

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 August 2009 (06.08.2009)

PCT

(10) International Publication Number
WO 2009/095909 A2

(51) International Patent Classification:
H01L 31/062 (2006.01)

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(21) International Application Number:
PCT/IL2009/000105

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date: 28 January 2009 (28.01.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/024,073 28 January 2008 (28.01.2008) US

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(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: SOLAR CELLS

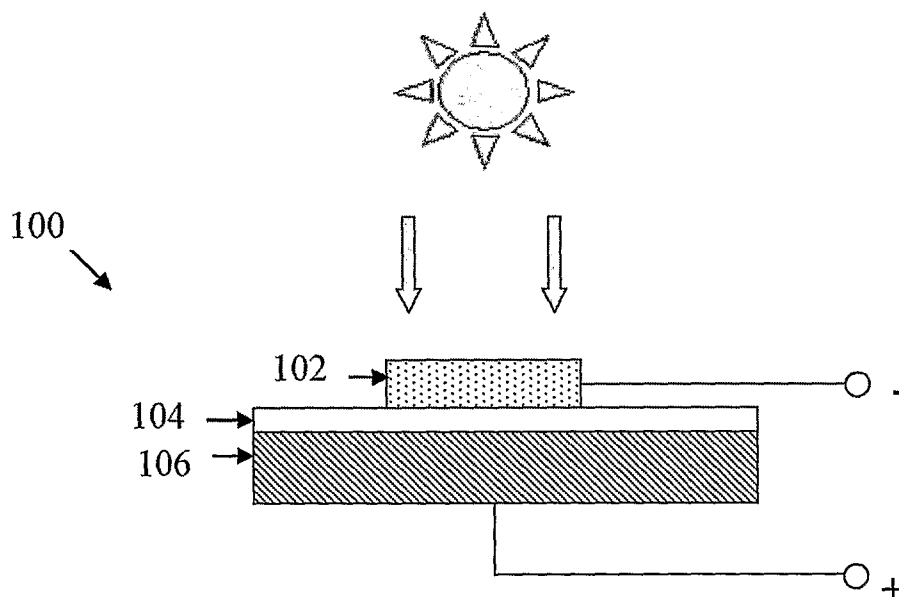


FIG. 1

(57) Abstract: The present invention discloses a novel solar cell comprising a multi-layer structure comprising a metal layer, a semiconductor layer; and an organic molecular monolayer in between the metal and semiconductor layers. The organic molecular monolayer operates as a thin controllable insulator layer; thereby enabling the multilayer structure to be operable as a MOIS (Metal-Organic-Insulator-Semiconductor) junction. According to the invention, the insulating layer is made of an organic monolayer having a high-degree of continuity of the molecules' arrangement within the layer, thus forming a large area junction.

WO 2009/095909 A2



Published:

- *without international search report and to be republished
upon receipt of that report*

SOLAR CELLS

FIELD OF THE INVENTION

The present invention relates to solar cells and methods of their fabrication.

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The following references are considered to be pertinent for the purpose of understanding the background of the present invention:

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BACKGROUND OF THE INVENTION

5 A photovoltaic cell is generally a device that directly converts photon energy into electrical energy. In semiconductor photovoltaic device, photons of sufficient energy interact with semiconductor atoms or molecules to produce negative and positive electrical charge carriers, *i.e.* electrons and holes, which can move freely throughout the semiconductor. The device collects electrons at
10 one electrical terminal and holes at the second electrical terminal before they recombine elsewhere within the semiconductor. To cause these free charge carriers to flow to their respective terminals, a barrier region is formed between the two terminals such that electrons move more easily than holes across the barrier in one direction and conversely for holes in the other direction.

15 Metal-Insulator-Semiconductor (MIS) solar cell is a type of photovoltaic cell functioning similarly to Schottky diode (metal/semiconductor contact). Their photovoltaic characteristics are improved by the addition of an extremely thin insulating film. In general, the insulating film is made of a natural oxide of the semiconductor. The thickness of the insulating film is chosen in a way that the
20 additional potential barrier caused by it, hinders the majority carrier flow from the semiconductor into the metal. On the other side, however, the minority carriers must still be able to cross the additional barrier without impairing the fill factor and the short-circuit current of the solar cells. This requires a technologically extensive, very precise and regular control and adjustment of the
25 thickness of the insulating film at a very low level of around 2 nm.

 It should be noted that, in principle, in this MIS structure, the close proximity of the photovoltaic (PV) junction to the solar cell's illuminated side

allow a better solar radiation collection, especially of short wavelengths, than in standard p-n junction solar cells.

The semiconductor's equilibrium band bending of such MIS structure is dominated primarily by the difference between the (n-type) semiconductor electron affinity and the metal work-function, following the Schottky-Mott model. Then, with the appropriate semiconductor-metal combination (n-semiconductor / high work function metal; p-semiconductor / low work function metal) the semiconductor interface is strongly depleted or even inverted. In the latter case, a p-n homojunction forms underneath the insulating layer. The current-voltage characteristics of such interface with such depletion / inversion conditions are as follows:

-in reverse and moderate forward bias: the diode dark current is limited by thermionic emission of majority carriers over the potential barrier (depletion), or by minority carrier generation and recombination rates (inversion). In both cases, forward current increases exponentially with applied bias with a slight difference in the pre-exponential factor between them, (situation called hereinafter "*semiconductor-limited*");

-at higher forward bias: the current rises exponentially with bias until it equals the rate at which minority carriers are supplied by tunneling from the metal. Beyond that, the diode becomes "*tunneling-limited*".

The current under illumination is, ideally, a superposition of the photo- and dark currents. This is true if the insulator is thin enough and that the uncompensated photocurrent can flow without entering in the diode "*tunneling-limited*" regime. Various analyses [5, 6, 7] show that this notion is valid up to a 1.5 – 2 nm insulator thickness, depending on the energy barrier height within the semiconductor. With thicker insulators, the fill factor drops rapidly, although the open-circuit voltage (V_{oc}) decreases only slightly.

Because of reproducibility, simplicity and time savings factors, it is desirable to use a physically deposited heterogeneous insulating material. Because of the extremely low thickness of the insulating layer, however,

variations of the film thickness or pinholes (microscopic holes) within the insulating film may be caused by a relatively small roughness on the surface of the photo-electrically active semiconductor and/or by extremely small dust particles. They have a very negative effect on the photovoltaic characteristics of the MIS solar cells, and special protective measures are required.

GENERAL DESCRIPTION

There is a need in the art in improving the performance and simplifying fabrication and reducing cost associated with the manufacture stage of photovoltaic cells of the kind utilizing the principles of MIS structures. The invention uses the advantages of molecular electronics, and provides a novel solar cell utilizing an electronic (e.g. a molecular electronic) junction. One of the broad aspects of the present invention is to provide thin insulating films which will not impair, or even improve the solar cell characteristics under the impact of light, namely its open-circuit voltage, fill factor and the short circuit current by using different deposition techniques.

The term "*molecular electronics*" has been used to describe phenomena or devices that include an organic molecule as a circuit element. The motivation for the field is the prospect of making extremely small (potentially one molecule) electronic components with a much wider range of functions than conventional semiconductor electronic devices. Molecular devices becoming practical induce a wide variety of applications in microelectronics, computing, imaging, display technology and chemical sensing.

Over the last decade, the electronic transport properties of molecular junctions have been studied more and more. Among such molecular junctions are those of a molecular monolayer, deposited between different types of electrodes. Metal-Molecules-Metal junctions, with either a single molecule or a molecular monolayer, sandwiched between two solid contacts were investigated, as well as Metal-Molecular monolayer –Semiconductor junctions fabricated using self-assembly technique. It should be noted that in the cases in which saturated

organic molecules are used to form the molecular monolayer, the resulting structure is called a Metal–Organic Insulator– Semiconductor (MOIS) structure.

