiation.

[0067] Referring next to **FIG. 5**, such illustrates an exemplary embodiment of a solar cell **200** configured in accordance with an aspect of the present invention. The solar cell is supported by a base **202**. Such base can comprise any suitable material or combination of materials, including, for example, glass, polymer (such as plastic) or metal (such as, for example, steel).

[0068] A first electrode **204** is over the base. The first electrode can comprise any suitable electrically conductive material, or combination of materials. In particular aspects, the first electrode will comprise, consist essentially of, or consist of one or both of silver and aluminum.

[0069] A first layer **206** of semiconductor material is over the first electrode **204**, and a second layer **208** of semiconductor material is over the first layer **206**. The first layer **206** is heavily doped with a first dopant type, and the second layer **208** is lightly doped with the first dopant type. The layer **206** can comprise, consist essentially of, or consist of conductively-doped silicon, conductively-doped germanium, or conductively-doped silicon-germanium. Similarly, the second semiconductor layer **208** can comprise, consist essentially of, or consist of conductively-doped silicon, conductively-doped germanium, or conductively-doped silicon-germanium. The first dopant type can be either n-type or p-type. In the exemplary embodiment, the first dopant type is p-type.

[0070] A layer **210** of semiconductor-enriched insulator is over the second layer **208** of semiconductor material. The semiconductor-enriched insulator can be a silicon-enriched insulator, and in particular aspects can comprise, consist essentially of, or consist of one or both of silicon-enriched silicon oxide and silicon-enriched silicon nitride. If the silicon-enriched insulator corresponds to silicon-enriched silicon nitride, such can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon, with the excess silicon being measured relative to Si_3N_4. If the silicon-enriched insulator corresponds to silicon-enriched silicon oxide, such can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon, with the excess silicon being measured relative to SiO_2.

[0071] The layer **210** can function as a tunnel medium during operation of the solar cell, and preferably has a thickness of from about 1 nanometer to about 100 nanometers. The layer **210** also acts as comprising carrier generation centers wherein electron-hole pairs are created. Additionally, the layer **210** can passivate the silicon surface to reduce recombination of high energy photo-generated electron-hole pairs near the interface of materials **208** and **210**, which can enhance energy efficiency of the solar cell **200**.

[0072] An antireflective material **212** is provided over layer **210**. Layer **212** can have compositional aspects in common with semiconductor-enriched layer **210**. As discussed previously, a semiconductor-enriched layer will typically comprise a matrix phase and an excess semiconductor phase. For instance, if layer **210** corresponds to silicon-enriched silicon nitride, it will typically comprise a phase of Si_3N_4, defining a matrix, and a phase of excess silicon within the matrix. Layer **212** can correspond to a composition having the same matrix as layer **210**. Accordingly, if layer **210** corresponds to silicon-enriched silicon nitride, layer **212** can comprise silicon nitride, and in particular aspects will consist essentially of, or consist of silicon nitride. The layer **212** can serve as an efficient transmitter of incident solar radiation. In some aspects, layers **210** and **212** can both comprise silicon-enriched silicon nitride, with layer **212** having less silicon enrichment than layer **210**. For instance, layer **210** can correspond to silicon-enriched silicon nitride having a refractory index of from about 2.5 to about 3, and layer **212** can correspond to a silicon-nitride-containing material having a refractive index of from about 2.0 to about 2.1.

[0073] In the shown aspect of the invention, layer **212** is patterned to have openings extending therethrough to the underlying layer **210**. Accordingly, layer **212** is shown to be in direct physical contact with various segments **209** of layer **210**, and to not be indirect physical contact with other segments **211** of layer **210**. The segments **211** can be considered to define bottom peripheries of the openings extending through layer **212**. Fingers (or stripes) of top electrode, such as **216** and **218** make direct contact to segments **211** of layer **210**.

[0074] A second antireflective material **214** is provided over layer **212**. Antireflective material **214** can comprise, for example, indium tin oxide, or any other suitable antireflective material, and can be omitted in some aspects of the invention.

[0075] Second electrodes **216** and **218** are provided over semiconductor-enriched insulator **210** and in direct physical contact with segments **211** of the semiconductor-enriched insulator. The second electrodes can comprise the same composition as first electrode **204**, or can comprise different compositions. In particular aspects, the first and second electrodes comprise one or both of silver and aluminum.

