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[Continued on next page]

(54) Title: SWIR TO VISIBLE IMAGE UP-CONVERSION INTEGRATED DEVICE

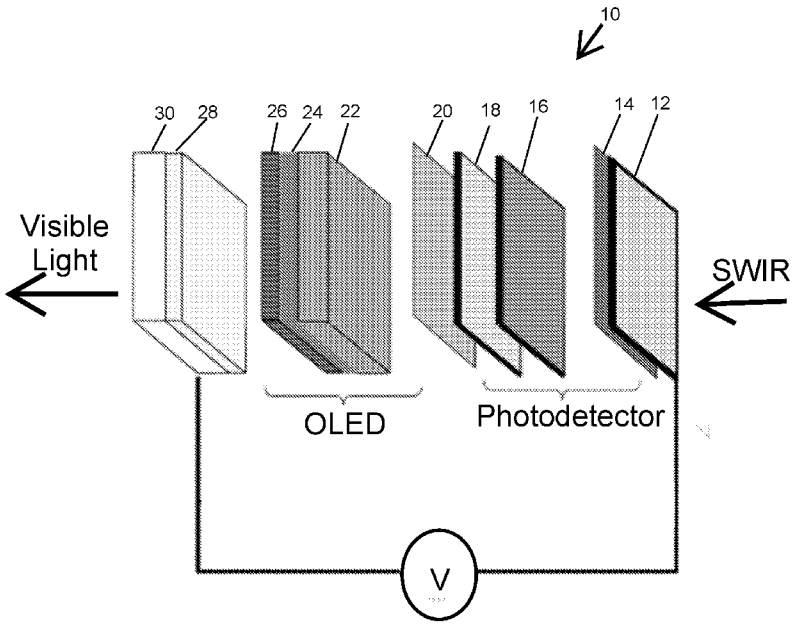

Fig. 1

(57) Abstract: Abstract Abstract Abstract The invention is a device for up-conversion of Short Wavelength Infra-Red (SWIR) images into visible images. The device comprises a sub micrometer thickness structure that is composed of several sub-layers, each having a typical thickness of tens to hundreds of nanometers. The device is composed of two main sections one on top of the other: (a) a highly efficient SWIR absorption thin layer and (b) a highly efficient organic light emitted diode (OLED). The generated visible image is emitted from the OLED through a top transparent cathode, which is deposited on the OLED.

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SWIR TO VISIBLE IMAGE UP-CONVERSION INTEGRATED DEVICE

Field of the Invention

The invention is from the field of photon up-conversion devices. Specifically the invention is from the field of up-conversion devices for converting images detected in short wavelength infrared light into images in the visible wavelength range.

Background of the Invention

There is great interest in photon up-conversion devices in many fields. In particular in the field of devices capable of allowing humans to see images of scenes that are in nearly total darkness. Particularly important in this respect are devices that are capable of converting short wavelength infrared (SWIR) images into visible ones.

The importance of the SWIR range of wavelengths is that the spectral irradiance of natural light sources such as nightglow known also as airglow is several times stronger in the SWIR range than in the near infrared (NIR) range. Also the transparency through fog and dust is much higher in the SWIR range than in the visible or NIR. Thus scenes and objects that cannot be seen in visible light even in daylight can be viewed using SWIR natural light. In addition in this wavelength range the device doesn't need cooling.

In general, present day advanced SWIR to visible up-conversion devices have several deficiencies including high cost, relatively large size and weight, and in some cases require cooling using liquid nitrogen. In addition, other proposed up-conversion devices suffer from low quantum efficiency due to low SWIR photon absorption and Low efficiency of the conversion process.

It is a purpose of the present invention to provide a thin low-cost up-conversion integrated device for converting SWIR images into visible images.

Further purposes and advantages of this invention will appear as the description proceeds.

Summary of the Invention

The invention is a device for up-conversion of Short Wavelength Infra-Red (SWIR) images into visible images. The device comprises a sub micrometer thickness structure that is composed of several sub-layers, each having a typical thickness of tens to hundreds of nanometers. The device is composed of two main sections one on top of the other: (a) a highly efficient SWIR absorption thin layer and (b) a highly efficient organic light emitted diode (OLED). The generated visible image is emitted from the OLED through a top transparent cathode, which is deposited on the OLED.