A main advantage of the MOIS structure over its predecessor, (e.g. the Metal-Insulator-Semiconductor (MIS)), lies in the ability to “tailor” the physical and electrostatic properties of the insulating layer. The insulator thickness varies with the length of the molecules. The differences in dark current-voltage measurements between junctions with alkyl chain molecules of several lengths have been demonstrated yet [1, 2]. Vilan et al [3] showed that the control of the metal/semiconductor junction’s Schottky barrier height by changing the molecules’ chemical end group, and thus changing their dipolar moment is possible.

The present invention provides a novel solar cell based on the use of the principles of an MOIS structure. The MOIS structure includes a metal layer, an organic monolayer acting as an insulator layer and a semiconductor layer. According to the invention, an insulating layer is made of an organic monolayer having a high-degree of continuity of the molecules' arrangement within the layer, thus forming a large area junction. The "large area junction" property enables a high light collection efficiency of the solar cell.

A variety of organic molecules that can be formed on oxide-free, H-terminated Si enable the exploration and optimization of the role(s) of the insulator layer's physical and electronic properties. Self-assembly of organic monolayers can be done at relatively low temperatures (< 230 °C), and metallic top electrodes can be deposited non-destructively by various methods, including bottom-up techniques, such as growing and ripening of nano-particles [8].

The solar cell of the present invention comprises a multi-layer structure comprising a metal layer, a semiconductor layer; and an organic molecular monolayer in between the metal and semiconductor layers. The organic molecular monolayer operates as a thin controllable and functional insulator layer. The multilayer structure is operable as a MOIS (Metal-Organic-Insulator-Semiconductor) junction.

In some embodiments, the organic molecular monolayer has a high-degree of continuity of the molecules' arrangement within the layer, forming a large area junction enabling a high light collection efficiency of the solar cell.

The organic molecular monolayer may also be a self-assembled monolayer, and a passivation layer. The organic monolayer can also be polar, for example by being composed, in total or in part of dipolar molecules. The organic molecular monolayer is configured and operable to protect the semiconducting absorber layer from defects and decrease the number of surface states. The organic molecular monolayer may be a thiol-terminated alkoxy monolayer or a methyl-terminated alkoxy monolayer.

In some embodiments, the metal layer is selected from the group comprising conducting polymer, an evaporated metal grid, a network of carbon nanotubes, or a thin film made through nanoparticles enhancement. The metal layer may be semi-transparent to a wavelength range of the solar spectrum being absorbed by said semiconductor absorber layer.

The semiconductor layer may be an amorphous semiconductor or a thin film.

In some embodiments, the organic molecular monolayer is a saturated alkyl chain monolayer and the semiconductor layer is an *n*-type silicon layer. The organic molecular monolayer thickness may be tuned using alkyl chain of different lengths, and this, together with the aforementioned possible polar character of the organic monolayer enables the optimization of the photovoltaic conversion efficiency of said solar cell.

According to the present invention, efficient photovoltaic properties of different organic monolayer deposited on crystalline Silicon are provided. For example, using an Hg-C12-O- *n*-Si structure, open-circuit voltages as high as 540 mV, are obtained.

Preferably, the present invention provides molecular junctions of saturated alkyl chain monolayers, deposited on *n*-type Si and using different top electrodes having a photovoltaic activity. The organic monolayer self-assembly may be

done at low temperatures (180°C-230°C), and the metallic top electrode can be either indirectly evaporated [4], spin coated using a conducting polymer, or grown in a bottom-up technique such as by growth and ripening of nanoparticles enhancement. The electrode can be a conducting polymer, an evaporated metal
5 grid, a network of carbon nanotubes, or a thin film made through nanoparticles enhancement.

The inventors have found that a closely packed organic monolayer can serve as an ideal insulator to form a Metal-Insulator-Semiconductor (MIS) junction. The thickness of the organic monolayer can be easily tuned using alkyl
10 chains of different lengths, to optimize the photovoltaic conversion efficiency of the device. The monolayer acts as passivation layer to protect the interfacial Si layer from defects and to decrease the number of surface states.

Moreover, the configuration of the photovoltaic cells of the present invention enables highly efficient light collection, provided by the ultra-thin
15 insulating layer on top of the semiconducting absorber layer, rather than using another semiconductor on top of the absorber, as commonly found in p-n hetero-junction cells, or by having the junction inside the semiconductor as is the case in most homo junction cells. In the conventional p-n homo- or hetero-junction cells, the light is absorbed in the top of the semiconductor layer and, thus, less than
20 fully efficient in generating the photovoltaic effect, except in highly specialized cells. This reduces the light collection efficiency, especially for short wavelength light (which is more likely to be absorbed in the top of the semiconductor). In the photovoltaic cells of the present invention, the light passes directly into the active area (semiconductor-insulator junction) and is thus exploited better for current
25 production.

According to another embodiment of the present invention, the organic monolayer can be used to manipulate the junction barrier height in accordance with photovoltaic demands.

According to another embodiment of the present invention, the semiconductor layer may be an amorphous semiconductors and/or thin films, reducing the fabrication costs even further.

5 BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic illustration of a MOIS structure operating as a solar
10 cell according to one embodiment of the present invention;

Fig. 2 is a graphical presentation of a dark I-V measurement of molecules with different lengths deposited on *n*-type silicon;

Fig. 3 is a graphical presentation of an I-V measurement of different molecular lengths' structures with Hg drop electrode and fixed halogen light;

15 **Fig. 4** is a graphical presentation of an I-V measurement of *n*-Si-O-C12 sample;

Fig. 5 is a graphical presentation of a photovoltage measurement of *n*-Si-O-C12 sample having an indirectly evaporated Au electrode; and;

Fig. 6 is a graphical presentation of the transmittance spectra of 60nm Au
20 pads;

Fig. 7 is a graphical presentation of a photovoltage measurement of *n*-Si-O-C₁₁ sample having a conducting polymer (PolyAniline pad) top contact;

Fig. 8 is a graphical presentation of current-voltage characteristics of an *n*-Si-O-C₁₁-S-Au structure, fabricated by molecular self-assembly and electro-less
25 Au plating;

Fig. 9 is a graphical presentation of a temperature-dependent dark I-V measurements on an *n*-Si-O-C₁₁-S-Hg; and;

Fig. 10 is a graphical presentation of a photovoltaic measurement on a junction, made by contacting an *n*-Si surface, to which a monolayer of $(\text{CH}_2)_{11}\text{CH}_3$ molecules is bound via Si-O-C bonds, with Hg (*n*-Si-O-C₁₁ / Hg).

DETAILED DESCRIPTION OF EMBODIMENTS

5 Reference is made to **Fig. 1**, showing a solar cell of the present invention. The solar cell comprises a multi-layer structure **100** configured as a MOIS structure. The MOIS structure **100** includes a metal layer **102**, an organic monolayer acting as an insulator **104** and a semiconductor layer **106**.

To provide a molecular junction according to the teachings of the present
10 invention, samples were prepared from single side polished Si (cleaved into $\sim 10 \times 20 \text{ mm}^2$ pieces) having a nominal resistivity of 1-10 $\Omega \text{ cm}$. The wafer pieces were cleaned by rinsing with solvents and blown dry under a stream of argon. Subsequently, the wafer pieces were immersed in piranha solution (98% H_2SO_4 :30% H_2O_2 , 3:1,v/v) at 90°C for at least 30 minutes, rinsed with copious
15 amounts of MilliQ water and etched in deoxygenated 40% NH_4F solution for about 15 minutes. This treatment (immersion in piranha solution, rinsing and etching in 40% NH_4F solution) was repeated once. Self-assembling monolayers (SAMs) of alkyl chains were formed via thermal hydrosilylation of alkenes. Using this technique, chemical and structural properties of the molecules in the
20 monolayer can be characterized using a wide range of surface sensitive techniques. The freshly etched piece of Si wafer was immersed in neat deoxygenated alkene under argon and heated at 200 °C for 4 hours. After the reaction, the sample, which comprised the Si wafer with the molecular monolayer, was removed, rinsed with solvents and then further cleaned by
25 immersion in boiling solvents and/or sonication in hexane and dried under a stream of inert gas. I-V measurements of the molecular junctions were performed using *n*-Si/ $\text{C}_n\text{H}_{2n+1}$ /Hg structures. The junctions were formed by placing an Hg (99.9999% purity) drop on the SAM, using a controlled growth hanging mercury drop (HMD) electrode apparatus. The samples were contacted on the back by

applying In-Ga eutectic, after scratching the surface with a diamond knife. The contact area between the Hg drop and the monolayer (typically 0.5 mm in diameter) was determined using an optical microscope.