[0076] The shown second electrodes have been patterned into a pair of spaced blocks. Actually, the second electrodes

would typically extend into and out of the plane of the shown cross-sectional view so that the electrodes would be stripes (or strips) along an upper surface of construction **200**.

[**0077**] Gaps **226**, **228** and **230** are between the spaced second electrodes. The gaps correspond to windows over segments of the semiconductor-enriched insulator **210**. Such windows permit electromagnetic radiation to reach the segments of the semiconductor-enriched insulator within the windows. The electromagnetic radiation is diagrammatically illustrated as waves **250** in the diagram of **FIG. 5**.

[**0078**] In the shown aspect of the invention, a plurality of second electrodes are spaced over a single continuous first electrode **204**. It is to be understood that the invention encompasses other aspects (not shown) in which multiple first electrodes are provided, as well as aspects in which only a single second electrode is utilized. Further, the shown aspect comprising a plurality of second electrodes can correspond to an aspect in which the electrodes appear to be separated in the cross-sectional view of **FIG. 5**, but join to one another at a location which is not visible in the view of **FIG. 5** so that the apparent plurality of second electrodes is actually a single second electrode which has been split into the shown plurality of stripes.

[**0079**] Circuitry **240** is provided between first electrode **204**, and second electrodes **216** and **218**. The circuitry includes a device **452** configured to be powered by an electric field gradient generated between the first electrode and the second electrodes.

[**0080**] The thin layer of semiconductor-enriched insulator **210** can be deposited in the same process, as the antireflective coating **212**. Advantageously, the processing utilized to form the solar cell **200** of **FIG. 5** can be accomplished with a series of blanket deposition steps, and a single photolithography step for top electrode stripe formation.

[**0081**] In operation, a depletion layer (diagrammatically illustrated by dashed-line **260**) is generated within second semiconductor layer **208**. Electromagnetic radiation generates electron-hole pairs within the silicon-enriched insulator region. Electrons can be separated from holes both within the silicon-enriched insulator region and within the depletion layer. The electrons migrate toward either the first electrode or the second electrodes, depending on the built-in potential on the respective electrodes. In an exemplary application, the electrons tunnel through the semiconductor-enriched insulator **210** and get collected by the top electrode stripes **216** and **218** when the semiconductor layer **208** is of p-type doped silicon (typically lightly-doped). A thin inversion layer is formed at the silicon/semiconductor-enriched insulator interface (i.e., the interface between layers **208** and **210**) which can significantly reduce surface recombination. Holes are collected by the opposite electrode to that which collects electrons, and would be collected by the bottom electrode in the exemplary application in which electrons are collected by the top electrodes. The electric field gradient generated by the separation of the electrons and holes can be utilized to power electrical devices.

[**0082**] **FIG. 6** illustrates a solar cell **300** illustrating another aspect of the present invention. In referring to solar cell **300**, similar numbering will be used as was utilized above in describing solar cell **200**, where appropriate. Solar cell **300** comprises the base **202**, first electrode **204**, first layer of semiconductor material **206**, second layer of semiconductor material **208**, second electrodes **216** and **218**, and circuitry **240** described previously. Construction **300** also comprises the windows **226**, **228** and **230** extending between the second electrodes **216** and **218**.

[**0083**] Construction **300** differs from the construction **200** of **FIG. 5** in that construction **300** comprises a very thin dielectric material **302** in direct physical contact with the second layer **208** of semiconductor material, and comprises semiconductor-enriched insulator **304** over the dielectric material. As discussed above, layers **206** and **208** can be either n-type doped or p-type doped. In applications in which layers **206** and **208** are p-type doped, dielectric material **302** can comprise, consist essentially of, or consist of silicon dioxide (SiO_2); and in applications in which layers **206** and **208** are n-type doped, dielectric material **302** can comprise, consist essentially of, or consist of aluminum oxide (Al_2O_3).

[**0084**] In the shown aspect of the invention, dielectric material **302** is in direct physical contact with both semiconductor-enriched insulator **304** and second layer **208** of semiconductor material. Further, second electrodes **216** extend through openings in semiconductor-enriched layer **304** to physically contact an upper surface of dielectric material **302**.

[**0085**] The semiconductor-enriched insulator **304** can comprise silicon-enriched insulator. In particular aspects, the semiconductor-enriched insulator **304** will comprise, consist essentially of, or consist of one or both of silicon-enriched silicon nitride and silicon-enriched silicon oxide.