The device of the invention, comprises an external current source that creates an electric field in the device that causes holes created by absorption of SWIR photons in a SWIR absorption layer to drift towards a cathode at one side of the device and electrons created by absorption of SWIR photons in the SWIR absorption layer to drift towards an anode at a second side of the device. The external current source also adapted to inject electrons into the device at the cathode that can recombine with the holes to create a visible image in an OLED layer.

In an embodiment of the device of the invention the sub-layers comprise:

a. a transparent anode layer;
b. a SWIR absorption layer;
c. a surface plasmon enhanced layer;
d. a structured pixilated metal layer;

e. a holes transport layer;
f. an OLED layer;
g. an electron transport layer; and
h. a transparent cathode layer.

In embodiments of the device of the invention the thickness of the SWIR absorbing layer is shorter than the charge carrier's diffusion length.

In embodiments of the device of the invention only the drifted holes maintain the spatial information of the image and visible photons are emitted at the same spatial location on one side of the device that the SWIR photons created the hole-electron pairs in the SWIR absorption layer on the other side of the device.

In embodiments of the device of the invention the SWIR absorbing layer is comprised of nano-columns that are grown perpendicular to a substrate.

In embodiments of the device of the invention the structured pixilated metal layer serves as a surface plasmon enhancer and also as a double sided mirror for the SWIR incident light and for the visible light emitted by the OLED on the other side.

In embodiments of the device of the invention metal nano-particles (nano-columns or nano-colloids) having specific shape and size to be tuned for SWIR wavelengths are immersed among the nano-columns in the SWIR absorption layer, thereby creating localized plasmon enhanced absorption.

All the above and other characteristics and advantages of the invention will be further understood through the following illustrative and non-limitative description of embodiments thereof, with reference to the appended drawing.

Brief Description of the Drawings

— Fig. 1 is a schematic drawing showing the structure of the device of the invention.

Detailed Description of Embodiments of the Invention

The invention is a thin device in the form of a sub micrometer thickness structure that is composed of several sub-layers, each having a typical thickness of tens to hundreds of nanometers. The device efficiently converts Short Wavelength Infra-Red (SWIR) images that are projected on one side of the device into visible images (e.g. green colored images) that are created on the other side of the device.

The wavelength up-conversion is done through a linear conversion and with relatively high conversion efficiency. An external electric field is induced to supplement the energy difference between the energy of the SWIR photons absorbed and the energy of the visible photons emitted.

The structure of the device of the invention is schematically shown in Fig. 1. The SWIR photons that create the image enter the device **10** via objective optics **12** through a transparent anode **14** made of wide bandgap semiconductor that serves also as a SWIR window and a holes blocking layer. Transparent anode **14** can be made from, for example, ITO, GaAs, or Si, etc. The projected SWIR image is then absorbed by a high absorption coefficient semiconductor thin layer **16** located on the focal plane of the objective optics. The absorption layer **16**, which is made from, for example PbS/PbSe or PbSe/CdSe, has the correct bandgap tuned by the diameter of the quantum dots (nano-colloids) or quantum rods (nano-columns) from which it is created to create electron-hole pairs.

Absorbing layer **16** should be very thin to avoid lateral diffusion of the charge carriers that may blur the visible image created on the other side of the device. Therefore the thickness of absorbing layer **16** is designed to be shorter than the charge carrier's diffusion length (or its carrier mean free path). Therefore, absorption should be increased via means that are different from increasing layer thickness.

One measure that can be introduced to increase the absorption of layer **16** is not to make the layer from bulk semiconductor material but to make it from nano-colloids (quantum dots) or nano-columns (quantum wires) especially of of a material having large Bohr Radius and therefore high Oscillator-Strength in relatively large diameter for the SWIR photon absorption that is translated into a high absorption coefficient. On the other hand one of the main drawbacks of using nano-colloids (quantum dots) in the absorbing layer is their poor charge mobility between the nano-colloids. For this reason in this invention nano-columns (or nano rods) that are grown perpendicular to the substrate are used. With the nano-columns, the oscillator strength parallel to the substrate is high due to the quantum confinement in these directions where along the z-direction (perpendicular to the substrate) the mobility remains equal to that of the high bulk mobility.