As the Hg drop is highly reflective, its use is not really suitable for photovoltaic measurements. Nevertheless, a HMD electrode being a very efficient and non-destructive top contact was used for initial characterization of photovoltaic properties of the different molecular systems. It should be noted that the photocurrent presented in the following graphs is collected solely from the Hg electrode's periphery, and is probably more affected by surface recombination in comparison with a usual solar cell or a photodetector.

Reference is made to **Fig. 2**, representing a typical dark I-V measurement (on a semi-logarithmic scale) of series of molecules lengths deposited as monolayers on the same initial *n*-type silicon wafer. In this non-limiting example, four samples made of *n*-Si/C_{*n*}/Hg structures were investigated, in which 1 is the dark current measured for a sample having a *n*-Si/C₁₂/Hg structure, 2 for a sample having a *n*-Si/C₁₄/Hg structure, 3 for a sample having a *n*-Si/C₁₆/Hg structure, and 4 for a sample having a *n*-Si/C₁₈/Hg structure.

In a semiconductor/insulator/metal junction, two types of barriers of transport process may exist. One is the Schottky barrier inside the semiconductor, and the other is the tunneling barrier presented by the insulator. The Schottky barrier is mainly determined by the semiconductor doping type and density, whereas the tunneling barrier is determined by the width of the insulator and by the height of the potential barrier, imposed by this insulating layer. Molecules chemically bound to the semiconductor are likely to affect the energy and density of surface states and, therefore, the semiconductor band bending.

As illustrated in **Fig. 2**, at low forward bias and reverse bias, the current is dominated by thermionic emission over a Schottky barrier in the semiconductor. At higher forward bias, the Schottky barrier decreases until it becomes so small that it no longer plays a role in transport. From such forward bias, the current is dominated by tunneling through the molecular layer.

Organic insulating layer thicknesses were measured by ellipsometry to be C12: 15-16Å, C14: ~18Å, C16: ~20Å, and C18: 22-23Å. The dark measurements of different lengths usually coincide along the negative biases and into the positive bias until reaching the flat-band voltage (potential) from there on. When the direct tunneling becomes dominant, a clear length dependence of the currents is observed. On the high biases regime, a clear splitting between curves according to molecular length is observed.

Reference is made to **Fig. 3** representing light I-V measurements taken with a fixed halogen bulb positioned 15 cm from the samples. Open circuit voltages (V_{oc}) in the range of 370-420mV were measured. The measurements show no distinctive trend between different molecular lengths. In this non-limiting example, the four samples made of n -Si/ C_n /Hg structures of **Fig. 2** were investigated, in which **1** is the photo-voltage measurement for a sample having a n -Si/ C_{12} /Hg structure, **2** for a sample having a n -Si/ C_{14} /Hg structure, **3** for a sample having a n -Si/ C_{16} /Hg structure, and **4** for a sample having a n -Si/ C_{18} /Hg structure.

Reference is made to **Fig. 4** representing a high intensity I-V measurement performed on n -Si-O-C12 sample with a Hg drop electrode, having a low dark ideality factor of $n=1.09$, (for an ideal diode $n=1$) represented in **1**. When illuminating the sample, illustrated in **2**, an extremely high fill factor of 80% was measured. Therefore, the current produced by the MOIS junction is indeed a superposition of the diode dark current, and the photo induced current.

In order to better estimate the photocurrents of such cells, an indirect method of evaporation is examined, in which Au pads are deposited softly on top of the monolayer without damaging the molecules. Reference is made to **Fig. 5** representing a photo-voltage measurement of an n -Si-C12 structure with a 30 nm indirectly evaporated Au film. It should be noted that a 30 nm Au film has a transparency of about 40% in the visible range of the spectrum. The short circuit current, illustrated in **1**, exceeds 7 mA/cm² and when taking into account the Au film transparency, the short circuit current might reach 15 mA/cm². The measured

open circuit voltage is about 0.26 V, illustrated in 2, which is much lower than measured with the Hg drop electrode. Still, the short-circuit current indicates good photon collection efficiency. The relatively low open-circuit voltage might point to Au diffusion towards the silicon through monolayer domain boundaries, or deposition directly not only on top but also inside the organic insulator, reducing the actual insulator thickness or even shorting the top electrode to the Si in those places. Therefore, this method of contacting appears less suitable for MOIS fabrication.

Reference is made to Fig. 6, representing the transmittance spectra of ready-made 60 nm Au pads, laid softly on the molecular layer. From 600 nm and higher, all wavelengths are either absorbed or reflected from the pads and less than 5% of the incident photon is transferred into the Si because at the thickness used Au is hardly transparent. Again, as in the case of the junction where the contact was made with an Hg drop, it is clear that most of collected current arises from light that is absorbed around the pad, where no light intensity attenuation occurs, rather than under the pad. As illustrated in Fig. 7, photo-voltage measurements of an *n*-Si-O-C11 structure with a conducting polymer (commercially available PolyAniline pad of dimensions of 2*2mm) spin-coated on top of the monolayer acting as a top electrode can provide a high open circuit of about 530mV illustrated in 2. The short-circuit current illustrated in 1, indicates good photon collection efficiency.

In some embodiments, the solar cell of the present invention may be made by binding alkyl chain molecules via Si-O-C bonds to oxide-free *n*-Si surfaces, using self-assembly.

In other embodiments, the MOIS solar cell can comprise an all solid-state covalently bound structure, in which a thiol-terminated alkoxy monolayer is adsorbed onto an *n*-Si substrate via Si-O-C bonds. The samples can be prepared by treating a single side polished 1-10 Ohm-cm *n*-Si (100) with a solution of HOC₁₁H₂₂SH. The samples can be then characterized by ellipsometry, water contact angle, FT-IR and XPS to verify the monolayer quality and that the

surface is free of measurable oxide. A continuous but porous, semi-transparent Au film is then grown on the thiol terminated monolayer in a two-step process. Au nano-particles (NPs), 3-5 nm in diameter, are bound to the monolayer from a toluene suspension. The NPs serve to seed the top electrode for electro-less
5 deposition. This, all-covalently-bound approach, leads to a structure with well-defined insulator thickness (as compared to, e.g., [9] where the PV behavior of methyl-passivated *n*-Si, contacted by spray-coating Au nano-particles and subsequent sintering, is shown).

It should be understood that, since the NP monolayer operates as the solar
10 cell top contact, the NP monolayer has to be transformed into an electrically continuous metal film with low sheet resistance, as transparent as possible to that part of the solar spectrum that can be absorbed by the monolayer. For example, using slow electro-less plating for 5 min, while monitoring film growth, gave a continuous film with a semi-transparency (e.g. 50-60% overall transparency)
15 over the visible and near-IR radiation (300-1000 nm wavelength range). It should be noted that, in all measurements, bias is applied to the top contact (metal layer) while the substrate's back contact is grounded.

Reference is made to **Fig. 8** illustrating current-voltage characteristics curves of a 2x2 mm *n*-Si-O-C₁₁-S-Au structure, fabricated as described above,
20 under illumination of about 25 mW/cm². As shown in the figure, the open-circuit voltage, Voc, is 480 mV, higher than reported for plain *n*-Si-Au or even *n*-Si-SiO₂-Au cells [10] and the fill factor (FF) is 58%.

The transition point between "*semiconductor*"- and "*tunneling-limited*" current regimes is found from temperature dependent I-V curves, using Hg as top
25 electrode. To a first approximation, tunneling does not depend on temperature. Therefore, the I-V plots in the *tunneling-limited* voltage regime should be temperature-independent, while in the *semiconductor-limited* regime currents, currents increase with temperature, as expected for a thermally activated process.

