



US007973308B2

(12) **United States Patent**  
**Meng et al.**

(10) **Patent No.:** **US 7,973,308 B2**  
(45) **Date of Patent:** **Jul. 5, 2011**

(54) **ORGANIC-SEMICONDUCTOR-BASED  
INFRARED RECEIVING DEVICE**

(75) Inventors: **Hsin-Fei Meng**, Hsinchu (TW);  
**Sheng-Fu Horng**, Hsinchu (TW);  
**Chia-Ming Yang**, Hsinchu (TW)

(73) Assignee: **National Chiao Tung University**,  
Hsinchu (TW)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 152 days.

(21) Appl. No.: **12/385,967**

(22) Filed: **Apr. 24, 2009**

(65) **Prior Publication Data**  
US 2009/0289247 A1 Nov. 26, 2009

(30) **Foreign Application Priority Data**  
May 21, 2008 (TW) ..... 97118809 A

(51) **Int. Cl.**  
**H01L 29/08** (2006.01)

(52) **U.S. Cl.** ..... **257/40; 257/184; 257/E51.012;**  
250/338.4

(58) **Field of Classification Search** ..... 257/40,  
257/184, 431, E51.012, E51.014, E51.017,  
257/E51.026; 250/338.4

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,523,555 A \* 6/1996 Friend et al. .... 250/214 R  
7,268,363 B2 \* 9/2007 Lenhard et al. .... 257/40

\* cited by examiner

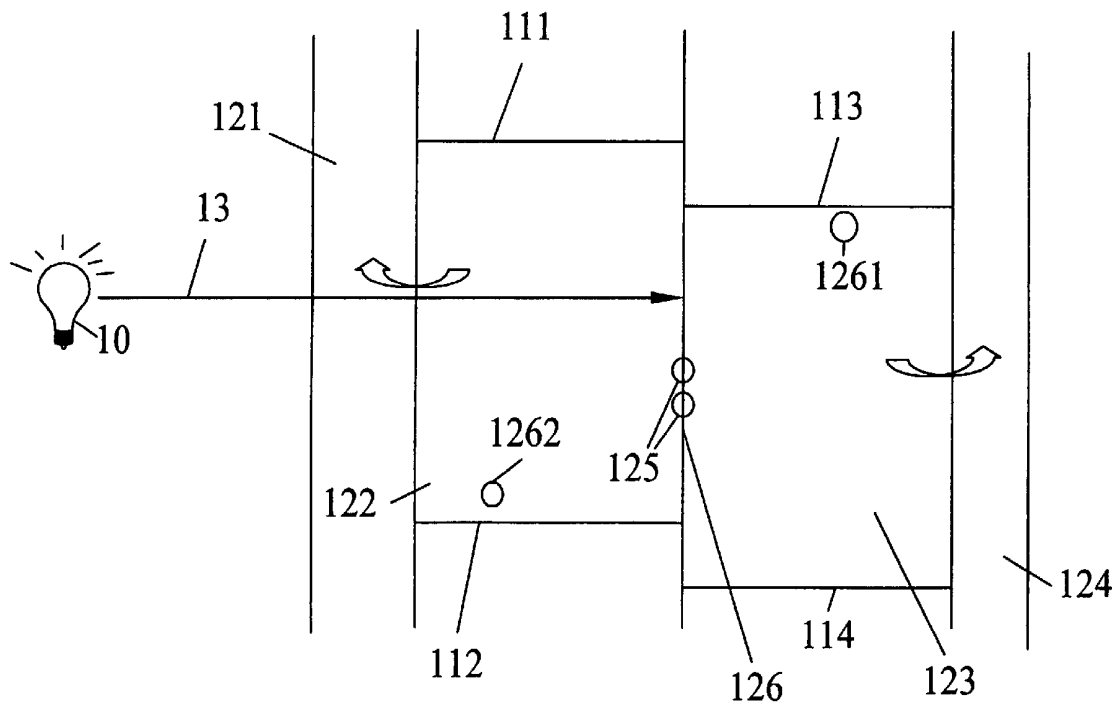
*Primary Examiner* — Mark Prenty

(74) *Attorney, Agent, or Firm* — Oliff & Berridge, PLC

(57) **ABSTRACT**

An organic-semiconductor-based infrared receiving device  
comprises an electrode layer having a positive layer and a  
negative layer to form an electric field, and a transport layer  
located between the positive and negative layers and having a  
first and a second predetermined material combined in a  
predetermined ratio. The energy of infrared light from a light  
source is received at an interface between the first and second  
materials. The thickness of the transport layer can be  
increased to enhance the light absorbance in the infrared light  
range to form electron-hole pairs, which are then parted to  
form a plurality of electrons and holes driven by the electric  
field to move to the negative layer and the positive layer,  
respectively, so that a predetermined photocurrent is gener-  
ated.

