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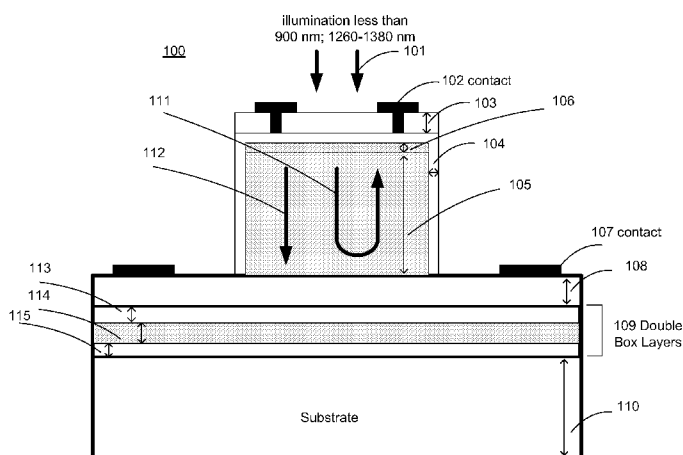


FIG. 1

(57) Abstract: A single optical receiver having a photo-detector with a wide optical bandwidth and high efficiency within the wide optical bandwidth, the photo-detector comprising: a first diode region of first doping type for receiving light; a second diode region of second doping type and of second thickness; an active region for converting the received light to an electronic signal, the active region having a third thickness and configured to reside between the first diode region and the second diode region; and a reflector coupled to the second diode region and having a silicon layer with a fourth thickness, the silicon layer residing between silicon oxide layers of fifth thicknesses, wherein the active region is configured to absorb the light of wavelengths of less than 900 nm, and wherein the reflector is configured to reflect the light of wavelengths from a range of 1260 nm to 1380 nm.



**A HIGH SPEED, WIDE OPTICAL BANDWIDTH, AND HIGH EFFICIENCY RESONANT  
CAVITY ENHANCED PHOTO-DETECTOR**

FIELD OF THE INVENTION

Embodiments of the invention relate generally to the field of photo-detectors.

- 5 More particularly, embodiments of the invention relate to an apparatus and a system for a single photo-detector which has a wide optical bandwidth and high efficiency within the wide optical bandwidth.

BACKGROUND

- As demand for high speed data transfers (e.g., 25 Gb/s per channel) is increasing,  
10 optical systems having photo-detectors are being used for receiving high speed data. Such photo-detectors are designed to operate efficiently in an optical receiver for a specific range of telecommunication wavelengths. For example, one set of photo-detectors are designed to detect incident light of short haul wavelengths (e.g., 850 nm). Another set of photo-detectors are designed to detect incident light of O-Band wavelengths (e.g., 1260  
15 nm to 1380 nm). Another set of photo-detectors are designed to detect incident light of long haul wavelengths used for intercontinental communication (e.g., 1550 nm).

- Therefore, depending on which frequency (or wavelength) range of incident light is being used for an optical system, a specific (or customized) optical receiver with a specific photo-detector is designed to operate to detect that range of wavelength of  
20 incident light. Hence, the customized optical receiver cannot be used for detecting a wide range of wavelengths of light while still providing data rate transfers of 25 Gb/s per channel e.g., for detecting wavelengths less than 900 nm and wavelengths in the range of 1260 nm to 1380 nm. Consequently, multiple customized receivers are used in optical systems to receive/detect a wide range of wavelengths of light thus potentially making the  
25 optical system costly.

BRIEF DESCRIPTION OF THE DRAWINGS

- Embodiments of the invention will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific  
30 embodiments, but are for explanation and understanding only.

**Fig. 1** illustrates a cross-section of a photo-detector operable to absorb light of wavelengths of less than 900 nm and wavelengths from a range of 1260 nm to 1380 nm, according to one embodiment of the invention.

**Fig. 2** illustrates a top view of the photo-detector of **Fig. 1**, according to one embodiment of the invention.

**Fig. 3** illustrates an array of photo-detectors based on the photo-detectors of **Fig. 1** and **Fig. 2**, according to one embodiment of the invention.

5 **Fig. 4** illustrates an optical system having the photo-detectors of **Fig. 1** in optical receivers, according to one embodiment of the invention.

