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(54) **COMPLEMENTARY BARRIER INFRARED DETECTOR (CBIRD)**

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(51) **Int. Cl.**
H01L 31/00 (2006.01)

(52) **U.S. Cl.** **257/21**; 257/22; 257/E31.032; 257/E31.033

(58) **Field of Classification Search** 257/21, 257/22, E31.032, E31.033
See application file for complete search history.

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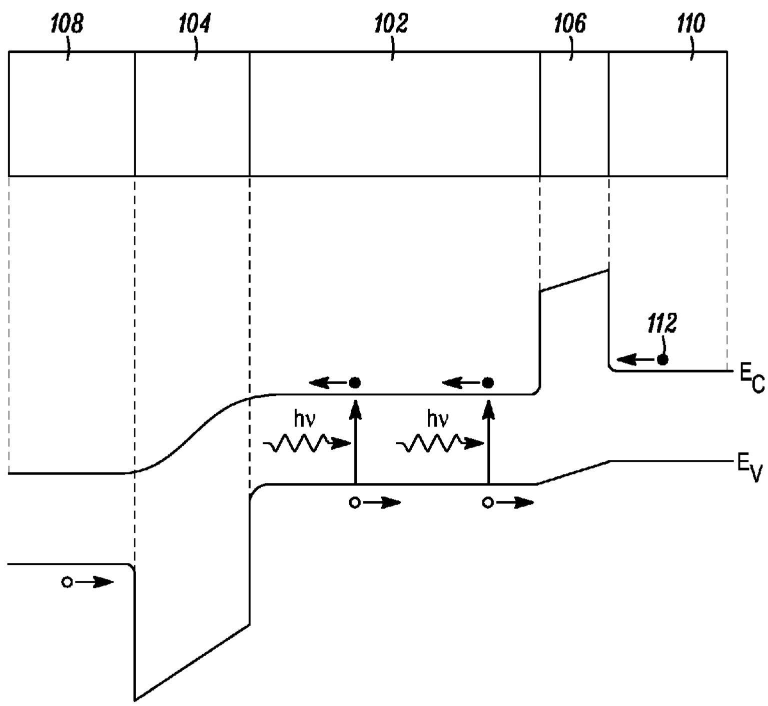
(57) **ABSTRACT**

An infrared detector having a hole barrier region adjacent to one side of an absorber region, an electron barrier region adjacent to the other side of the absorber region, and a semiconductor adjacent to the electron barrier.