**10 Claims, 6 Drawing Sheets**





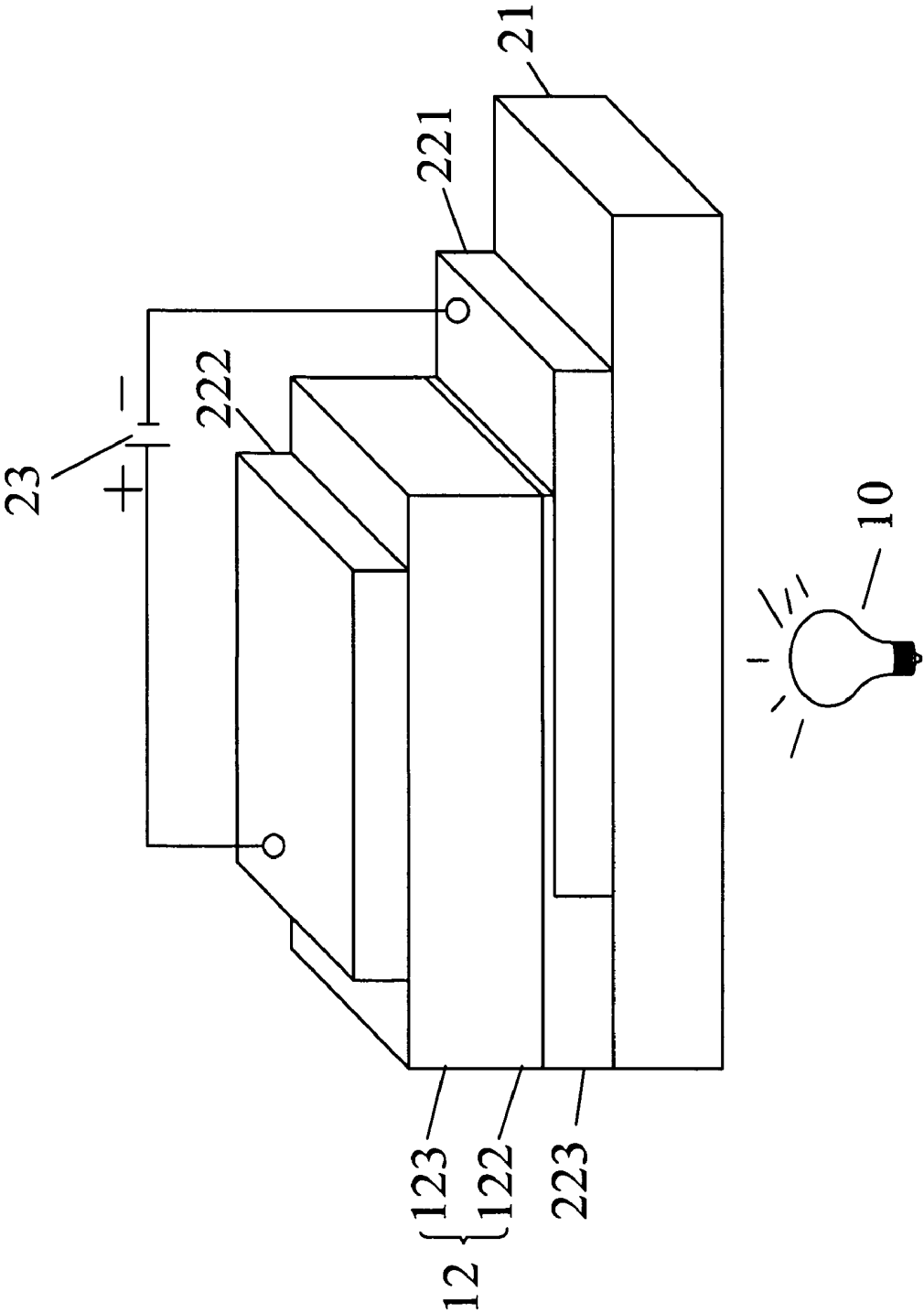


FIG.2

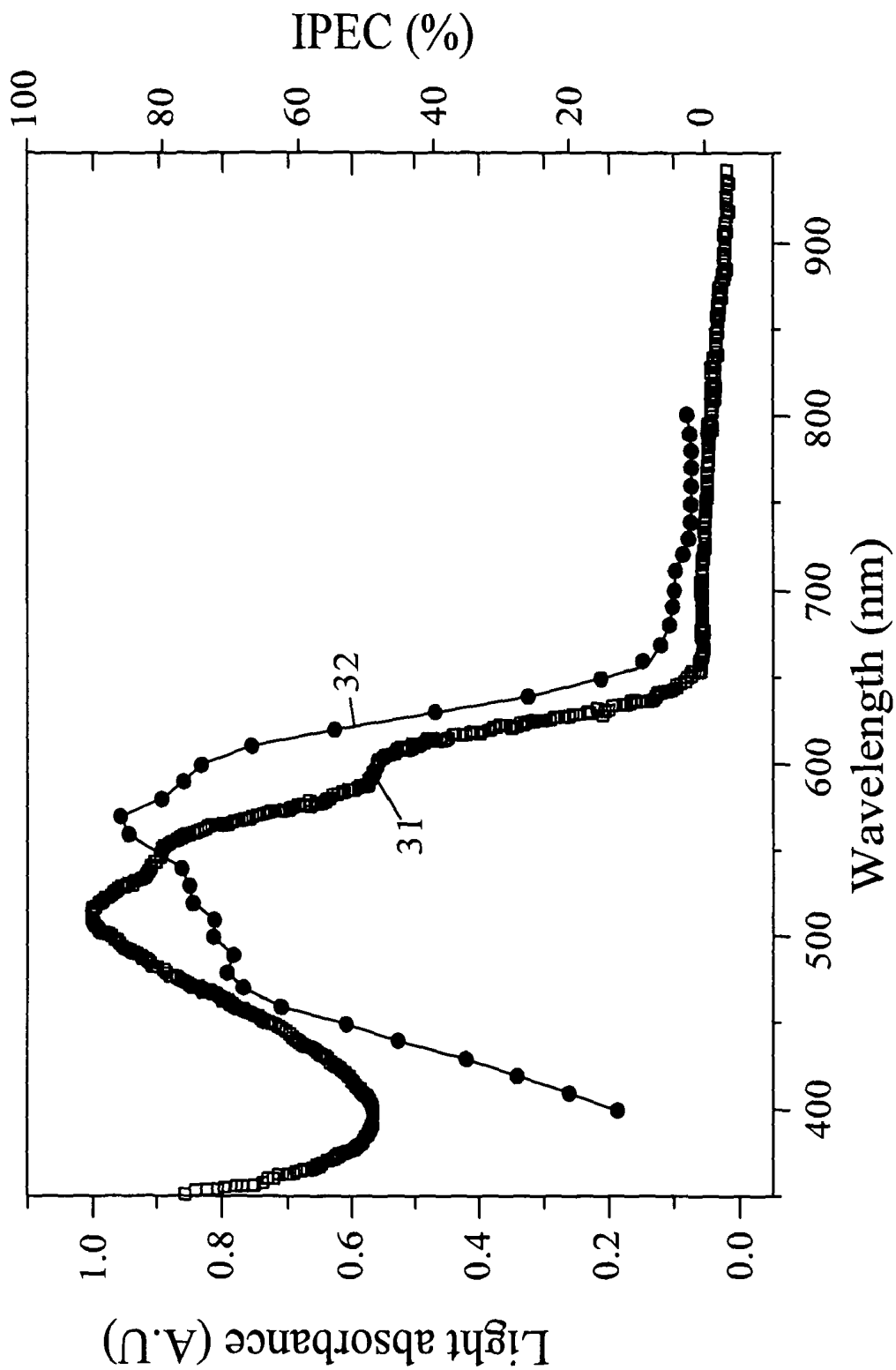


FIG.3

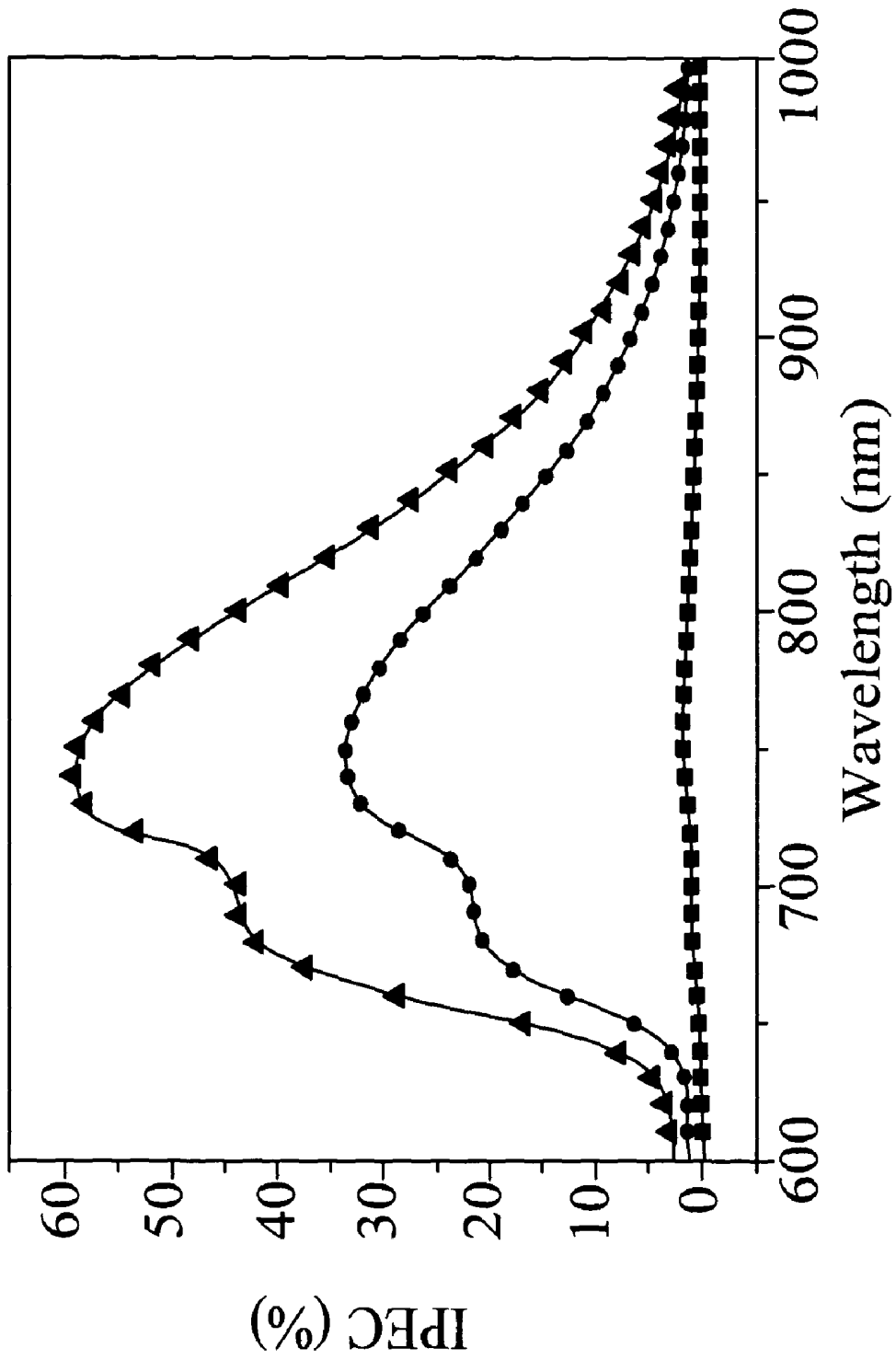


FIG.4

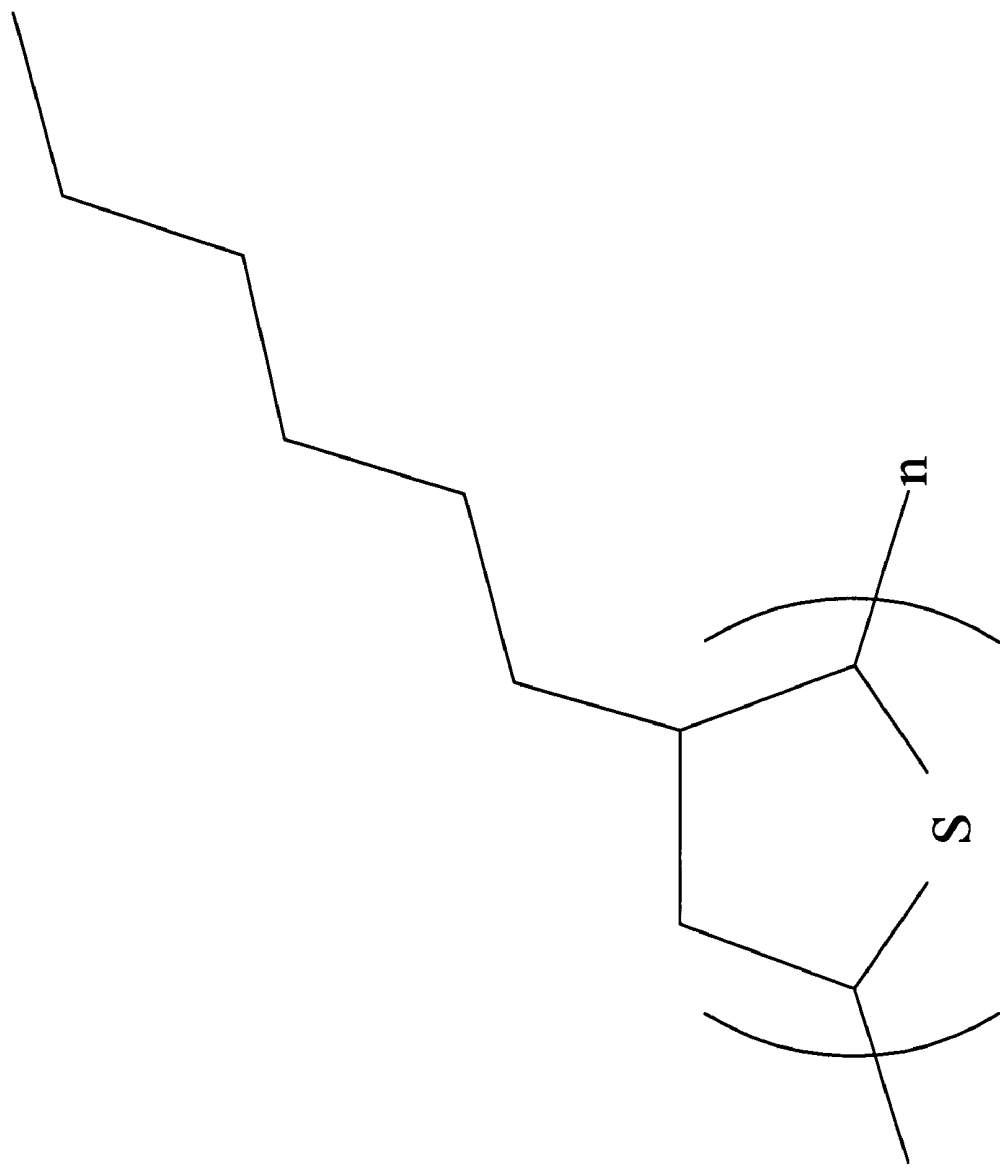


FIG. 5

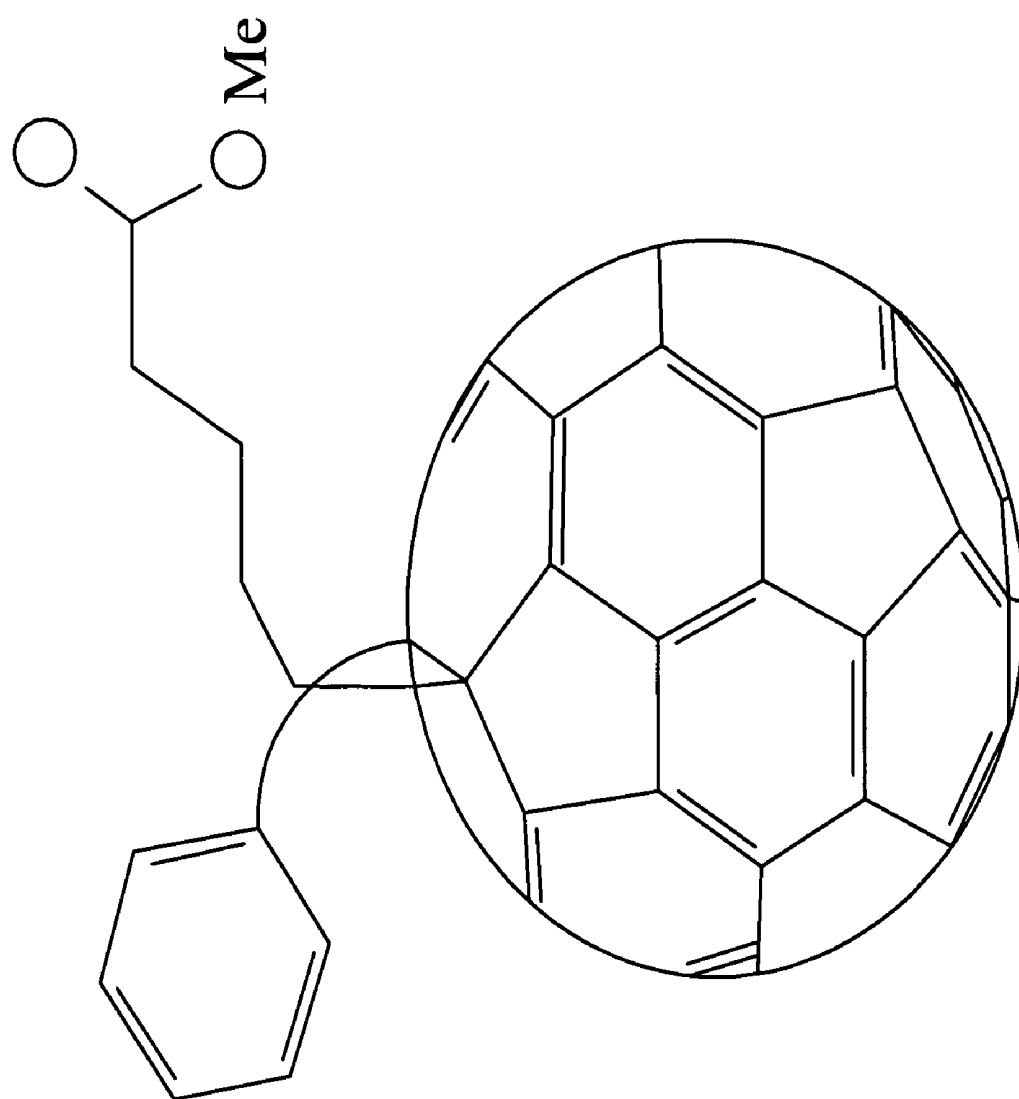


FIG.6

## ORGANIC-SEMICONDUCTOR-BASED INFRARED RECEIVING DEVICE

### FIELD OF THE INVENTION

The present invention relates to an organic-semiconductor-based infrared receiving device, and more particularly to an organic-conductive-polymer-based sensing unit capable of converting incident photons into electric current.

### BACKGROUND OF THE INVENTION

In recent years, organic semiconductor materials have replaced inorganic semiconductor materials as a working layer material in manufacturing new types of photovoltaic semiconductor elements. Compared to the conventional inorganic semiconductor elements, the organic semiconductor elements have the advantages of being light in weight, flexible, inexpensive, convenient to process, etc. In early stages, the organic semiconductors have energy conversion efficiency as low