[**0086**] The solar cells of **FIGS. 5 and 6** are amenable to low-temperature processing (i.e., can be formed utilizing processing from about room temperature to about 300° C.) which can provide higher efficiency and cost reduction relative to high-temperature processes. The semiconductor material of layers **206** and **208** can comprise, for example, single crystal or polycrystalline silicon. The heavily-doped interface layer **206** can reduce series contact resistance and enhance light absorption.

[**0087**] The modification of the solar cell **300** of **FIG. 6** relative to solar cell **200** of **FIG. 5** creates a thin interface layer of dielectric material (which can be aluminum oxide or silicon dioxide in exemplary aspects of the invention) to reduce surface recombination and to enhance collection and thereby also enhance solar cell efficiency. A strong inversion layer is created in n-type silicon of layer **208** due to fixed negative charges in an aluminum layer **302**. Similarly, fixed positive charges in silicon dioxide can create a strong inversion layer in p-type doped semiconductor material **208** to improve cell efficiency. It is noted that for the structures of **FIGS. 5 and 6**, cell efficiency can be possibly further improved by selecting a dual layer substrate of silicon/silicon-germanium (not shown) for layer **208**. Such can enable the band gap in layer **208** to be varied from about 0.8 electron volts to about 1.1 electron volts, which may improve absorption efficiency of the electromagnetic radiation spectrum.

[**0088**] Another exemplary solar cell is illustrated as cell **400** in **FIG. 7**. Cell **400** comprises a base layer **402** which can comprise any suitable material or combination of materials, similar to the base layer **202** described previously.

[0089] Solar cell **400** comprises a first electrode **404** supported by the base layer. First electrode **404** can comprise any suitable electrically conductive composition or combination of compositions, and in particular aspects will comprise, consist essentially of, or consist of one or both of aluminum and silver.

[0090] A textured buffer layer **406** is over the first electrode. Textured buffer layer **406** can, for example, comprise, consist essentially of, or consist of a relatively transparent conductive oxide, such as, for example, zinc oxide.

[0091] A first layer **408** of semiconductor material is over textured buffered layer **406**, a second layer **410** of semiconductor material is over first layer **408**, and a third layer **412** of semiconductor material is over second layer **410**. First layer **408** is heavily-doped with either p-type dopant or n-type dopant, and can comprise, consist essentially of, or consist of doped silicon or doped silicon-germanium. Layers **410** and **412** can be essentially undoped with conductivity-enhancing dopant. In particular aspects, one of layers **410** and **412** comprises consists essentially of, or consists of, silicon without any substantial concentration of germanium (i.e., silicon with less than 0.5 atomic percent germanium, and frequently with no detectable germanium), and the other comprises silicon-germanium. In particular aspects, one of layers **410** and **412** consists essentially of, or consists of silicon and the other consists essentially of or consists of silicon-germanium. The silicon and/or germanium of layers **408**, **410** and **412** can be amorphous in particular aspects of the invention. The layers comprising silicon in combination with germanium can comprise any suitable concentration of germanium. In particular aspects such layers will comprise from 1 atomic % germanium to 99 atomic % germanium; and, in some aspects, the layers will comprise from about 5 atomic % germanium to about 50 atomic % germanium.

[0092] Layer **408** is shown in direct physical contact with layer **406**, and layer **406** is shown in direct physical contact with layer **404**.

[0093] Although the illustrated solar cell **400** comprises three semiconductor layers **408**, **410** and **412**, it is to be understood that the invention encompasses other-solar cell devices comprising more than three semiconductor layers or less than three semiconductor layers. For instance, the invention encompasses aspects in which one of the layers **410** and **412** is eliminated, and the remaining layer consists essentially of, or consists of either amorphous silicon or amorphous silicon-germanium.

[0094] A semiconductor-enriched insulator layer **414** is over the third layer **412** of semiconductor material, and is shown in direct physical contact with an upper surface of layer **412**. Semiconductor-enriched insulator layer **414** can comprise any suitable semiconductor-enriched composition, and in particular aspects will comprise, consist essentially of, or consist of one or both of silicon-enriched silicon nitride and silicon-enriched silicon oxide. An exemplary silicon-enriched silicon nitride can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon, relative to Si_3N_4; and an exemplary silicon-enriched silicon oxide can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon relative to SiO_2.