#### DETAILED DESCRIPTION

Embodiments of the invention describe an apparatus and a system for a single optical receiver with one or more resonant cavity enhanced (RCE) photo-detectors having  
10 a wide optical bandwidth and high efficiency and configured to allow high data rates per channel.

The term high data rate per channel herein means data rates of around 25 Gb/s per channel. The term wide optical bandwidth herein refers to the ability to absorb light of wavelengths of less than 900 nm and wavelengths from a range of 1260 nm to 1380 nm.

15 In one embodiment, the thicknesses of the layers in the RCE photo-detector are configured to absorb the light of wavelengths of less than 900 nm and wavelengths from a range of 1260 nm to 1380 nm. In such an embodiment, a single optical receiver having the RCE photo-detector is able to operate for a wide range of wavelengths of incident light without the need for special/custom optical receivers to detect either light of wavelengths  
20 of less than 900 nm or wavelengths from a range of 1260 nm to 1380 nm while maintaining high data rates of around 25 Gb/s per channel.

In the following description, numerous details are discussed to provide a more thorough explanation of embodiments of the present invention. It will be apparent, however, to one skilled in the art, that embodiments of the present invention may be  
25 practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present invention. In the following description, the RCE photo-detector is interchangeably referred to as a photo-detector.

**Fig. 1** illustrates a cross-section of the photo-detector 100 which detects incident  
30 light 101, according to one embodiment of the invention. In one embodiment, the photo-detector 100 comprises a first diode region 106 of first doping type for receiving incident light 101. In one embodiment, the first diode region 106 is composed of Germanium (Ge) or Silicon (Si) where the first doping type is an N or a P doping type. In one embodiment,

Phosphorus is used for N doping type while Boron is used for P doping type. In other embodiments, other chemicals (elements and/or compounds) may be used for generating an N type doping and a P type doping for Ge and Si.

5 The photo-detector 100 further comprises a second diode region 108 of the second doping type. In one embodiment the second diode region 108 is composed of Si and the second doping type is of opposite polarity from the first doping type of the first diode region. For example, if the first doping type is of N doping type then the second doping type is of P doping type and visa versa. In one embodiment, the thickness of the second diode region 108 is from a range of 529 nm to 551 nm. In one embodiment, the thickness  
10 of the second diode region 108 is 540 nm.

The photo-detector 100 further comprises an active region 105 for converting the received light to an electronic signal. In one embodiment, the active region 105 is configured to reside between the first diode region 106 and the second diode region 108. In one embodiment, the active region is composed of Ge. In one embodiment, the  
15 thickness of the active region 105 is from a range of 1078 nm to 1122 nm to absorb the light of wavelengths of less than 900 nm with high optical response. In one embodiment, the thickness of the active region 105 is 1100 nm to absorb the light of wavelengths of less than 900 nm with high optical response.

The term optical response herein is also known as quantum efficiency ( $\eta$ ) and  
20 refers to a percentage of absorption of incident light by a photo-detector. The term high  $\eta$  herein refers to 80 % or more absorption of incident light by the photo-detector.

The arrow 112 in **Fig. 1** represents the absorption of the light of wavelengths of less than 900 nm in a single pass i.e., with little to no reflection of incident light, nearly all (80% and more) incident light 101 is absorbed by the active region 105. In one  
25 embodiment, the thickness of the active region 105 is approximately half of the thickness used in a typical Ge based normal-incidence photo-detector which is designed to absorb light of 1310 nm wavelength.

A person skilled in the art would realize that electrons and holes are generated in the active region upon receiving incident light. These electrons/holes generate an  
30 electrical signal representing the incident light.

In one embodiment, a reflector 109 is coupled to the second diode region 108 and a substrate 110. In one embodiment, the reflector 109 comprises a double box layer of Si layer 114 sandwiched between Si oxide ( $\text{SiO}_2$ ) layers 113 and 115 respectively. In one

embodiment the Si layer 114 has a thickness of 276 nm to 288 nm while the SiO<sub>2</sub> layers 113 and 115 have thicknesses in the range of 223 nm to 233 nm. In one embodiment, the thickness of the Si layer 114 is 282 nm. In one embodiment, the thickness of the SiO<sub>2</sub> layer is 228 nm. In one embodiment, the thickness of the layers of the reflector 109 is  
5 configured to effectively increase the thickness of the Ge active region 105 (without actually increasing the thickness) by creating a multiple-pass optical path for the incident light 101. In such an embodiment, the thinner Ge active region 105—thinner than a typical photo-detector—leads to higher speed compared to a typical photo-detector while maintaining high quantum efficiency.