as 3%. However, the energy conversion efficiency of the organic semiconductors has been upgraded to the range from about 5% to about 10%. The organic semiconductors may be divided into two major types, namely, small-molecule semiconductors and polymer semiconductors. The small-molecule semiconductor elements must be inconveniently manufactured through the vacuum vaporization process. On the other hand, the polymer semiconductor elements may be conveniently and economically manufactured through solution process by way of spin-coating, inject printing, etc. to largely reduce the manufacturing cost of the semiconductor elements.

The traditional photo detector uses an inorganic material as its sensing material. It is expensive and uneasy to manufacture inorganic semiconductors by doping silicon to enable different photo-detecting wavelengths. On the other hand, due to intrinsic properties thereof, the organic semiconductors can only detect lights in the ultraviolet and visible light ranges, and do not respond to light in the infrared range.

It is therefore tried by the inventor to develop an organic-semiconductor-based infrared receiving device, which has a transport layer with increased thickness to enable enhanced light absorbance, so as to increase the excitons formed at an interface between two combined predetermined semiconductor materials of the transport layer and thereby overcome the problem of low light absorbance of organic matters. In the organic-semiconductor-based infrared receiving device of the present invention, organic polymer semiconductors are used to absorb infrared light and generate photocurrent, allowing the infrared receiving device to be applied in the fields of distance sensing, bio-sensing, photo-sensing, etc.

### SUMMARY OF THE INVENTION

Therefore, one of objects of the present invention is to provide an organic-semiconductor-based infrared receiving device for receiving and detecting energy in a predetermined wavelength range of infrared light from a light source.

To achieve the above and other objects, the present invention discloses a organic-semiconductor-based infrared receiving device which comprises an electrode layer having a positive