[0095] An antireflective material **416** is provided over layer **414**, and in the shown aspect of the invention is in direct physical contact with an upper surface of layer **414**. Antireflective material **416** can comprise any suitable composition, and in particular aspects will comprise, consist essentially of, or consist of indium tin oxide.

[0096] Second electrodes **418** and **420** are over antireflective material **416**, and in the shown aspect of the invention are in direct physical contact with an upper surface of antireflective material **416**. Although two electrodes are shown, it is to be understood that the invention encompasses aspects utilizing more than two electrodes or utilizing only a single electrode. Further, it is to be understood that the shown two electrodes could join to one another at a location outside of the shown cross-sectional view so that electrodes **418** and **420** are portions of a common electrode. In the shown aspect, electrodes **418** and **420** are shown electrically connected to one another to form a common second electrode **405**. Electrodes **418** and **420** can comprise any suitable composition, and in particular aspects will comprise, consist essentially, or consist of one or both of silver and aluminum.

[0097] Electrodes **418** and **420** are over segments **422** and **424**, respectively, of semiconductor-enriched insulator **414**. The electrodes are spaced from one another to form gaps **430**, **432** and **434**. Segments of semiconductor-enriched insulator **414** are beneath such gaps, and are labeled as **436**, **438** and **440**.

[0098] Gaps **430**, **432** and **434** can be considered windows which allow one or more particular wavelengths of electromagnetic radiation to reach the segments **436**, **438** and **440** of semiconductor-enriched insulator **414**. The particular wavelengths of electromagnetic radiation which reach the semiconductor-enriched material **414** are wavelengths which can penetrate materials above semiconductor-enriched insulator **414** within the windows. In the shown aspect, such would be wavelengths which can penetrate antireflective material **416**. In some aspects, the segments **422** and **424** blocked by second electrodes and **418** and **420** can be considered first segments, and the segments **436**, **438** and **440** within the windows can be considered second segments of the semiconductor-enriched insulator.

[0099] In operation, electromagnetic radiation **450** generates electron-hole pairs through interaction with semiconductor-enriched material **414**, as well as semiconductor materials **412** and **410**. Such electron-hole pairs are separated by the electric field gradient of a depletion layer below **414** (not shown). Electrons and holes are subsequently drifted and collected at the top and bottom electrode **405** and **404**, respectively, providing power to external circuitry (with such external circuitry being represented by block **452** in the diagram of **FIG. 7**).

[0100] The textured buffer layer **406** of solar cell **400** can enhance the efficiency of light trapping by the solar cell. Typical thicknesses for layers **408**, **410** and **412** are from about 0.1 micron to about 1 micron, and the relative thicknesses of the layers to one another can be anything suitable, including the exemplary shown relative thicknesses or other relative thicknesses.

[0101] All of the processing steps utilized to form the structure of **FIG. 7** can advantageously be performed in a temperature range of from room temperature to about 250° C., which can be advantageous for achieving high efficiency and low cost of a fabrication process.

[0102] Another exemplary solar cell is shown in **FIG. 8** as a solar cell **500**. Such solar cell is supported over a base **502** which can have a similar composition to the base **402** discussed above with reference to **FIG. 7**.

[0103] The solar cell **500** comprises a first electrode **504** over base **502**, and comprises a textured buffer layer **506** over the first electrode and shown in direct physical contact with the first electrode. Textured buffer layer **506** can comprise the same compositions discussed above for textured buffer layer **406** of the **FIG. 7** construction.

[0104] The solar cell **500** also includes a first layer **508** of semiconductor material over the textured buffer layer, and shown in direct physical contact with the textured buffer layer. Layer **508** can comprise, consist essentially of or consist of heavily-doped semiconductor material, such as, for example, heavily-doped silicon, heavily-doped germanium, or heavily-doped silicon-germanium. The heavily-doped semiconductor material can be in any suitable form, such as, for example, amorphous form. The heavily-doped material can be either n-type doped or p-type doped, and will typically be n-type doped.

[0105] Three light-detecting regions **510**, **512** and **514** are provided over first semiconductor layer **508**. Each of the light-detecting regions can be configured to have a different composition than the others of the light-detecting regions so that the specific light-detecting regions are configured to detect different wavelengths of light relative to one another. For instance, one of the light-detecting regions can be configured to detect blue light, another can be configured to detect green light, and another can be configured to detect red light and/or infrared light. It can be desired that the light-detecting regions configured to detect shorter wavelength light be above those configured to detect longer wavelength light, in that shorter wavelength light will generally not penetrate as well into a substrate (i.e., will generally not penetrate as deeply into a substrate) as will longer wavelength light. Although only three light-detecting regions are shown, it is to be understood that the invention encompasses aspects in which more than three light-detecting regions are utilized, and further it is to be understood that the invention can encompass aspects in which less than three light-detecting regions are utilized.