10 A person skilled in the art would realize that the thicker the active region, the higher the quantum efficiency and the slower the photo-detector. The opposite is true for thinner active regions. A thicker active region results in a slower photo-detector because the transit time for the photo-detector is longer.

The term transit time herein refers to the time the slowest carrier takes to travel  
15 from one end of the active region 105 to another end of the active region 105 i.e., the time it takes the slowest carrier in the active region 105 to reach the metal contact 107 once the active region 105 receives incident light 101.

As mentioned above, the embodiments of the invention achieve higher quantum efficiency with a thinner Ge active region 105, than a typical Ge active region, and thus  
20 achieve high transit times needed for data transfers of 25 Gb/s per channel.

In one embodiment, the reflector 109 is configured to reflect light of wavelengths from a range of 1260 nm to 1380 nm. This reflected light is shown by the arrow 111. In one embodiment, the light reflected by the reflector 109 is also partially reflected by an interface layer 103 causing a greater percentage of the incident of wavelengths 1260 nm to  
25 1380 nm to be absorbed over multiple reflections within the active region 105. In one embodiment, the reflector 109 is a Double-Silicon-On-Insulator (DSOI) reflector. In another embodiment, the reflector 109 is a Distributed Bragg Reflector (DBR).

In one embodiment, the thickness of the Si layer 114 is an odd multiple of a quarter of a wavelength of light, normalized by the Si refractive index, while the thickness of the  
30 second diode region 108 does not have to be an odd multiple of a quarter of a wavelength of light as seen in typical DBR structures. In the embodiment of the invention, the thickness of the second diode region 108 is configured to maximize the quantum efficiency of the photo-detector 100 and is not a multiple of a quarter of a wavelength of

light. In such an embodiment, the overall quantum efficiency of this resonant cavity photo-detector 100 is higher over the broad 1260 nm to 1380 nm wavelength range than for a typical resonant cavity photo-detector.

As mentioned above, the photo-detector 100 further comprises an interface layer 103 having an anti-reflective-coating (ARC) and coupled to a passivation layer 104. In one embodiment, the passivation layer 104 surrounds a portion of the active region 105 and the first diode region 106. In one embodiment, the ARC is composed of silicon nitride ( $\text{Si}_3\text{N}_4$ ). In another embodiment, the ARC is composed of silicon oxide ( $\text{SiO}_2$ ). In one embodiment, the thickness of the interface layer 103 having ARC composed of  $\text{Si}_3\text{N}_4$  is from a range of 500 nm to 521 nm. In one embodiment, the thickness of the ARC layer composed of  $\text{Si}_3\text{N}_4$  is 511 nm.

In one embodiment, the portion of the passivation layer 104 which couples to both the interface layer 103 and the first diode region 106 is of the first doping type. In one embodiment, the passivation layer 104 is composed of Si. In one embodiment, the passivation layer 104 is composed of amorphous silicon. In another embodiment, the passivation layer 104 is composed of poly silicon. The thickness of the passivation layer 104 is of such value that it maximizes the device optical/light absorption while helping to suppress dark currents. In one embodiment, the thickness of the passivation layer 104 is either less than 30 nm or from a range of 184 nm to 192 nm. In one embodiment, the thickness of the passivation layer 104 is 188 nm. The photo-detector 100 further comprises a substrate 110 that is composed of high resistance Si. In one embodiment, the high resistivity of the substrate is approximately 100 ohm-cm which minimizes parasitic effects that can adversely affect the photo-detector's speed.

The electric current generated by the incident light is collected via electrical contacts 102 and 107, according to one embodiment of the invention. In one embodiment, contact 102 is coupled to the first diode region while contact 107 is coupled to the second diode region.