Reference is made to **Fig. 9** representing temperature-dependent dark I-V
30 measurements for an *n*-Si-O-C₁₁-S-Hg junction. Hg has a work function of 4.5

eV which is only slightly lower than the values 4.6–4.8 eV, measured for chemically-deposited Au, using Kelvin probe contact potential difference (CPD) measurements. As shown in the figure, the plots show the voltage where the temperature dependence changes from increasing to decreasing current with increasing temperature, with increasing forward bias, indicating that, indeed, around 470 mV, the diode behavior becomes *tunneling-limited*, as expected from the photovoltaic measurements.

High density methyl-terminated SAM's are chemically non-reactive and very hydrophobic. To be able to test if changing the terminating group of the molecules affect PV performance (by affecting the interface energetics) in the alkoxy systems, a methyl-terminated monolayer is used as an insulator in MOIS cells, but now with Hg as the top contact.

Reference is made to **Fig. 10**, illustrating PV measurements of a structure made by contacting an *n*-Si surface, to which a monolayer of $(\text{CH}_2)_{11}\text{CH}_3$ molecules is bound via Si-O-C bonds, with Hg (*n*-Si-O-C₁₁ / Hg). The structure is illuminated using a white light source, adjusted to yield roughly 100 mW/cm² with a 3300 K blackbody spectrum.

With Hg as top electrode, the photocurrents, shown in **Fig. 10**, stem solely from light collected from the Hg electrode's periphery, making it not possible to normalize the current in terms of current density. However, because the current is collected from the areas surrounding the electrode, it is likely to be more affected by surface recombination than in a usual solar cell or photodetector. Therefore, the *V*_{oc} and FF, measured on this structure present lower limits for a full PV device.

The junction in **Fig. 10** showed a good, low, dark ideality factor (*n*=1.09) and, under illumination, a fill factor of 80%. The *V*_{oc} is 540 mV, for *n*-Si based MIS cells of that resistivity. With the all-covalently-bound approach, the MOIS cell's open-circuit voltage may be increased by using amine-, rather than thiol-terminated alkoxies, to get a more negative dipole moment, while still allowing binding semi-transparent metal films. Alternatively, physisorbing suitable

transparent conductors on top of methyl-terminated monolayers so as not to damage the layer, should allow significantly improved performance of these cells.

CLAIMS:

1. A solar cell comprising a multi-layer structure comprising a metal layer, a semiconductor layer; and an organic molecular monolayer being a self-assembled monolayer in between the metal and semiconductor layers, said organic
5 molecular monolayer operating as a thin controllable insulator layer; said multilayer structure being operable as a MOIS (Metal-Organic-Insulator-Semiconductor) junction.
2. The solar cell of Claim 1, wherein said organic molecular monolayer has a high-degree continuity of the molecules' arrangement within the layer, forming a
10 large area junction enabling a high light collection efficiency of the solar cell.
3. The solar cell of Claim 1, wherein said organic molecular monolayer is a passivation layer.
4. The solar cell of Claim 1, wherein said organic molecular monolayer is polar.
- 15 5. The solar cell of Claim 1, wherein said organic molecular monolayer is configured and operable to protect the semiconducting absorber layer from defects and decrease the number of surface states.
6. The solar cell of Claim 1, wherein said metal layer is selected from the group comprising conducting polymer, an evaporated metal grid, a network of
20 carbon nanotubes, or a thin film made through nanoparticles enhancement.
7. The solar cell of Claim 1, wherein said semiconductor layer is an amorphous semiconductor or a thin film.
8. The solar cell of Claim 1, wherein said organic molecular monolayer is a saturated alkyl chain monolayer and wherein said semiconductor layer is an *n*-
25 type silicon layer.
9. The solar cell of Claim 1, wherein said organic molecular monolayer is a thiol-terminated alkoxy monolayer.
10. The solar cell of Claim 1, wherein said organic molecular monolayer is a methyl-terminated alkoxy monolayer.

11. The solar cell of Claim 1, wherein said organic molecular monolayer thickness is tuned using alkyl chain of different lengths, enabling the optimization of the photovoltaic conversion efficiency of said solar cell.
12. The solar cell of Claim 1, wherein said metal layer is semi-transparent to a
5 wavelength range of the solar spectrum being absorbed by said semiconductor layer.
13. A method of manufacturing a solar cell comprising:
interacting between a semiconductor substrate and an organic layer operating as an insulator to obtain a molecular junction;
10 interacting a metal layer with said molecular junction creating a multi-layer structure formed by a metal-organic insulator-semiconductor junction; and,
illuminating the multilayer structure inducing the generation of a current produced by said structure.