[0106] The various light-detecting regions can all comprise one or both of amorphous silicon and amorphous germanium, and can differ from one another in the relative concentrations of silicon and germanium. For instance, one of the light-detecting regions can consist essentially of, or consist of, amorphous silicon without any substantial concentration of germanium, and can thus be configured to detect primarily blue light. Another of the light-detecting regions can comprise amorphous silicon-germanium (i.e., can comprise a mixture of amorphous silicon and amorphous germanium), with the germanium concentration being from about 1 atomic % to about 10 atomic % so that the light-detecting region is configured for detecting green light. Yet another of the light-detecting regions could comprise amorphous silicon-germanium, with the germanium concentration being from greater than about 10 atomic % to less than or equal to about 45 atomic % so that the light-detecting region is configured for detecting red and/or infrared light. In such aspects, it can be advantageous that the light-detecting region configured for detecting blue light be the uppermost region **514** of solar cell **500**, the light-detecting region configured for detecting green light be the middle region **512** of the solar cell, and the light-detecting region configured for detecting red and/or infrared light be the lower-most region **510** of the solar cell. The light-detecting regions comprising silicon-germanium can further comprise a layer of amorphous silicon stacked with the silicon-germanium. In such cases, the layer of amorphous silicon can be either above the silicon-germanium composition in the stack, or below the silicon-germanium composition in the stack. Also, it is to be understood that a single light-detecting region can comprise multiple layers of amorphous silicon and silicon-germanium stacked with one another.

[0107] In the shown aspect of the invention, light-detecting region **510** is separated from light-detecting region **512** by a first stack **516** of semiconductor materials **518** and **520**; and second light-detecting region **512** is separated from third light-detecting region **514** by a second stack **522** of semiconductor materials **524** and **526**. The first and second stacks of semiconductor materials can comprise an n-type doped semiconductor material in combination with a p-type doped semiconductor material. Specifically, the semiconductor materials **518** and **524** can be p-type doped semiconductor materials (such as, for example, p-type doped silicon), and the layers **520** and **526** can correspond to n-type doped semiconductor material (such as n-type doped silicon). In other words, layers **518**, **520**, **524** and **526** can comprise, consist essentially of, or consist of conductively-doped silicon. The silicon can be in any suitable form, including, for example, amorphous form. It can be advantageous that stacks **516** and **522** be configured to have a layer of n-type doped semiconductor material in combination with a layer of p-type doped semiconductor material, and it can be further advantageous that the layer of p-type doped semiconductor material be beneath the layer of n-type doped semiconductor material within the individual stacks. The stacks **516** and **522** provide depletion layers to separate electron-hole pairs generated from radiation absorbed in regions **510** and **512**, respectively. Alternatively, the stacks **516** and **522** could be replaced by appropriate thicknesses of one or more silicon-rich insulators, similar to layer **530**.

[0108] A layer of semiconductor-enriched insulator **530** is provided over the third light-detecting region **514**, and in the shown aspect of the invention is in direct physical contact with an uppermost surface of the light-detecting region **514**. Semiconductor-enriched insulator **530** can comprise, consist essentially of, or consist of silicon-enriched semiconductor in particular aspects of the invention. Specifically, the semiconductor-enriched insulator **530** can comprise, consist essentially of, or consist of one or both of silicon nitride and silicon oxide in particular aspects of the invention. If the semiconductor-enriched insulator corresponds to silicon-enriched silicon nitride, such can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon, relative to Si_3N_4; and if the semiconductor-enriched insulator corresponds to silicon-enriched silicon oxide, such can comprise from about 1 atomic % excess silicon to about 20 atomic % excess silicon relative to SiO_2.

[0109] An antireflective material **540** is provided over semiconductor-enriched insulator **530**. Antireflective material **540** can correspond to any suitable material, and in particular aspects will comprise, consist essentially of, or consist of indium tin oxide.