**Fig. 2** illustrates a top view 200 of the photo-detector 100 of **Fig. 1**, according to one embodiment of the invention. **Fig. 2** is described with reference to **Fig. 1**. The circle 103 in the center of the top view 200 is the interface layer 103 of the photo-detector 100. Metal contacts 102 and 107 provide electrical connections to the photo-detector 100 to carry current generated by the photo-detector 100 from the incident light 101. The circle 103 is of diameter 201 that indicates the size of the photo-detector. In one embodiment,

the diameter 201 of the photo-detector is 30 $\mu$ m or less. A larger diameter means a bigger interface to receive incident light.

**Fig. 3** illustrates an array 300 of photo-detectors 200<sub>1-N</sub> based on the photo-detectors of **Fig. 1** and **Fig. 2**, according to one embodiment of the invention. In one  
5 embodiment, N is 2. In another embodiment, N is 6. In other embodiments, N can be different number other than 2 and 6. In one embodiment, the array 300 resides in an optical receiver shown in **Fig. 4**.

**Fig. 4** illustrates an optical system 400 having the photo-detectors of **Fig. 1** in optical receivers 300, according to one embodiment of the invention. In one embodiment,  
10 the system 400 comprises one or more optical transmitters 401<sub>1-N</sub>. Each optical transmitter from the optical transmitters 401<sub>1-N</sub> comprises an electrical to optical conversion unit 406 coupled to a transmitter 407. In one embodiment, the transmitter 407 transmits an optical signal having a wavelength of less than 900 nm or wavelengths from a range of 1260 nm to 1380 nm to the optical receivers 402<sub>1-N</sub> via multiplexer 405, optical waveguide 403, and  
15 de-multiplexer 404.

In one embodiment, each optical receiver from among the optical receivers 402<sub>1-N</sub> comprises a receiver 300 coupled to an optical to electrical conversion unit 408. In one embodiment, the receiver 300 comprises an array 300 of photo-detectors. In one embodiment, the de-multiplexer 404 couples an optical transmitter from among the optical  
20 transmitters 401<sub>1-N</sub> to a corresponding optical receiver from among the optical receivers 402<sub>1-N</sub>. In one embodiment, the optical waveguide is an optical Universal Serial Bus (USB) cable. In one embodiment, the optical transmitters 401<sub>1-N</sub> and receivers 401<sub>1-N</sub> reside in their respective computer systems (not shown).

In one embodiment, each transmitter 407 transmits a narrow-band optical signal  
25 centered at a specific wavelength to the optical receivers 402<sub>1-N</sub>. Traditionally, a customized receiver is needed to receive/absorb light centered at that specific wavelength transmitted by the transmitter. However, in the embodiments discussed herein, the receiver 300 is configured to absorb a wide range of wavelengths i.e., wavelength of less than 900 nm and wavelengths from a range of 1260 nm to 1380 nm, and so customized  
30 receivers are no longer needed.

Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some

embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

While the invention has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. The embodiments of the invention are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

CLAIMS

We claim:

1. A photo-detector comprising:
  - a first diode region of first doping type for receiving light;
  - 5 a second diode region of second doping type and of second thickness;
  - an active region for converting the received light to an electronic signal, the active region having a third thickness and configured to reside between the first diode region and the second diode region; and
  - a reflector coupled to the second diode region and having a silicon layer with a  
10 fourth thickness, the silicon layer residing between silicon oxide layers of fifth thicknesses, wherein the third thickness of the active region is configured to absorb light of wavelengths of less than 900 nm, and wherein the forth and the fifth thicknesses of the reflector are configured to reflect light of wavelengths from a range of 1260 nm to 1380 nm.
- 15 2. The photo-detector of claim 1 further comprising:
  - a passivation layer of sixth thickness surrounding a portion of the active region and the first diode region; and
  - an interface layer having an anti-reflective-coating (ARC) of first thickness and coupled to the passivation layer, wherein a portion of the passivation layer is of the  
20 first doping type and is coupled to the interface layer.
3. The photo-detector of claim 2, wherein the passivation layer includes silicon.
4. The photo-detector of claim 2, wherein:
  - the first thickness is from a range of 500 nm to 521 nm, and
  - the sixth thickness is from a range of 184 nm to 192 nm.
- 25 5. The photo-detector of claim 1, wherein the fifth thicknesses are an odd multiple of a quarter of a wavelength of light normalized by the refractive index of silicon-oxide ( $\text{SiO}_2$ ).
6. The photo-detector of claim 1 wherein:
  - the second thickness is from a range of 529 nm to 551 nm,
  - 30 the third thickness is from a range of 1078 nm to 1122 nm,
  - the fourth thickness is from a range of 276 nm to 288 nm, and
  - the fifth thicknesses are from a range of 223 nm to 233 nm.