15 Claims, 2 Drawing Sheets



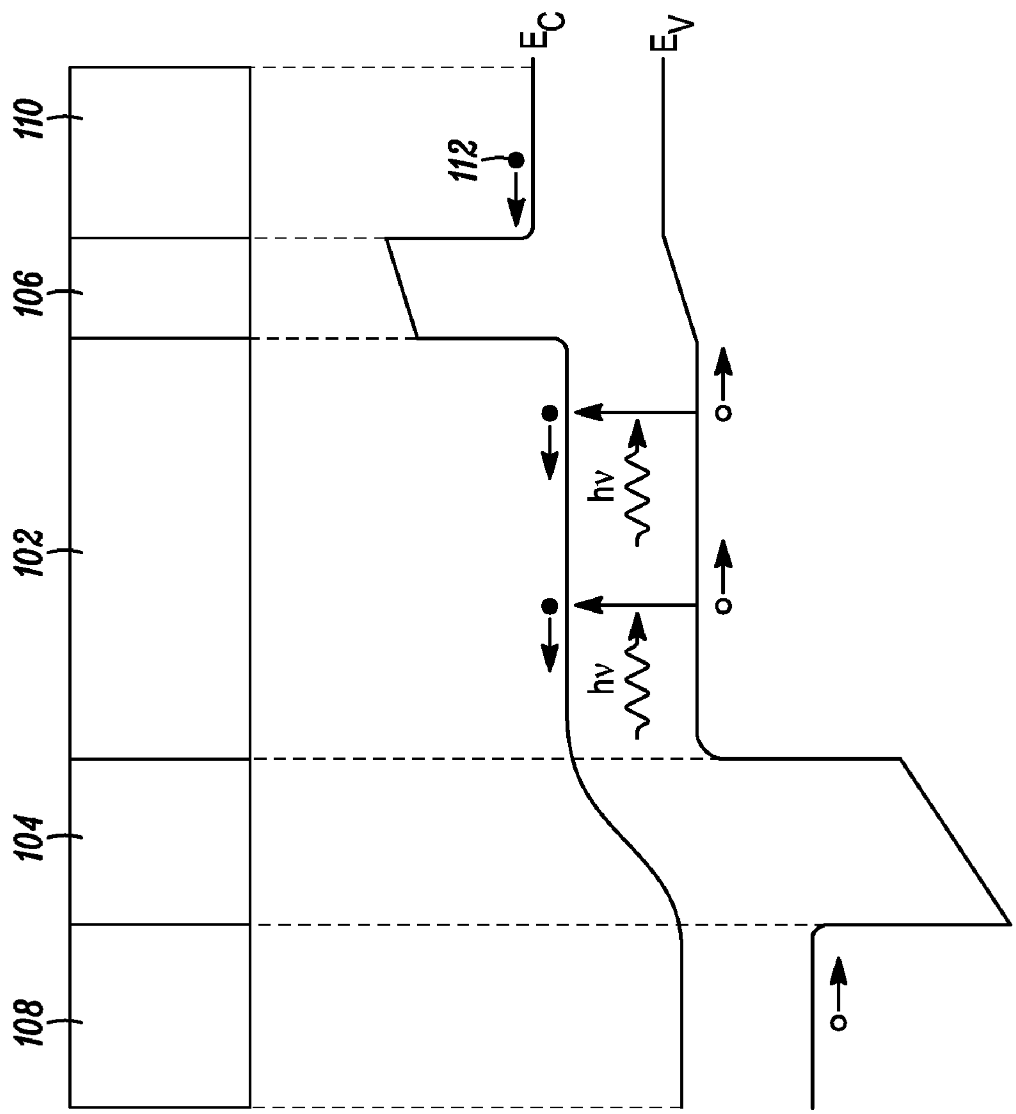


FIG. 1

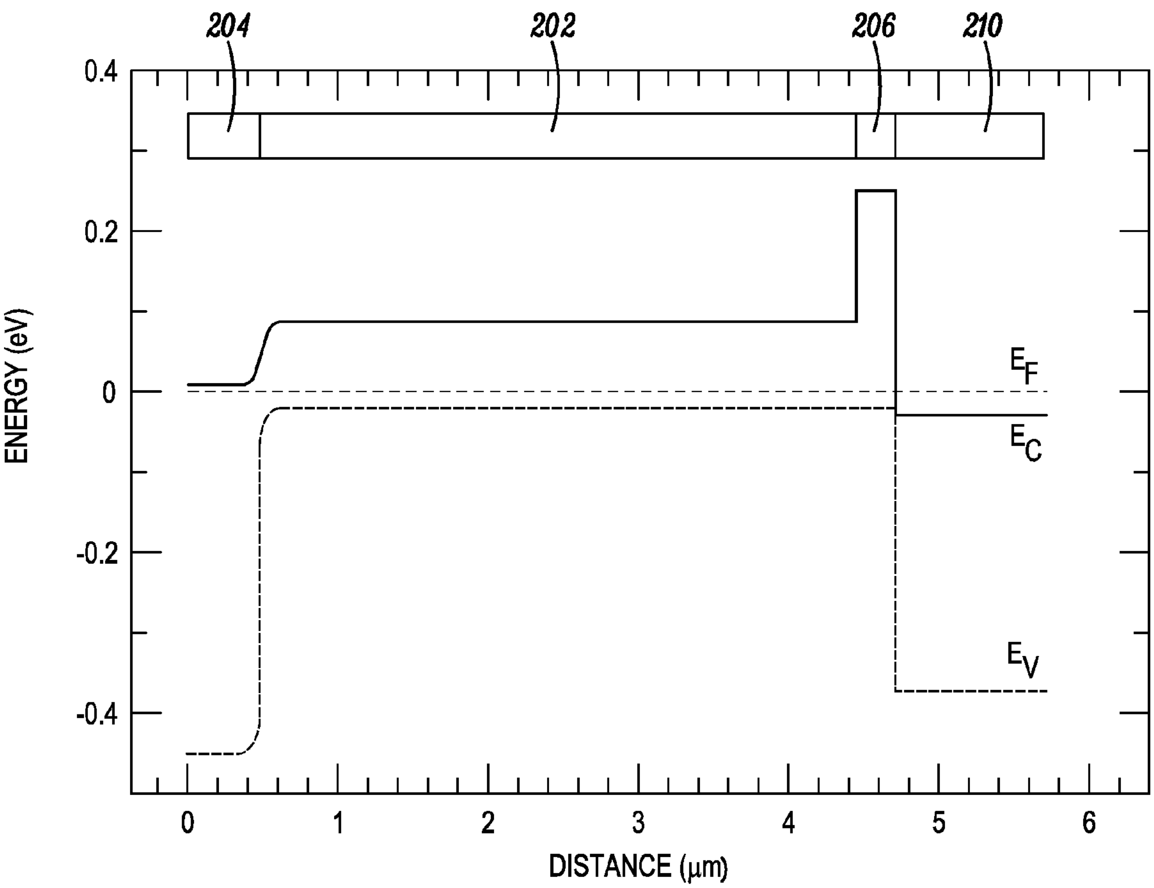

204
202
206
210
0.4
0.2
0
-0.2
-0.4
ENERGY (eV)
E_F
E_C
E_V
0
1
2
3
4
5
6
DISTANCE (μm)