In order to further compensate for the low absorption due to the low thickness of the absorption layer **16**, enhancement is done using surface plasmon absorption techniques. The surface plasmon enhanced absorption takes place in layer **18**, which is interlaced with a structured pixilated metal layer **20**. Layer **20** is made for example from gold, aluminum, silver, etc. and with the proper structuring for SWIR serves as the surface plasmon enhancer and also as a double sided mirror for the SWIR incident light and for the visible light emitted by the OLED on the other side.

Another measure used in the present invention in order to increase the absorption of layer **16** is to immerse metal nano-particles having specific shape and size to be tuned for SWIR wavelengths among the nano-colloids or the nano-rods in absorbing layer **16**. This creates localized plasmon enhanced absorption, i.e. localized oscillation fields due to excited collective electrons that increase the absorption cross section.

After SWIR light absorption, electron-hole pairs are generated in layer **16**. The electrons are drifted by the external applied electric field towards the anode 12 and are injected through external current source **V**, which can be for example a 10-20 volt battery, to the other side of the device through a transparent cathode **28**.

The holes are drifted through the device toward cathode **28**, crossing the absorbing layer, the top pixilated metal reflector, and holes transport layer **22** and are recombined with the injected electrons, which drift from cathode **28** through electron transport layer **26**, in an Organic Light Emitting Diode (OLED) layer **24** giving rise to and emission of visible photons. Since the device is very thin, lateral diffusion of the holes is negligible, thus the visible photon maintain the spatial position of the absorbed SWIR photon so the visible image shouldn't not be blurred.

In the architecture of the device of the invention only the drifted holes maintain the spatial information of the image and the visible emitted photons are emitted at the same spatial location on the collimating optics layer **30** that the SWIR photons created the hole-electron pairs on the absorption layer **16** on the other side of the device.

Since the visible photons are emitted with uniform illumination in 4π Strd, the metal reflector layer **20** that is located between the SWIR absorption layer **16** and the OLED layer **24**, back reflects the visible light to 2π Strd.

The visible light is collected by a collimating optics layer **30** that projects the image to the retina. Since the visible image is seen via the cathode surface, it therefore should be transparent to visible light and yet serve as a good cathode, namely it must have a low work function and hence not create an electron blocking interface.

Although embodiments of the invention have been described by way of illustration, it will be understood that the invention may be carried out with many variations, modifications, and adaptations, without exceeding the scope of the claims.

Claims

1. A device for up-conversion of Short Wavelength Infra-Red (SWIR) images into visible images, the device comprising a sub micrometer thickness structure that is composed of several sub-layers, each having a typical thickness of tens to hundreds of nanometers; wherein the device is composed of two main sections one on top of the other:
   a. a highly efficient SWIR absorption thin layer and
   b. a highly efficient organic light emitted diode (OLED); and

   the generated visible image is emitted from the OLED through a top transparent cathode, which is deposited on the OLED.

2. The device of claim 1, comprising an external current source that creates an electric field in the device that causes holes created by absorption of SWIR photons in a SWIR absorption layer to drift towards a cathode at one side of the device and electrons created by absorption of SWIR photons in the SWIR absorption layer to drift towards an anode at a second side of the device, said external current source also adapted to inject electrons into the device at the cathode that can recombine with the holes to create a visible image in an OLED layer.

3. The device of claim 1, wherein the sub-layers comprise:
   a. a transparent anode layer;
   b. a SWIR absorption layer;
   c. a surface plasmon enhanced layer;
   d. a structured pixilated metal layer;
   e. a holes transport layer;
   f. an OLED layer;
   g. an electron transport layer; and
   h. a transparent cathode layer.

4. The device of claim 2, wherein the thickness of the SWIR absorbing layer is shorter than the charge carrier's diffusion length.

5. The device of claim 2, wherein only the drifted holes maintain the spatial information of the image and visible photons are emitted at the same spatial location on one side of the device that the SWIR photons created the hole-electron pairs in the SWIR absorption layer on the other side of the device.

6. The device of claim 2, wherein the SWIR absorbing layer is comprised of nano-columns that are grown perpendicular to a substrate.

7. The device of claim 3, wherein the structured pixilated metal layer serves as a surface plasmon enhancer and also as a double sided mirror for the SWIR incident light and for the visible light emitted by the OLED on the other side.

8. The device of claim 6, wherein metal nano-particles (nano-columns or nano-colloids) having specific shape and size to be tuned for SWIR wavelengths are immersed among the nano-columns in the SWIR absorption layer, thereby creating localized plasmon enhanced absorption.