7. The photo-detector of claim 1 further comprising electrical contacts coupled to the first diode region and the second diode region, the electrical contacts for providing the electronic signal generated from the received light.
8. The photo-detector of claim 1, wherein the first diode region includes germanium,  
5 wherein the second diode region includes silicon, and wherein the first and the second doping types are of opposite polarities, one of an N-doping type doping and the other of a P-doping type doping.
9. The photo-detector of claim 1, wherein the reflector is a Double-Silicon-On-Insulator (DSOI) reflector.
10. The photo-detector of claim 1, wherein the reflector is a Distributed Bragg Reflector (DBR).
11. A system comprising:
  - a transmitter to transmit an optical signal over an optical waveguide; and
  - a receiver to receive the optical signal and having a photo-detector comprising:  
15 a first diode region of first doping type;  
a second diode region of second doping type and of second thickness;  
an active region for converting the received optical signal to an electronic signal, the active region having a third thickness and configured to reside between the first diode region and the second diode region; and  
20 a reflector coupled to the second diode region and having a silicon layer with a fourth thickness, the silicon layer residing between silicon oxide layers of fifth thicknesses, wherein the third thickness of the active region is configured to absorb light of wavelengths of less than 900 nm, and wherein the forth and the fifth thicknesses of the reflector are configured to reflect light of wavelengths from a  
25 range of 1260 nm to 1380 nm.
12. The system of claim 11 further comprising:
  - a passivation layer of sixth thickness surrounding a portion of the active region and the first diode region; and
  - an interface layer having an anti-reflective-coating (ARC) of first thickness and  
30 coupled to the passivation layer, wherein a portion of the passivation layer is of the first doping type and is coupled to the interface layer.
13. The system of claim 12, wherein the passivation layer includes silicon.
14. The system of claim 12, wherein:

the first thickness is from a range of 500 nm to 521 nm, and

the sixth thickness is from a range of 184 nm to 192 nm.

15. The system of claim 11, wherein the fifth thicknesses are an odd multiple of a quarter of a wavelength of light normalized by the refractive index of Silicon-oxide ( $\text{SiO}_2$ ).

5 16. The system of claim 11 wherein:

the second thickness is from a range of 529 nm to 551 nm,

the third thickness is from a range of 1078 nm to 1122 nm,

the fourth thickness is from a range of 276 nm to 288 nm, and

the fifth thicknesses are from a range of 223 nm to 233 nm.

10 17. The system of claim 11 further comprising electrical contacts coupled to the first diode region and the second diode region, wherein the electrical contacts for providing the electronic signal being generated from the received light.

18. The system of claim 11, wherein the first diode region includes germanium, wherein the second diode region includes silicon, and wherein the first and the second doping types are of opposite polarities, one of an N-doping type doping and the other of a P-doping type doping.