FIG. 2

COMPLEMENTARY BARRIER INFRARED DETECTOR (CBIRD)

PRIORITY CLAIM

This application claims the benefit of U.S. Provisional Application No. 61/134,577, filed Jul. 11, 2008.

GOVERNMENT INTEREST

The invention claimed herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the Contractor has elected to retain title.

FIELD

The present invention relates to infrared detectors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an infrared detector, with a representative energy band diagram, according to an embodiment.

FIG. **2** illustrates an infrared detector, with an energy band diagram, according to another embodiment.

DESCRIPTION OF EMBODIMENTS

In the description that follows, the scope of the term "some embodiments" is not to be so limited as to mean more than one embodiment, but rather, the scope may include one embodiment, more than one embodiment, or perhaps all embodiments.

FIG. **1** illustrates an infrared detector according to an embodiment, comprising infrared absorber region **102**, hole barrier region **104** on one side of infrared absorber region **102**, electron barrier region **106** on the other side of the infrared absorber region **102**, and contact regions **108** and **110** in contact with hole barrier region **104** and electron barrier region **106**, respectively. The illustration of the detector in FIG. **1** is pictorial in nature and is not necessarily drawn to scale. In practice, the various regions making up an embodiment may be epitaxial layers grown on a substrate.

The conduction and valence energy band levels for the infrared detector are illustrated below their corresponding regions, with the conduction band edge labeled with an E_C and the valence band edge labeled with an E_V. The dashed lines mark the various regions so as to provide a correspondence from the energy band diagrams to regions **102**, **104**, **106**, **108**, and **110**. The regions and energy bands are not necessarily drawn to scale.

For the part of the energy bands corresponding to infrared absorber region **102**, the absorption of light is pictorially represented by the wavy lines with "hv" above them to represent the photon energy, where h is Planck's constant and v is the frequency of the incoming infrared radiation. The absorption of a photon excites an electron from the valence band to the conduction band, which is represented by the vertical arrows pointing from the valence band to the conduction band. The illustrated solid circles near the conduction band represent electrons, and the illustrated hollow circles near the valence band represent holes. An arrow next to an electron or a hole pictorially represents the direction of the electron or hole under a bias voltage applied between contact regions **110** and **108**, where contact region **108** is biased positively with respect to contact region **110**.

Electrons are collected at contact region **108**, and holes are collected at contact region **110**. The bias voltage applied to contact regions **108** and **110** depends upon the type of material used, and some embodiments may operate at zero bias voltage. For example, with contact region **110** comprising a p-doped semiconductor and contact region **108** comprising an n-doped semiconductor, contact region **108** may be positively biased with respect to contact region **110** for some embodiments.

FIG. **1** illustrates a unipolar hole barrier in the valence energy band corresponding to hole barrier region **104**, and a unipolar electron barrier in the conduction energy band corresponding to electron barrier region **106**. The unipolar electron barrier region **106** blocks electrons from absorber region **102**, but allows the flow of holes from absorber region **102**. Similarly, the unipolar hole barrier region **104** blocks holes from absorber region **102**, but allows the flow of electrons from absorber region **102**. Contact region **108** is adjacent to hole barrier region **104** for collecting electrons, and contact region **110** is adjacent to electron barrier region **106** for collecting holes. Because of this placement, these complementary barriers do not impede the flow of photon-induced current (photo-current), and it is believed that a number of benefits may result from their use. These benefits are discussed below.

A prior art infrared detector, such as for example an n-π-p detector, may suffer from generation-recombination (G-R) current due to the Shockley-Read-Hall (SRH) process taking place in the space-charge region, where for example in a n-π-p detector a space-charge region is between the n-doped region and the π absorber region. Because wide band gap barriers (regions **104** and **106**) in the embodiment of FIG. **1** are adjacent to absorber region **102**, a significant reduction in SHR generated dark current is expected.