1/10

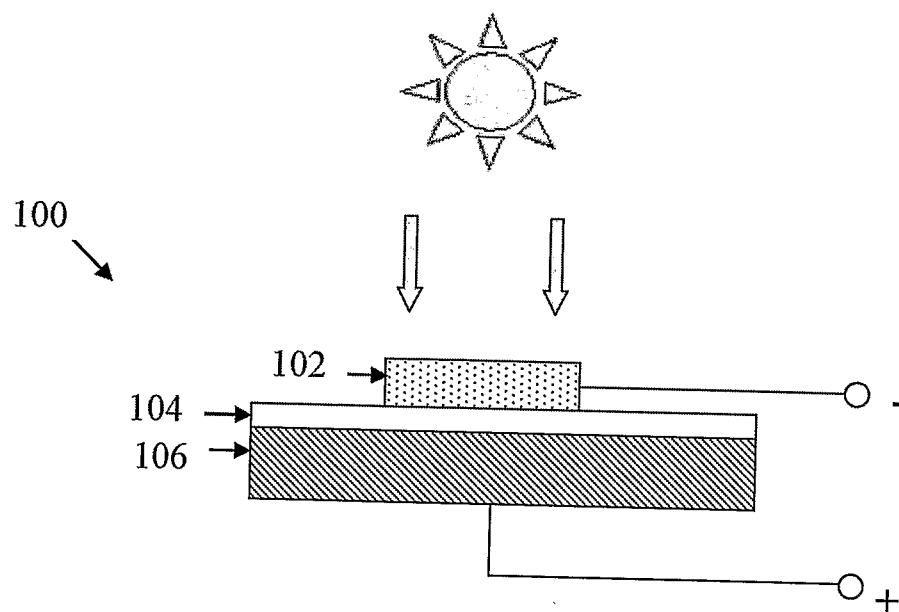


FIG. 1

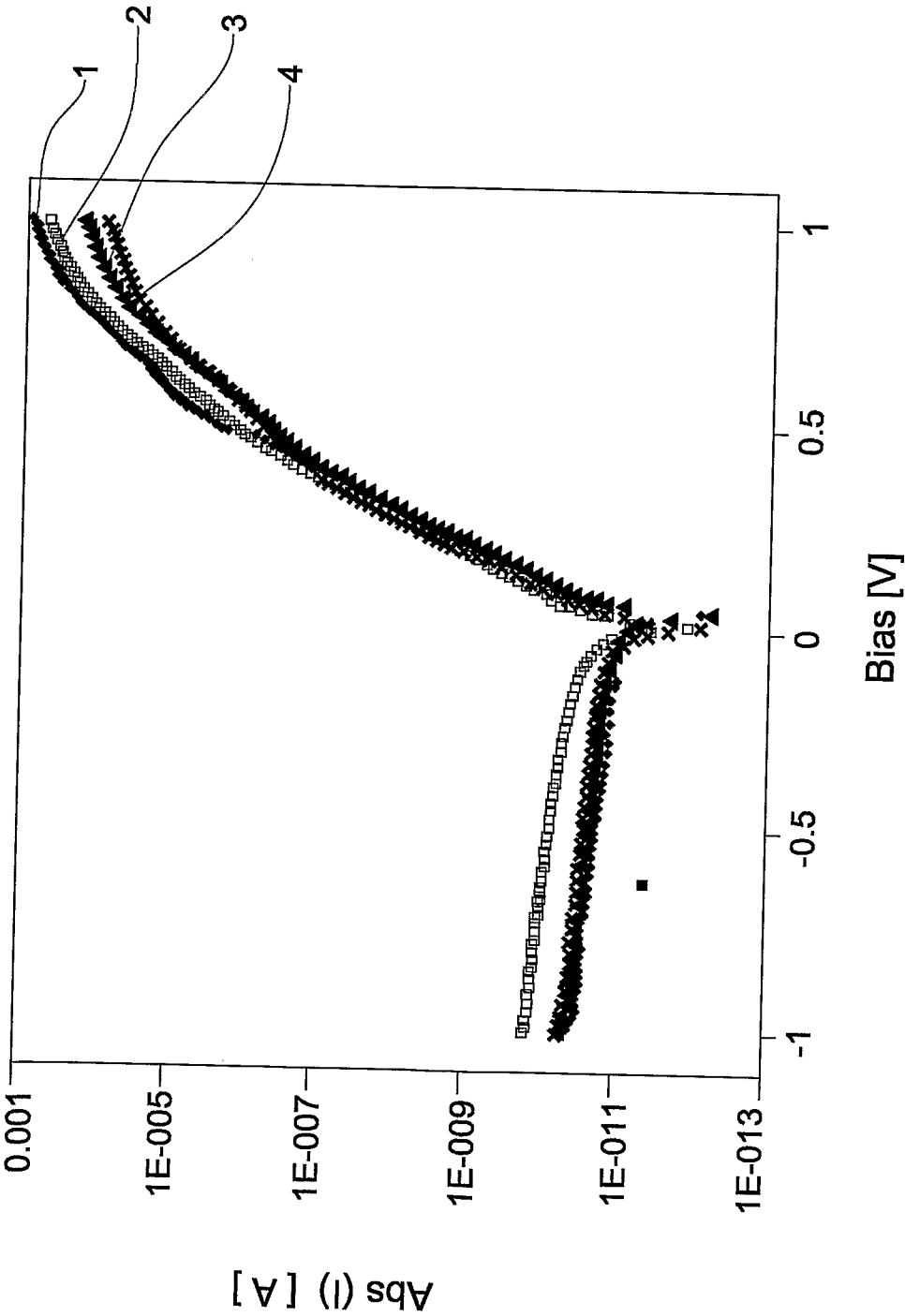


FIG. 2

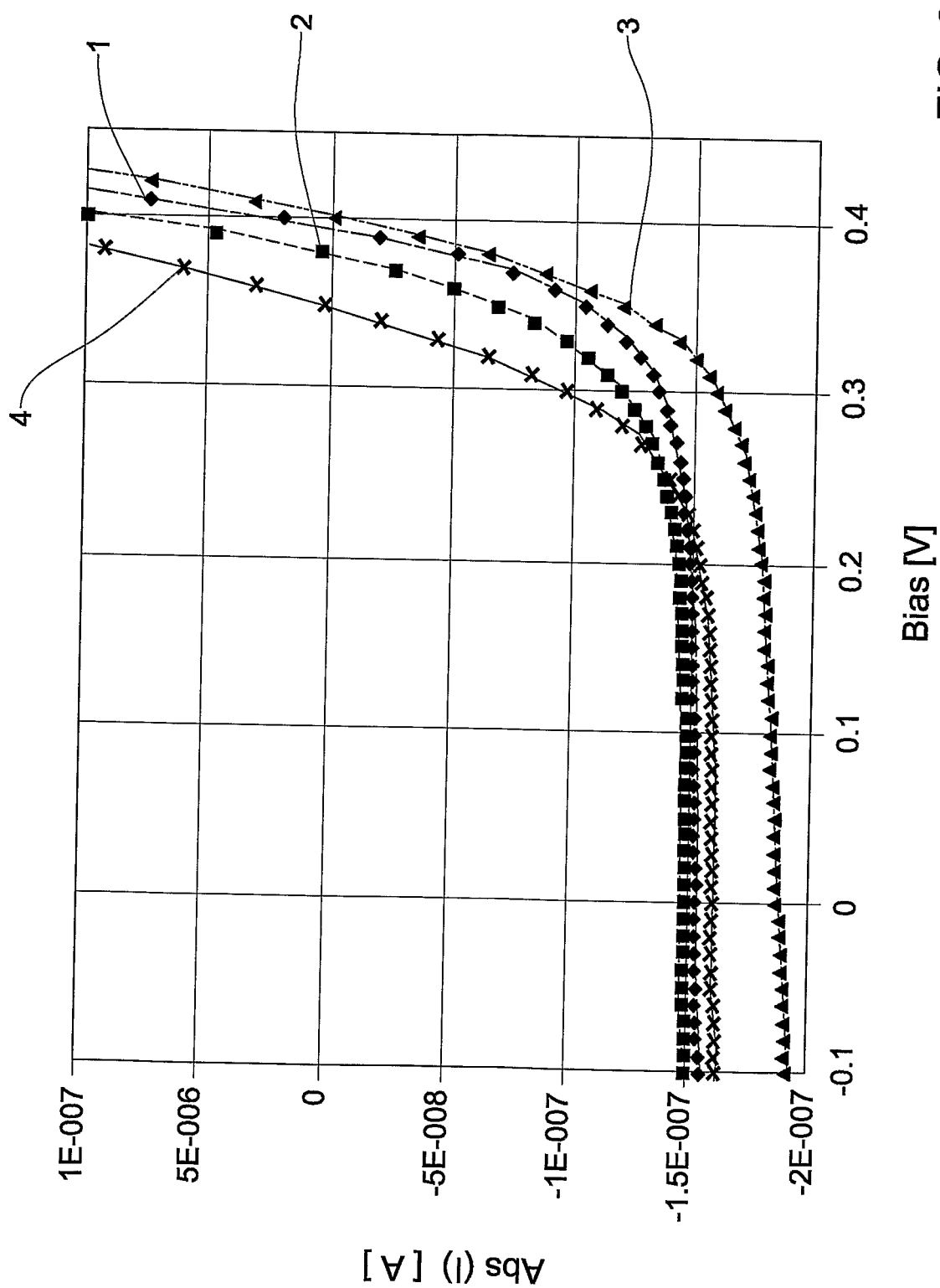