15

19. The system of claim 11, wherein the reflector is a Double-Silicon-On-Insulator (DSOI) reflector.

20. The system of claim 11, wherein the photo-detector is an array of photo-detectors.

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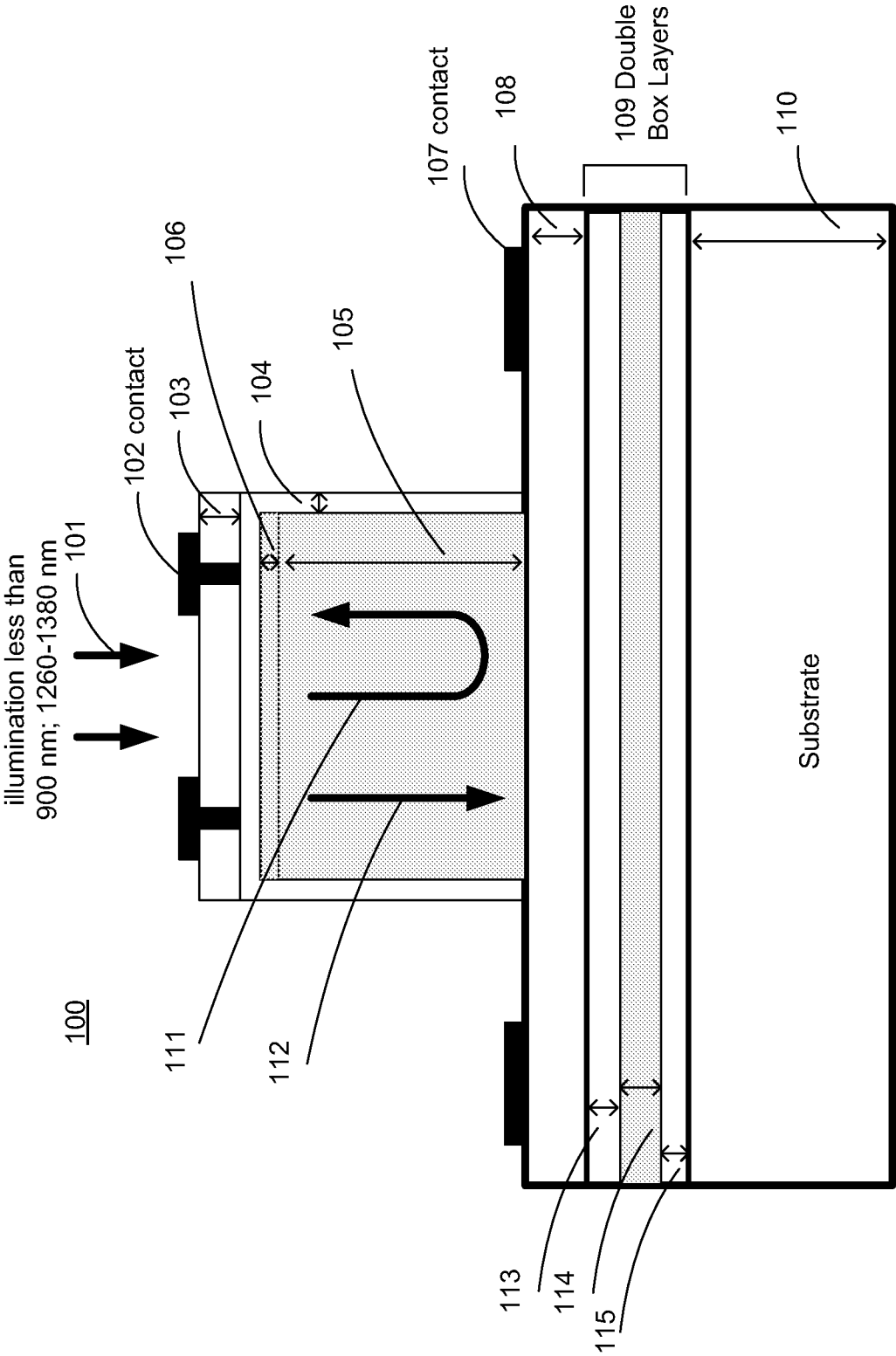