electrical layer and a negative electrical layer to form an electric field, and a transport layer being located between the positive and the negative electrical layer and having of a first and a second predetermined semiconductor material combined in a predetermined ratio. At an interface between the first and the second predetermined semiconductor mate-

rial, energy in a predetermined infrared wavelength range is absorbed to form a plurality of electron-hole pairs, which are then parted into a plurality of electrons and holes. The plurality of electrons and the plurality of holes are driven by the internal electric field to move to the negative electrical layer and the positive electrical layer respectively, so that a predetermined amount of photocurrent is generated.

### BRIEF DESCRIPTION OF THE DRAWINGS

The structure and the technical means adopted by the present invention to achieve the above and other objects can be best understood by referring to the following detailed description of the preferred embodiments and the accompanying drawings, wherein

FIG. 1 is a conceptual view showing how the organic-semiconductor-based infrared receiving device of the present invention works;

FIG. 2 is a conceptual perspective view of the organic-semiconductor-based infrared receiving device of the present invention;

FIG. 3 is a curve diagram showing a light absorbance curve and an IPCE curve measured from an embodiment of the organic-semiconductor-based infrared receiving device of the present invention;

FIG. 4 shows different IPCE curves separately measured from the present invention when different negative bias voltages are applied across the transport layer of the organic-semiconductor-based infrared receiving device;

FIG. 5 shows the chemical structure of an organic semiconductor material P3HT used in the present invention; and

FIG. 6 shows the chemical structure of another organic semiconductor material PCBM used in the present invention.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Exemplary embodiments of the present invention are described herein in the context of a method, system and apparatus for providing an organic-semiconductor-based infrared receiving device.