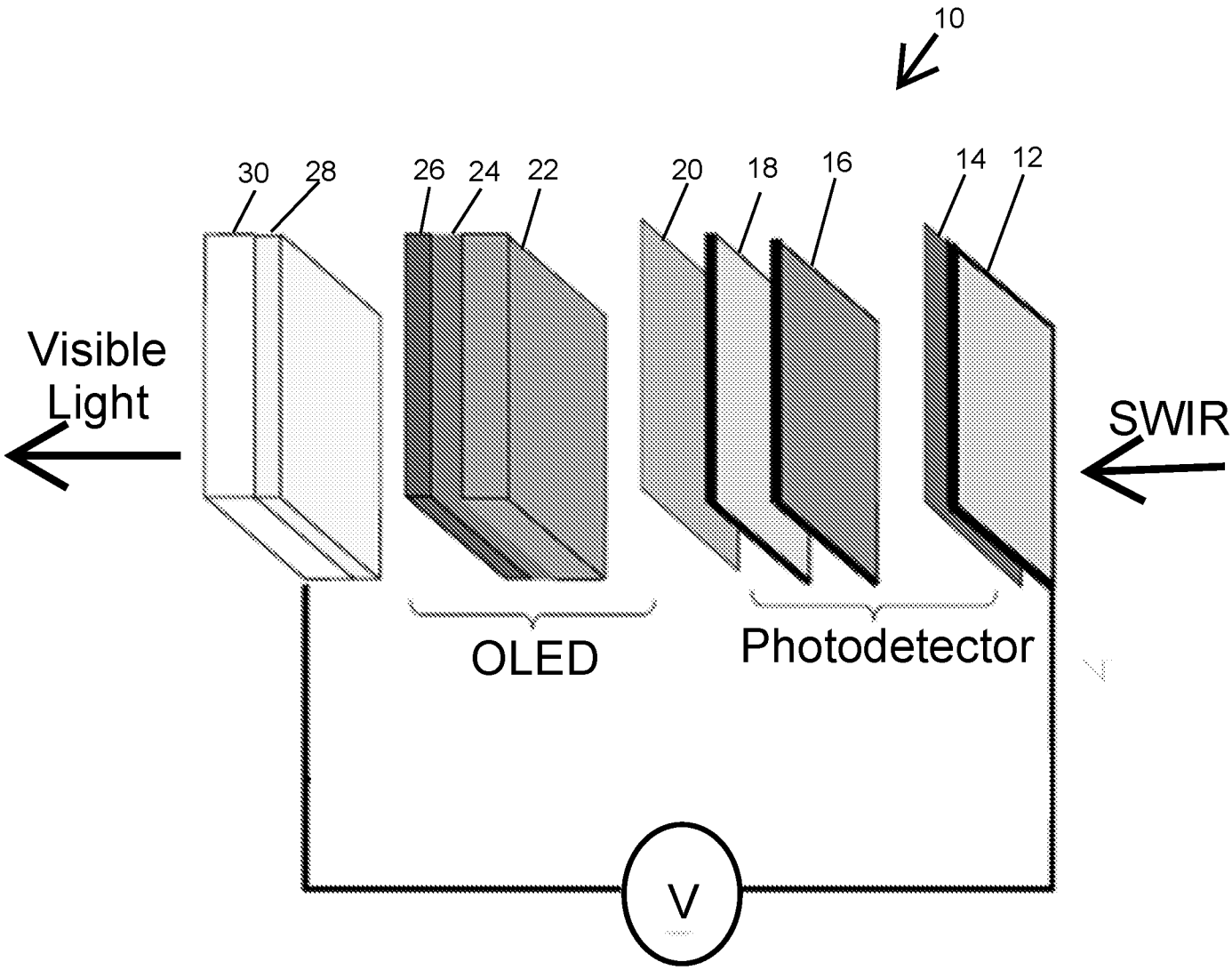
10
30
28
26
24
22
20
18
16
14
12
Visible Light
SWIR
OLED
Photodetector
V

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
IPC (2015.01) H01L 31/00, H01L 27/32

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)
IPC (2015.01) H01L 31/00, H01L 27/32

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Databases consulted: Esp@cenet, Google Patents, FamPat database

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Y	The whole document	3-8

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 Sep 2015	03 Sep 2015
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616	Authorized officer BITTON Oren Telephone No. 972-2-5657812

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