[0110] Second electrodes **542** and **544** are provided over the antireflective material **540**. The second electrodes are spaced from one another, and can correspond to either a pair of entirely separate electrodes, or to portions of a common electrode which joins at a location outside of the shown cross-section of **FIG. 8**. In the shown aspect, electrodes **542** and **544** are shown electrically coupled with one another to form a common top electrode **505**.

[0111] The spaced electrodes **542** and **544** have gaps **546**, **548** and **550** beside them. Such gaps define windows where one or more particular wavelengths of electromagnetic radiation can reach underlying portions of semiconductor-enriched insulator **530**. Specifically, second electrodes **542** and **544** block some segments of semiconductor-enriched insulator **530**, while other segments of the semiconductor-enriched insulator are exposed within the gaps to radiation passing through the gaps. The electromagnetic radiation within the gaps is diagrammatically illustrated by waves **552**.

[0112] In operation, the electromagnetic radiation passing into solar cell **550** generates electron-hole pairs in regions **530**, **514**, **512** and **510**. Depletion layers below **530** and regions **522** and **516** separate electrons and holes from one another. Electrons and holes drifted by the electric field gradients collect at the opposite electrodes **505** and **504**, respectively, providing power to external circuitry (shown diagrammatically in **FIG. 8** as circuitry **560**).

[0113] The solar cell of **FIG. 8** advantageously can generate electricity from multiple components of a spectrum of white light (such as, for example, sunlight).

[0114] The light-detecting regions **510**, **512** and **514** of the solar cell **500**, as well as the intervening stacks **516** and **522**, can all advantageously be deposited in the same process tool, and in some aspects the semiconductor-enriched material **530** can also be deposited in the same process tool. In particular aspects of the invention, all of the processing steps utilized to form the solar cell **500** of **FIG. 8** can be conducted within a temperature range of from about room temperature to about 250° C.

[0115] In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

1-174. (canceled)

175. A method of forming an optoelectronic device, comprising:

providing a lightly-doped semiconductor material, and defining a body region within such material; the light doping being with a first type of dopant;

forming a gate stack over the body region; the gate stack comprising, in ascending order from the body region, a layer of semiconductor-enriched insulator, and a covering material; the covering material being at least partially transparent to one or more wavelengths of light; and

forming a pair of heavily-doped regions within the semiconductor material on opposing sides of body region, the heavily-doped regions being directly against the body region, and being doped with a second type of dopant; one of the first and second types of dopant being n-type and the other being p-type.

176. The method of claim 175 wherein the semiconductor-enriched insulator comprises one or both of silicon-enriched silicon oxide and silicon-enriched silicon nitride.

177. The method of claim 175 wherein the covering material comprises one or both of indium tin oxide and Si_3N_4.

178. The method of claim 175 wherein the covering material consists essentially of one or both of indium tin oxide and Si_3N_4.

179. The method of claim 175 wherein the covering material consists of one or both of indium tin oxide and Si_3N_4.

180. The method of claim 175 further comprising forming dielectric material over the semiconductor material; and forming the layer of semiconductor-enriched insulator over the dielectric material.

181. The method of claim 180 wherein the dielectric material comprises silicon dioxide.

182. The method of claim 180 wherein the dielectric material is formed directly against the semiconductor material, wherein the semiconductor-enriched insulator is formed directly against the dielectric material, and wherein the dielectric material consists essentially of silicon dioxide.

183. The method of claim 175 further comprising electrically grounding the semiconductor-enriched insulator and the body region.

184. The method of claim 175 wherein the first type of dopant is p-type and the second type of dopant is n-type.

185. The method of claim 184 wherein the semiconductor material comprises silicon, and wherein the p-type dopant of the body region is substantially entirely one or both of boron and indium.

186. The method of claim 184 wherein the semiconductor material comprises silicon, and wherein the p-type dopant of the body region comprises both boron and indium.

187. The method of claim 175 wherein the first type of dopant is n-type and the second type of dopant is p-type.

188. The method of claim 175 wherein the semiconductor-enriched insulator consists essentially of silicon-enriched silicon nitride, and comprises from about 1 atomic percent excess silicon to about 20 atomic percent excess silicon, with the excess silicon being measured relative to Si_3N_4.

189. The method of claim 175 wherein the semiconductor-enriched insulator consists essentially of silicon-enriched silicon oxide, and comprises from about 1 atomic percent excess silicon to about 20 atomic percent excess silicon, with the excess silicon being measured relative to SiO_2.

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