FIG. 1

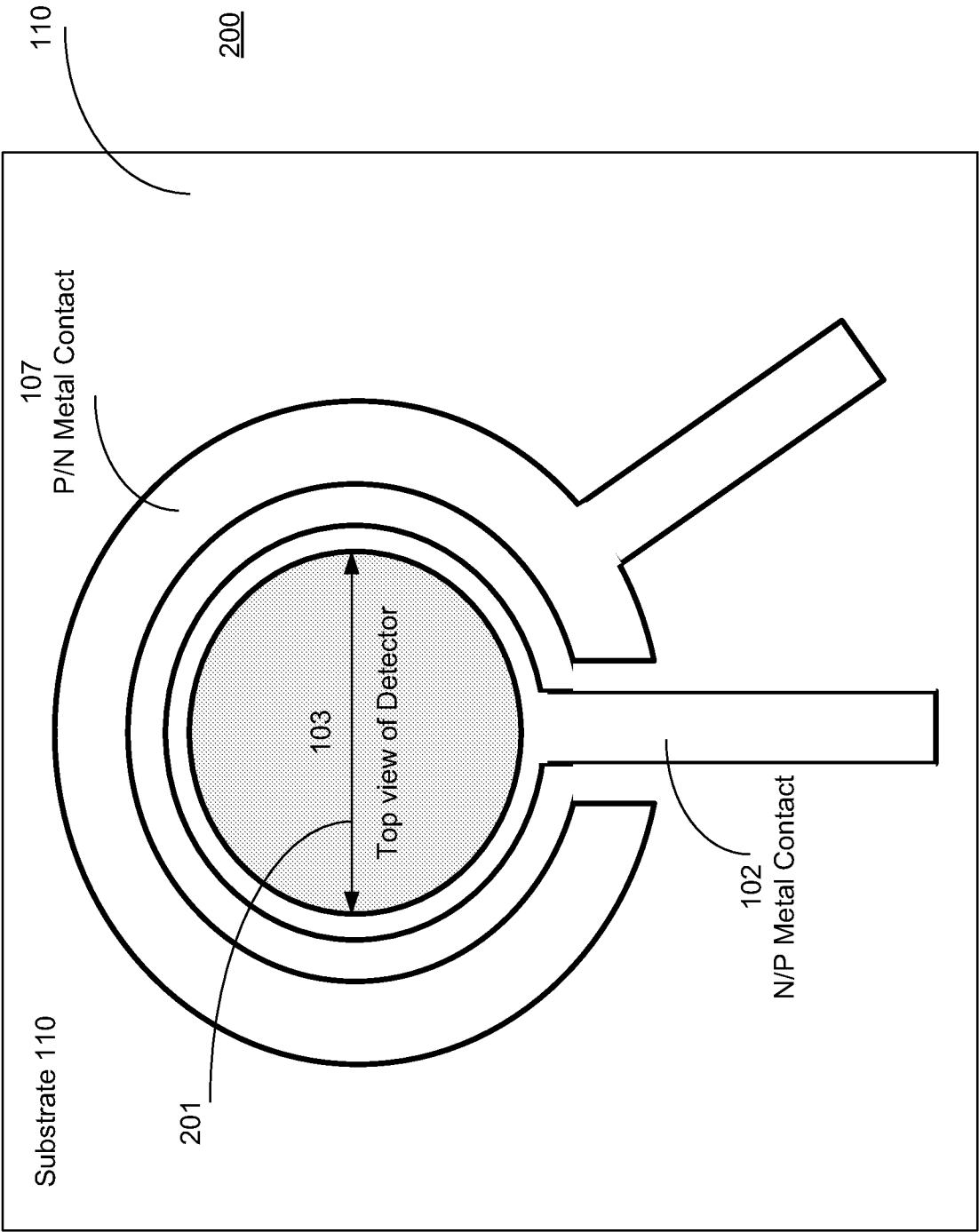
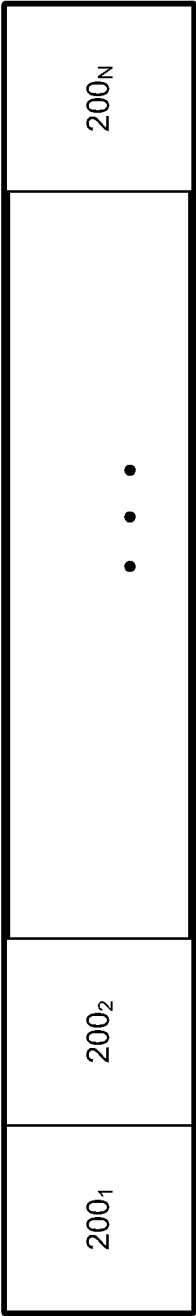