Those of ordinary skilled in the art will realize that the following detailed description of the exemplary embodiment (s) is illustrative only and is not intended to be in any way limiting. Other embodiments will readily suggest themselves to such skilled persons having the benefit of this disclosure. Reference will now be made in detail to implementations of the exemplary embodiment(s) as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts.

FIG. 1 illustrates a conceptual view showing how the organic-semiconductor-based infrared receiving device of the present invention works. The organic-semiconductor-based infrared receiving device is configured to receive energy in a predetermined wavelength range of infrared light **13** from a light source **10**, and includes a first predetermined semiconductor material **122**, which has a lowest unoccupied molecular orbital (LUMO) energy level **111** and a highest occupied molecular orbital (HOMO) energy level **112**; and a second predetermined semiconductor material **123**, which has a LUMO energy level **113** and a HOMO energy level **114**. Preferably, the first predetermined semiconductor material **122** can be P3HT (poly(3-hexylthiophene)), a chemical structure thereof is shown in FIG. 5. The LUMO energy level **111** and the HOMO energy level **112** of the semiconductor material P3HT are about 2.7 and 4.8, respectively. Preferably, the



second predetermined semiconductor material **123** is PCBM (6,6-phenyl-C61-butyric Acid Methyl Ester), a chemical structure thereof is shown in FIG. 6. The LUMO energy level **113** and the HOMO energy level **114** of the semiconductor material PCBM are about 3.8 and 6.1, respectively.

The organic-semiconductor-based infrared receiving device of the present invention further comprises an electrode layer having a positive layer **121** and a negative layer **124** to form an electric field, with a negative bias voltage applied between the positive layer **121** and the negative layer **124**. A transport layer is located between the positive layer **121** and the negative layer **124**, and has the first predetermined semiconductor material **122** and the second predetermined semiconductor material **123**, which may be blended in a predetermined ratio, such as 1:1 or any kinds of ratio, such that energy in a predetermined wavelength range of the infrared light **13** is received at a molecular interface **126** between the first and the second predetermined semiconductor material **122**, **123**. The interface energy gap of the first and second predetermined semiconductor materials **122**, **123** absorb photons of the light source **10** to generate a plurality of interface excitons **125**, such as electron-hole pairs.

Because of the potential energy difference at the interface between the P3HT **122** and the PCBM **123**, the electrons and the holes are parted to generate free electrons **1261** and free holes **1262**. The free electrons **1261** and the free holes **1262** are then collected at negative electrode and positive electrode respectively due to a reverse bias, so that the photocurrent is generated. That is, in a photo-induced charge transfer process, holes **1262** formed after light absorbing and excitons separation are collected by a transparent conductive indium tin oxides (ITO) coating of the positive layer **121**, and most electrons **1261** are collected by the negative layer **124**, which is aluminum or aluminum modified by a metal material with suitable work function. After connecting the infrared receiving device to an external circuit, electric current is generated.

FIG. 2 illustrates a conceptual perspective view showing the organic-semiconductor-based infrared receiving device of the present invention. The organic-semiconductor-based infrared receiving device comprises an infrared light source **10**, a glass substrate **21**, a transparent conductive ITO coating **221**, a P3HT material **122**, a PCBM material **123**, a metal **222**, a conductive layer **223** and an applied voltage **23**. Preferably, the infrared light source **10** can be a point light source or a surface light source, such as a light-emitting diode or a tungsten lamp.

The organic-semiconductor-based infrared receiving device of the present invention can be manufactured through a simple process, such as spin-coating, immersion-coating and inject printing. The P3HT material **122** included in the transport layer **12** is substantially able to absorb visible lights, and the PCBM material **123** also included in the transport layer **12** is substantially able to absorb ultra-violet light. The first and the second predetermined semiconductor material **122**, **123** are conductive polymers combined in a predetermined ratio of 1:1, so as to increase a contact area at an interface between the first and the second predetermined semiconductor material **122**, **123** and thereby increase the probability of excitons separation.