The use of wide band gap barriers is expected to help reduce thermally generated minority carriers in the diffusion wings from contributing to the photo current. For example, electron **112** represents a thermally generated electron, but because of electron barrier region **106**, the probability of electron **112** tunneling through hole barrier region **106** to contact region **108** is very small. Furthermore, photo-generated electrons in absorber region **102** diffusing in a direction toward contact region **110** are deflected back by electron barrier region **106** with very high probability; and photo-generated holes in absorber region **102** diffusing in a direction toward contact region **108** are deflected back by hole barrier region **104** with very high probability.

For some embodiments, contact regions **108** and **110** may comprise material so as to have a wider band gap than absorber region **102**, thereby acting as a window to allow longer wavelength radiation to reach absorber region **102**. For some embodiments, contact regions **108** and **110** may comprise material so as to have smaller band gaps than hole barrier region **104** and electron barrier region **106**, so as to facilitate in making ohmic contacts to reduce contact resistance. For some embodiments, both contact regions **108** and **110** may be doped as either n-type or p-type. Some embodiments may not include one or both of these contact regions, in which case electrical contact is made directly to one or both of the barrier regions.

For some embodiments, some or all of regions **102**, **104**, and **106** may be superlattices. For some embodiments, absorber region **102** may be a superlattice designed for Auger suppression to further reduced dark current. Some or all of these superlattices may be chirped, and some of the regions may be graded by introducing an alloy composition grading. Some embodiments may have band offsets between some of the various regions. For example, one or both of the absorber-barrier interfaces may have staggered band offsets, or the barrier-contact interfaces may have nested band offsets, where the offsets are such that electrons and holes may flow unimpeded by these types of band offsets when contact region **104** is biased positively with respect to contact region **106**. The doping levels of the barrier regions and absorber region **102** may be adjusted to control various device properties.

Energy band diagrams, including the Fermi level, for a specific example of an embodiment in which electrical contact is made directly to the hole barrier region are illustrated in FIG. **2**. As in FIG. **1**, a simplified view of the various regions making up an embodiment are shown with their corresponding energy band levels, but because electrical contact is made directly to hole barrier region **204**, a contact region corresponding to contact region **108** is not needed.

For the embodiment of FIG. **2**, contact region **210** has a wider band gap than absorber region **202** and is doped n-type. Electron barrier region **206** for the embodiment of FIG. **2** is doped p-type. Having an n-type contact region next to electron barrier region **206** creates a second p-n junction (the first being the one between hole barrier region **204** and absorber region **202**) over which an applied voltage bias drop may be developed. This reduces the voltage drop over absorber region **202**, thereby reducing dark current generation in absorber region **202**.

For the embodiment of FIG. **2**, absorber region **202**, hole barrier region **204**, and electron barrier region **206** are superlattice structures. Contact region **210** for collecting holes comprises InAsSb. These regions are shown in HG. **2** with their corresponding energy bands, where the y-axis is energy in electron volts (eV), and the x-axis denotes distance in microns, and where the origin of the x-axis is taken at the left hand side of hole barrier region of **204**. Note that the embodiment illustrated in FIG. **2** does not have a contact layer for collecting electrons, but rather an ohmic contact may be made directly to hole barrier region **204** for collecting electrons. As illustrated in FIG. **2**, the layer **210** could be made of a material such that the conduction band of the layer **210** overlaps with the valence band of the electron barrier **206** to facilitate the removal of excess holes from the absorber region **202**.

In the particular embodiment of FIG. **2**, absorber region **202** is a 600 period (44 Å, 21 Å) InAs/GaSb superlattice structure. That is, a structure comprising a 44 Å thick InAs layer adjacent to a 21 Å thick GaSb layer is repeated 600 times along the x-axis. Hole barrier region **204** is an 80 period (46 Å, 12 Å) InAs/AlSb superlattice, and electron barrier region **206** is a 60 period (22 Å, 21 Å) InAs/GaSb superlattice. For the particular embodiment of FIG. **2**, hole barrier region **204** and electron barrier region **206** are designed to have, respectively, an approximately zero conduction sub-band offset with respect to absorber region **202** and an approximately zero valence sub-band offset with respect to absorber region **202**. Hole barrier region **204** is nominally doped at $n=1\cdot10^{16}$ cm^{-3}, absorber region **202** is nominally doped at $p=1\cdot10^{16}$ cm^{-3}, and electron barrier region **206** is nominally doped at $p=1\cdot10^{16}$ cm^{-3}. Contact region **210** is an $n=1\cdot10^{18}$ cm^{-3} doped $InAs_{0.91}Sb_{0.09}$ layer. The particular embodiment illustrated in FIG. **2** was grown on a 50-mm diameter Te-doped GaSb (100) substrate in a molecular beam epitaxial chamber. These parameters are cited merely as an example embodiment.