FIG. 3

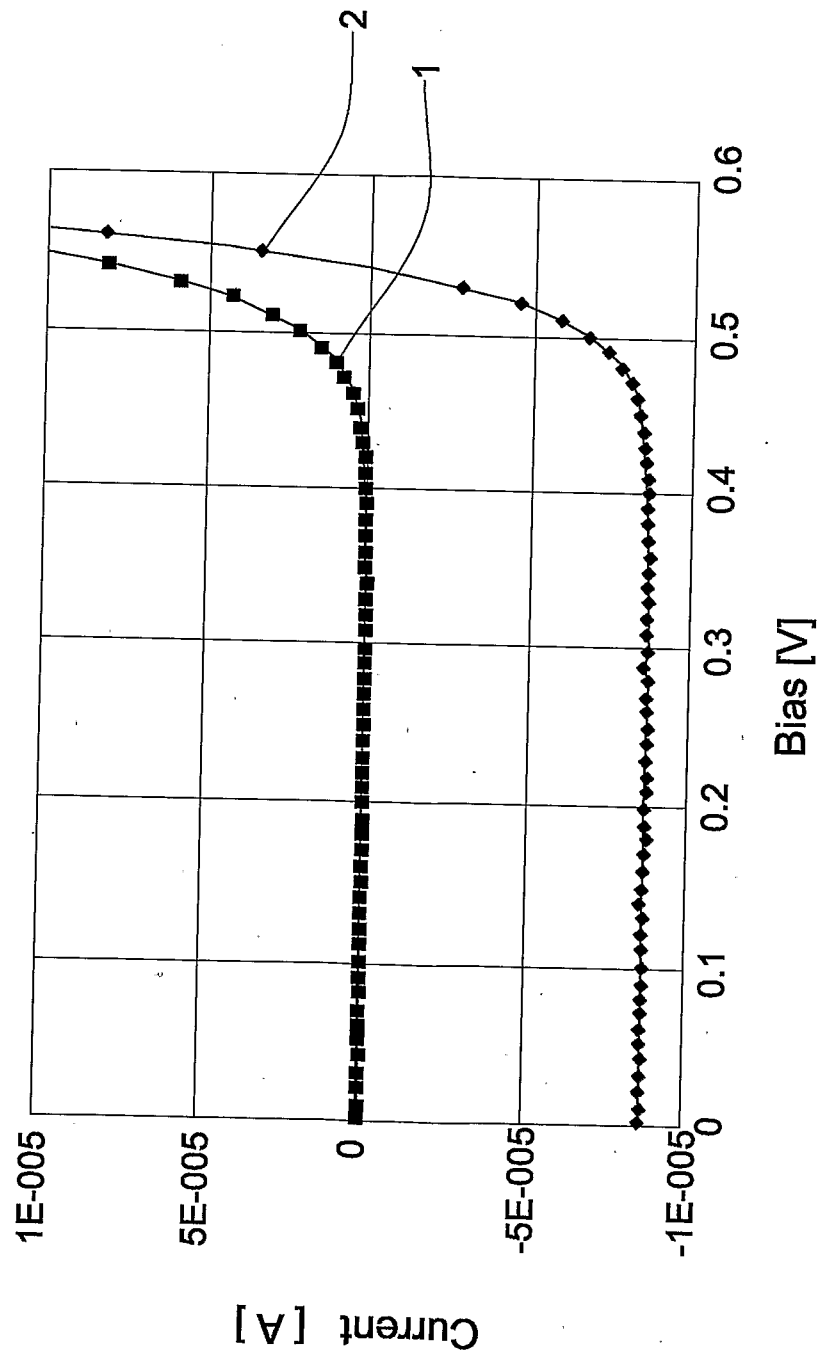


FIG. 4

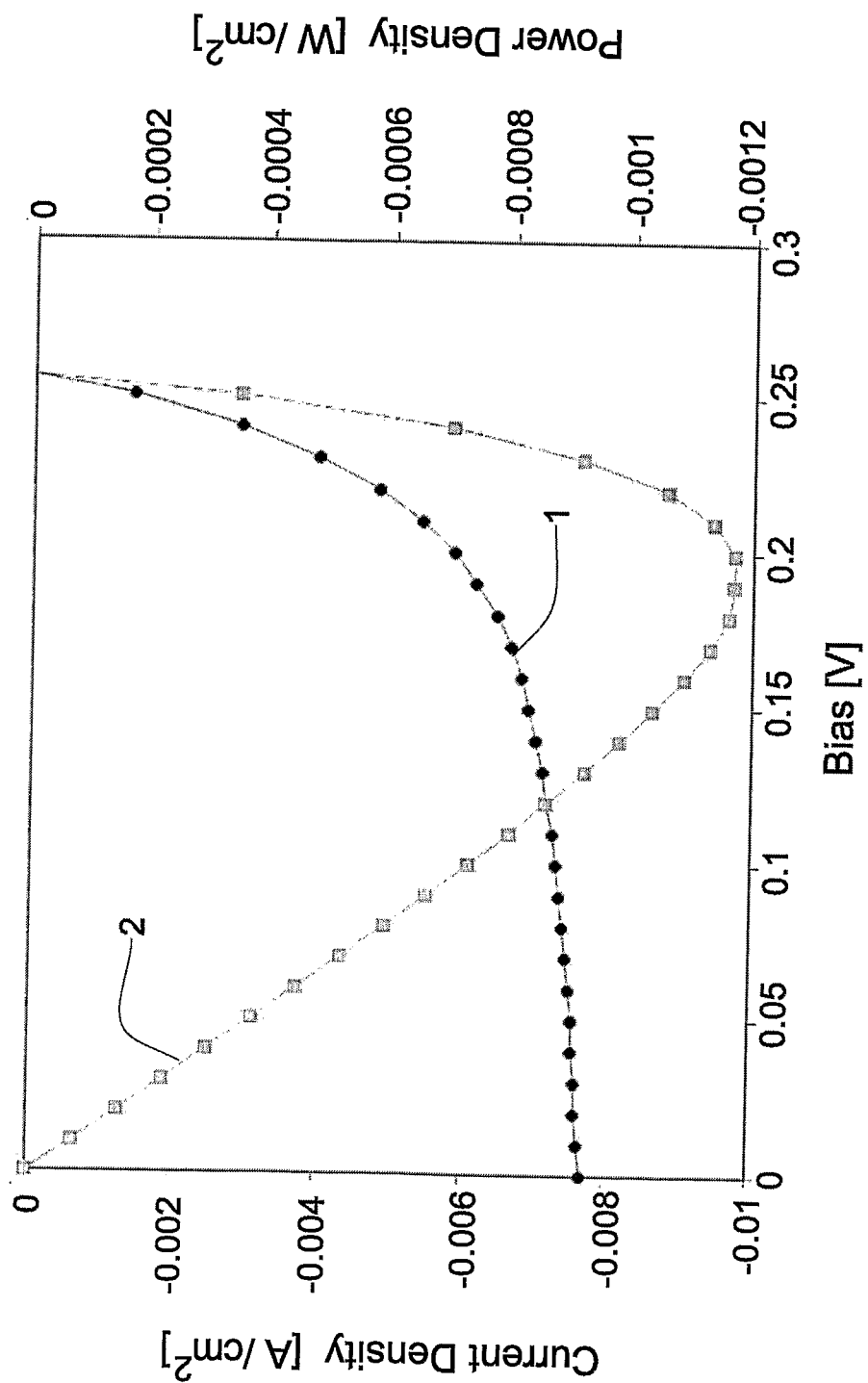


FIG. 5

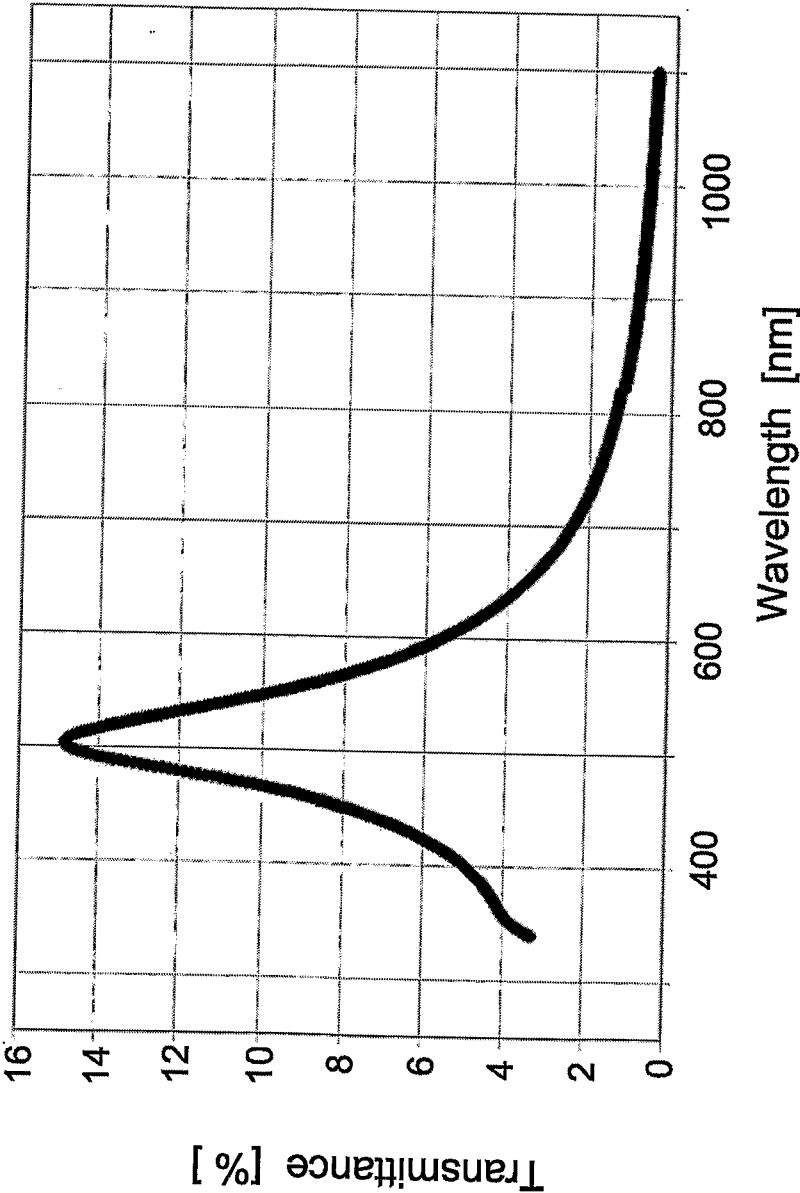