For conductive polymers, electron-hole pairs subjected to light irradiation move in pairs and are parted at the interface between the two predetermined semiconductor materials **122**, **123** of the transport layer **12**. Due to different HOMO and LUMO of the two predetermined semiconductor materials **122**, **123**, the separation probability of parted electron-hole pairs at the interface between the two predetermined semiconductor materials **122**, **123** is increased.

After the electron-hole pairs become parted, the parted electrons and holes are transferred in electron acceptor and electron donor, and are finally collected by the negative layer and the positive layer, respectively, at two opposite ends of the transport layer **12**. That is, the holes are collected by the transparent conductive ITO coating **221** having high work function, and the electrons are collected by the electrode made of an aluminum metal **222** having low work function. The conductive layer **223** may be PEDOT:PSS or [poly(3,4-ethylenedioxythiophene)-poly(styrene sulfonates)] to increase the conductivity thereof and thereby maintain a clear path for smooth hole transfer, which is an extremely important requirement.

FIG. 3 illustrates a curve diagram showing the light absorbance and the incident photon to current conversion efficiency (IPCE) of the organic-semiconductor-based infrared receiving device of the present invention when the transport layer **12** thereof has a thickness of 200 nm. In FIG. 3, the curve **31** is a light absorbance curve indicating the energy in the visible light wavelength range absorbed by the organic-semiconductor-based infrared receiving device, and the curve **32** is an IPCE curve indicating the incident photon to current conversion efficiency of the organic-semiconductor-based infrared receiving device. When a negative bias voltage of  $-5V$  is applied across the transport layer **12** and the transport layer **12** absorbs the energy in a predetermined infrared wavelength range, the IPCE of the organic-semiconductor-based infrared receiving device may be as high as 80%. It should be appreciated by the person of with ordinary skills in the art that the thickness of the transport layer can be adjusted according to the desired light absorbance of the infrared light.

FIG. 4 illustrates different IPCE curves separately measured from the present invention when the transport layer **12** has a thickness of  $14\ \mu m$  and different negative bias voltages are applied across the transport layer **12**. In FIG. 4, the curve **41** indicates the IPCE of the unit in the infrared range when a voltage of  $0V$  is applied; the curve **42** indicates the IPCE of the unit in the infrared range when a negative bias voltage of  $-100V$  is applied; and the curve **43** indicates the IPCE of the unit in the infrared range when a negative bias voltage of  $-200V$  is applied. As can be seen from FIG. 4, when the applied negative bias voltage is  $-200V$ , the IPCE of the unit of the present invention in the infrared range at the wavelength of  $750\ nm$  is about 60%, which is much higher compared to the IPCE achieved in the same infrared wavelength range when the applied voltage is  $0V$ . This means the organic-semiconductor-based infrared receiving device of the present invention has a relatively high sensitivity in terms of its IPCE.

In brief, the organic-semiconductor-based infrared receiving device of the present invention has the following advantages:

1. By using conductive organic polymer materials as its semiconductor materials, the device can be more conveniently manufactured.
2. By using the potential energy gap at the interface between the electron acceptor and the electron donor of the conductive organic polymer materials, the device is able to detect light in the infrared wavelength range and form photocurrent.

What is claimed is:

1. An organic-semiconductor-based infrared receiving device for receiving energy in a predetermined wavelength range of infrared light from a light source, comprising:
  - an electrode layer having a positive layer and a negative layer to form an electric field; and
  - a transport layer being located between the positive layer and the negative layer, and having a first predetermined

5

semiconductor material and a second predetermined semiconductor material combined in a predetermined ratio;

wherein the first and the second predetermined semiconductor material themselves do not absorb infrared wavelength, and the energy in the predetermined infrared wavelength range is received at an interface between the first and the second predetermined semiconductor material to form electron-hole pairs, which are then parted into a plurality of electrons and holes; and wherein the plurality of negative electrons and the plurality of holes are driven by the electric field to move to the negative layer and the positive layer, respectively, so that a predetermined amount of photocurrent is generated.

2. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the light source is a point light source or a surface light source.

3. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the light source is a light emitting diode or a tungsten lamp.

4. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the positive layer is a transparent conductive coating.

6

5. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the negative layer is a metal material.

6. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the first predetermined semiconductor material is poly(3-hexylthiophene) or P3HT.

7. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the second predetermined semiconductor material is 6, 6-phenyl-C61-butyric acid methyl ester or PCBM.

8. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the first and the second predetermined semiconductor material are combined in any ratio.

9. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein the organic-semiconductor-based infrared receiving device is manufactured by a coating process.

10. The organic-semiconductor-based infrared receiving device as claimed in claim 1, wherein thickness of the transport layer can be adjusted according to desired light absorbance of the infrared light.

\* \* \* \* \*