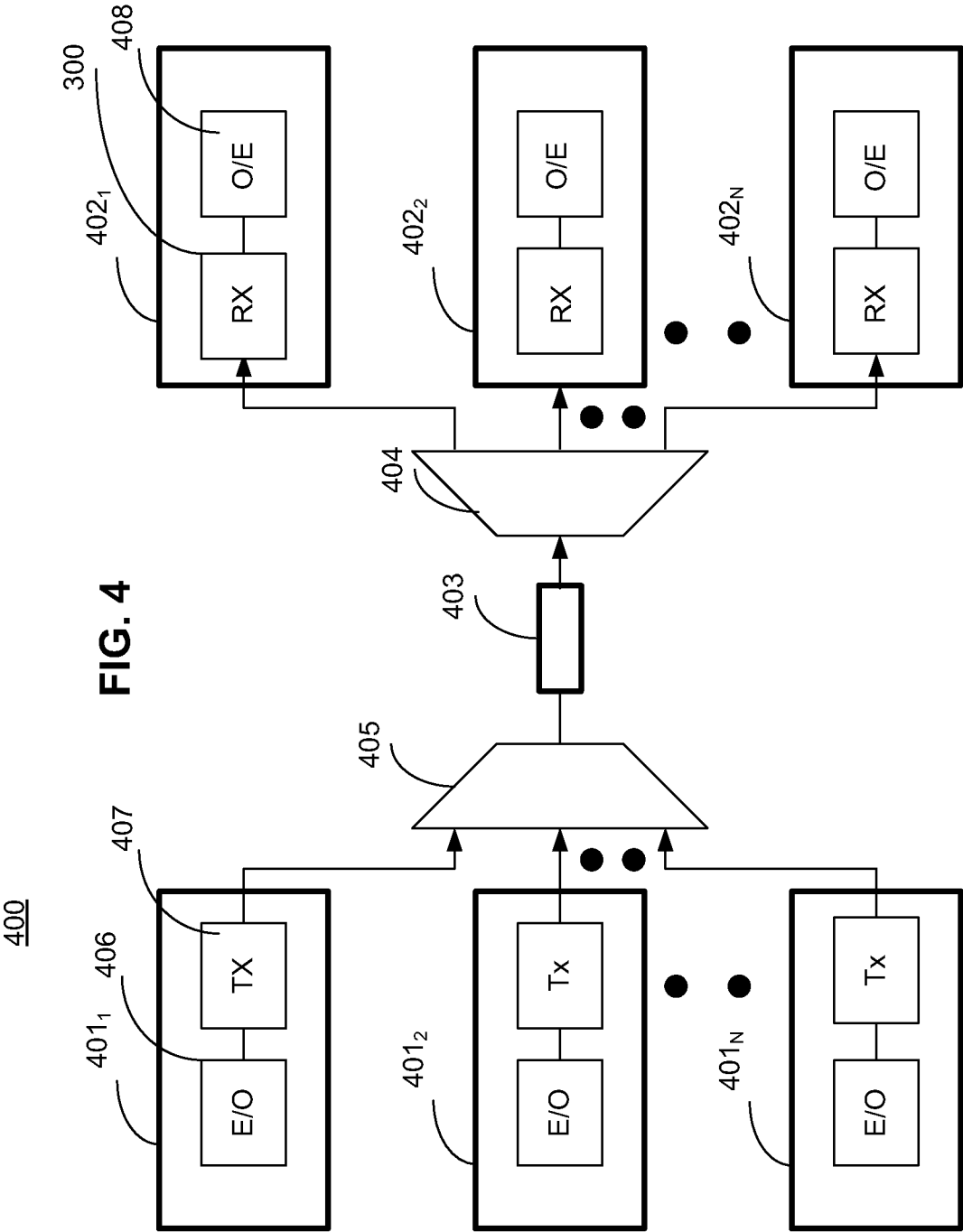
FIG. 2

300



1 x N Photo-detector Array

**FIG. 3**



**A. CLASSIFICATION OF SUBJECT MATTER****H01L 31/10(2006.01)i, H04B 10/02(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H01L 31/10; H01L 31/107; H01L 27/146; H01L 21/20; H01L 35/24; H01L 33/00; H01L 31/105; H01L 31/0256

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords: photo detector, wavelength, reflector, diode.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                   | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | EP 1796169 A1 (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE)<br>13 June 2007<br>See abstract, paragraphs [0017]-[0033], claims 1-4, 9-11 and figures 1A-1I. | 1-20                  |
| A         | US 2010-0019275 A1 (NAKATA TAKESHI) 28 January 2010<br>See abstract, claim 23 and figures 1-4.                                                                       | 1-20                  |
| A         | US 2009-0179225 A1 (FERTIG MATTHIAS et al.) 16 July 2009<br>See abstract, paragraphs [0034]-[0043], claims 1-5 and figures 1-2.                                      | 1-20                  |
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| A         | WO 2006-011766 A1 (EPIVALLEY CO., LTD. et al.) 02 February 2006<br>See abstract, claims 1-2, 9 and figures 5-8.                                                      | 1, 11                 |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

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Date of mailing of the international search report

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

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