For some embodiments, contact region **210** may serve as a bottom contact layer, and hole barrier region **204** may serve as a top contact layer. For a positive bias applied to hole barrier region **204** with respect to contact region **210**, the voltage drop is can take place over the junction formed by electron barrier region **206** and contact region **210**. This junction is away from absorber region **202**, thereby mitigating dark current generation. In general, for a non-negative bias applied to hole barrier region **204** with respect to contact region **210**, photo generated minority carriers (electrons) in absorber region **202** diffuse or drift towards hole barrier region **204** to be collected by a contact applied to hole barrier region **204**. The excess hole population redistributes by dielectric relaxation, and may recombine with electrons injected into absorber region **202** from contact region **210**.

Various modifications may be made to the disclosed embodiments without departing from the scope of the invention as claimed below.

What is claimed is:

1. A detector comprising:

a p-type absorber region to generate electrons and holes in response to electromagnetic radiation;

a unipolar hole barrier region having inner and outer ends and disposed such that the inner end is positioned adjacent to the absorber region;

a first n-type contact region disposed adjacent to the outer end of the hole barrier comprising a semiconductor material that allows the un-impeded flow of minority carriers from the absorber region;

a unipolar electron barrier region having inner and outer ends and disposed such that the inner end is positioned adjacent to the absorber region; and

a second contact region disposed adjacent to the outer end of the electron barrier, comprising a semiconductor material that allows the un-impeded flow of majority carriers from the absorber region

wherein the absorber region, the unipolar hole barrier region and the unipolar electron barrier region are all substantially lattice-matched to a semiconductor substrate; and

wherein the energy band gap of the barriers between the absorber and the contacts are selected such that the undesirable generation-recombination (G-R) dark current produced through the Shockley-Read-Hail (SRH) processes is reduced.

2. The detector as set forth in claim **1**, wherein the absorber region, the hole barrier region, and the electron barrier region are selected from the group consisting of a bulk semiconductor and a superlattice semiconductor.

3. The detector as set forth in claim **2**, wherein the absorber region comprises an InAs/GaSb superlattice semiconductor.

4. The detector as set forth in claim **3**, wherein the hole barrier region comprises an InAs/AlSb superlattice semiconductor.

5. The detector as set forth in claim **4**, wherein the electron barrier region comprises an InAs/GaSb superlattice semiconductor.

6. The detector as set forth in claim **5**, wherein the absorber region is a 600 period (44 Å, 21 Å) superlattice semiconductor.

7. The detector as set forth in claim **6**, wherein the absorber region is a 600 period (44 Å, 21 Å) superlattice, the hole barrier region is an 80 period (46 Å, 12 Å) superlattice, and the electron barrier region is a 60 period (22 Å, 21 Å) superlattice.

8. The detector as set forth in claim **1**, wherein the first contact region has a wider band gap than that of the absorber region.

9. The detector as set forth in claim **1**, wherein the electron barrier region comprises a p-type doped semiconductor.

10. The detector as set forth in claim 9, wherein the hole barrier region comprises an n-type doped semiconductor, and the absorber region comprises a p-typed doped semiconductor.

11. The detector as set forth in claim 1, wherein the electromagnetic radiation is infrared.

12. The detector as set forth in claim 1, wherein the first n-type contact is formed by the unipolar hole barrier.

13. The detector as set forth in claim 1, wherein the second contact is a p-type contact.

14. The detector as set forth in claim 1, wherein the second contact is an n-type contact in a broken gap alignment to the electron barrier.

15. A detector comprising:

an n-type absorber region to generate electrons and holes in response to electromagnetic radiation;

a unipolar electron barrier region having inner and outer ends and disposed such that the inner end is positioned adjacent to the absorber region;

a first p-type contact region disposed adjacent to the outer end of the electron barrier, comprising a semiconductor material that allows the un-impeded flow of minority carriers from the absorber region;

a unipolar hole barrier region having inner and outer ends and disposed such that the inner end is positioned adjacent to the absorber region; and

a second contact region disposed adjacent to the outer end of the hole barrier, comprising a semiconductor material that allows the un-impeded flow of majority carriers from the absorber region;

wherein the absorber region, the unipolar hole barrier region and the unipolar electron barrier region are all substantially lattice-matched to a semiconductor substrate; and

wherein the energy band gap of the barriers between the absorber and the contacts are selected such that the undesirable generation-recombination (G-R) dark current produced through the Shockley-Read-Hall (SRH) processes is reduced.

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