FIG. 6

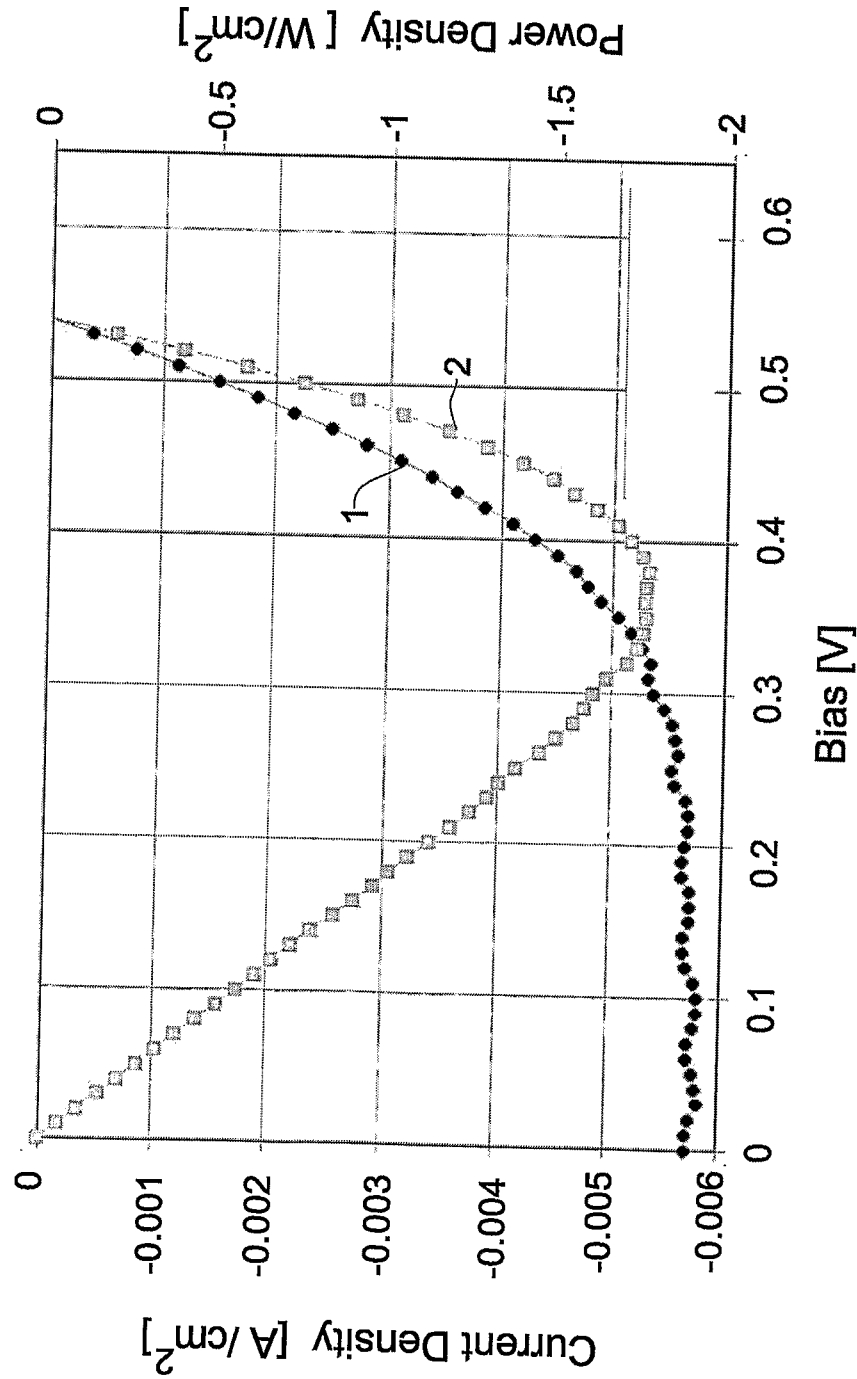


FIG. 7

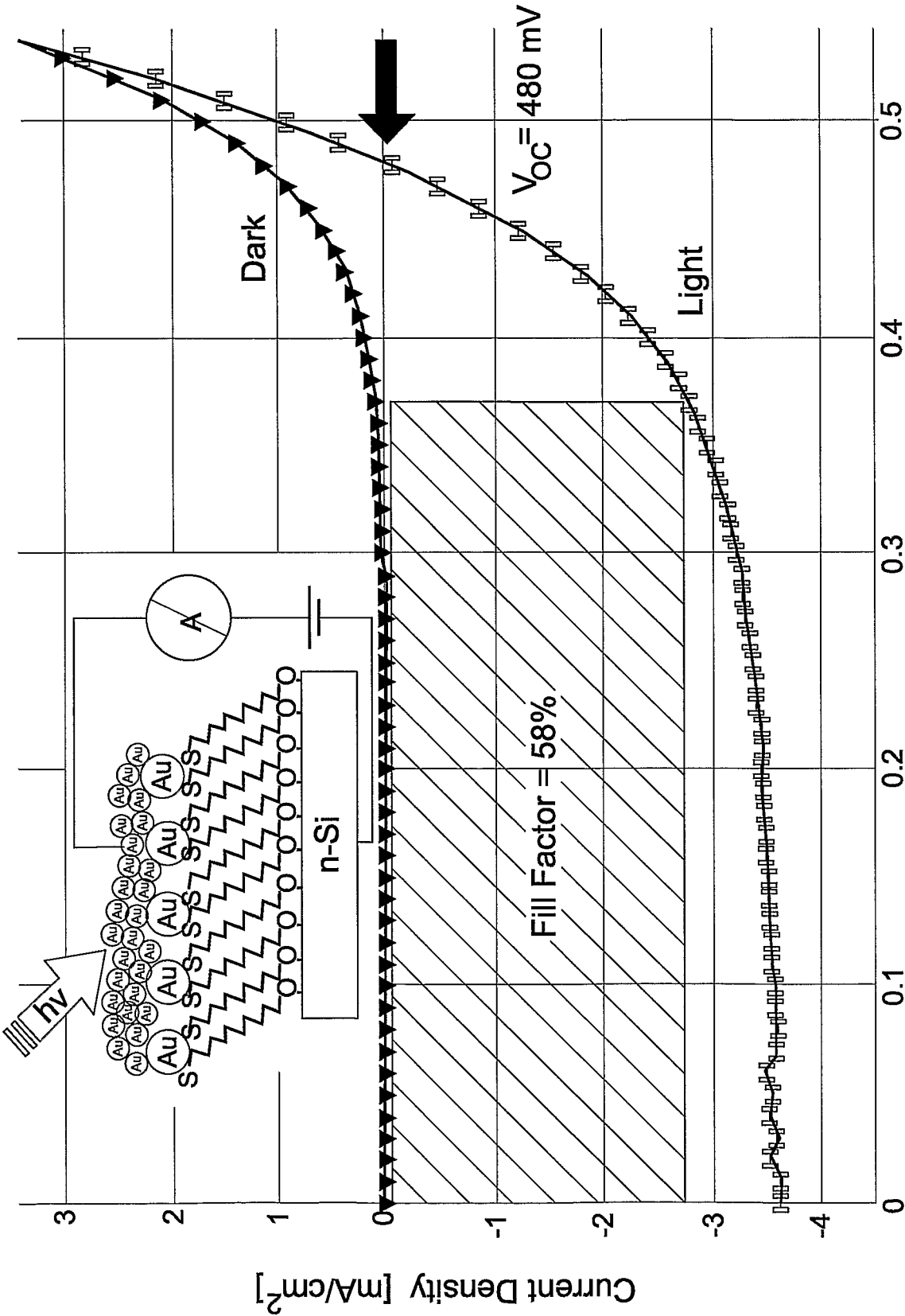


FIG. 8

Bias [V]

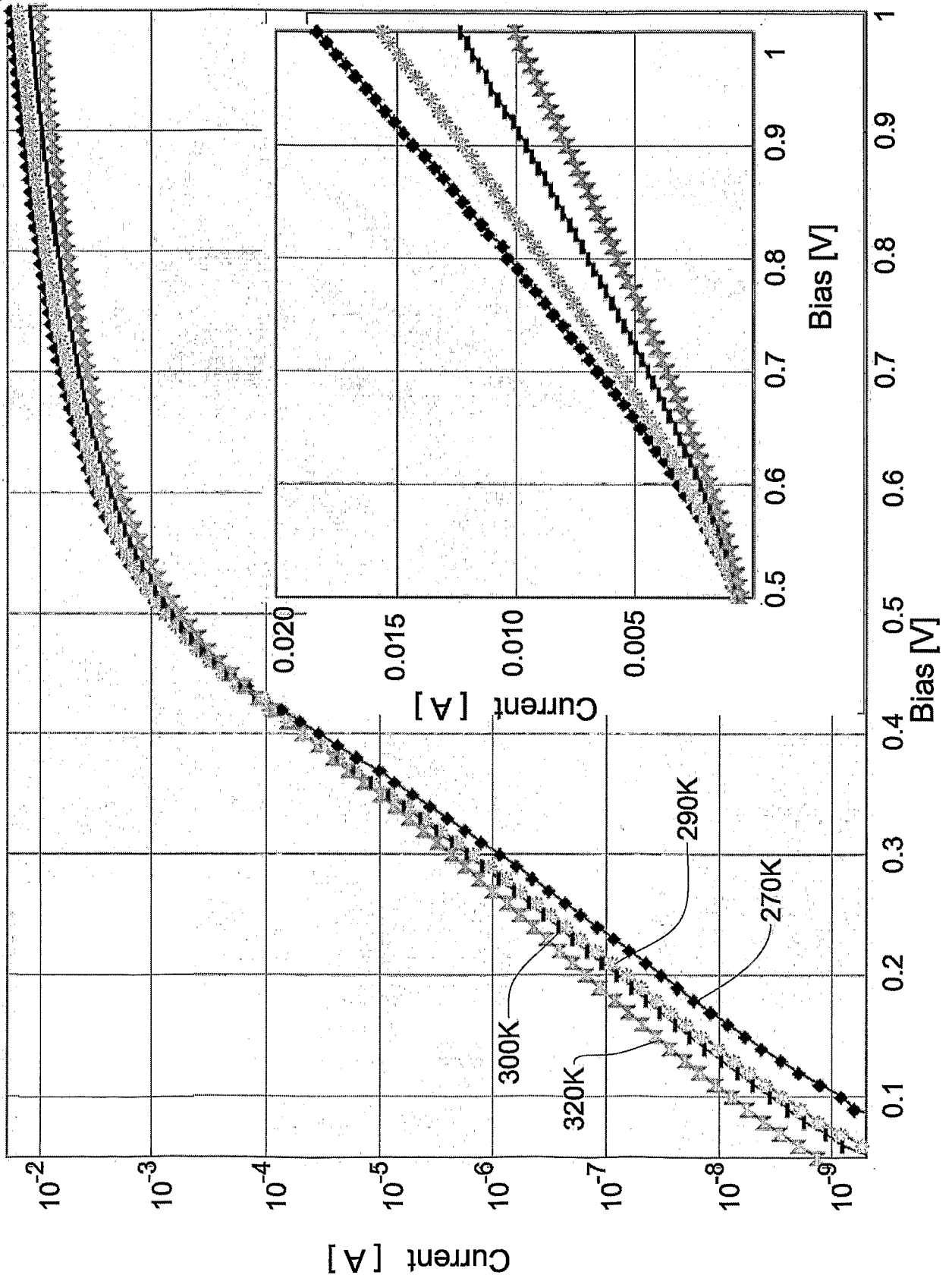


FIG. 9

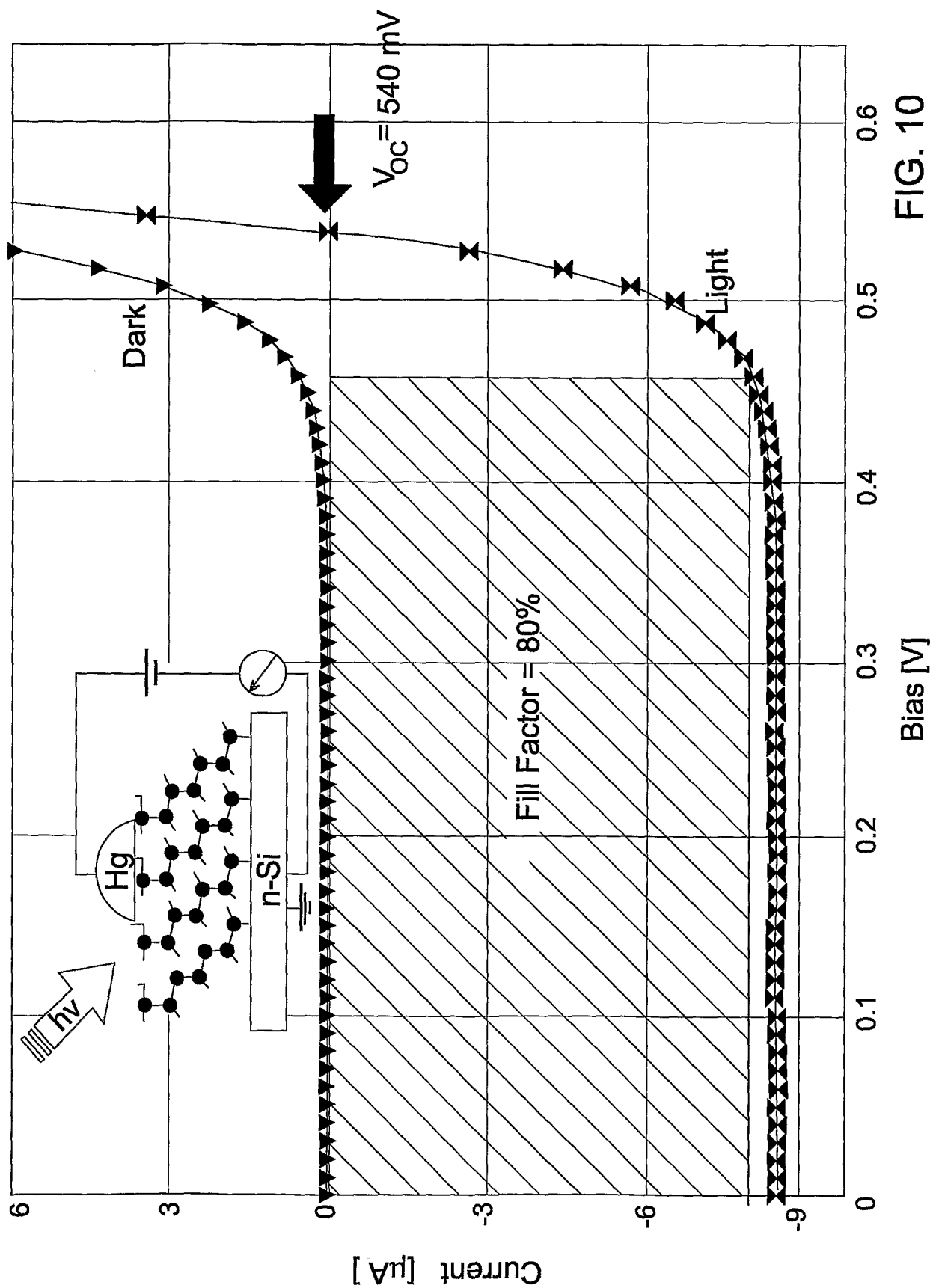


FIG. 10