(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 November 2010 (18.11.2010)

PCT

(10) International Publication Number
WO 2010/131241 A2

(51) International Patent Classification: Not classified

(21) International Application Number:
PCT/IL2010/000351

(22) International Filing Date:
3 May 2010 (03.05.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/177,657 13 May 2009 (13.05.2009) US

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(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, CL, 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, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, 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, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: IMPROVED PHOTO-VOLTAIC CELL STRUCTURE

(57) Abstract: A photovoltaic device is disclosed. The device is configured as a bulk portion sandwiched between two collecting electrodes. The said bulk portion is a compound structure comprising a photo-active component and an electric non-conducting field-inducing component wherein at least a fraction of said photo-active component being in electrical contact with said collecting electrodes such that a continuous electrical conduction path is provided between the collecting electrodes.

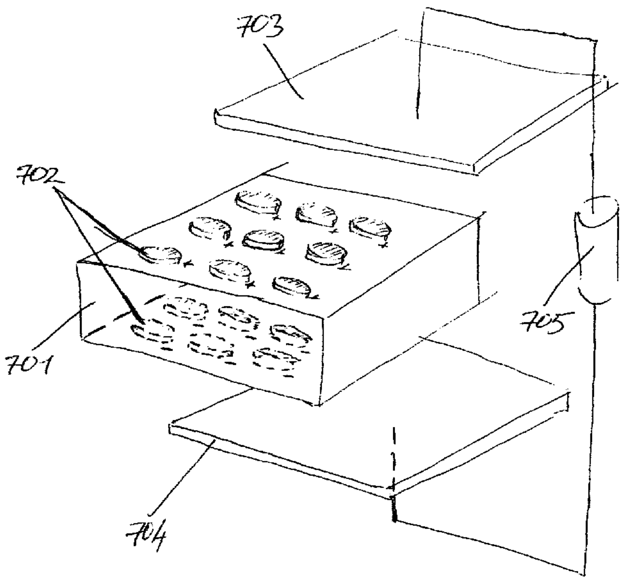


Fig. 7

WO 2010/131241 A2

Improved photo-voltaic cell structure

Field of invention

This invention relates to conversion of electromagnetic radiation into electrical energy. More particularly the invention refers to photovoltaic devices or so-called solar cells with compound internal structure that contains a photoactive component capable to convert light directly into electricity by the photovoltaic effect and non-conducting field-inducing component.

Background of the invention

Traditional semiconductor solar cell contains pn-junction separating photo-generated electron-hole pairs due to built-in field at the junction. More advanced cell contains pin-junction. Due to presence of intrinsic region those devices have a large optical depth in comparison with a pn-junction devices, but their production is much more complicated.

There are known attempts to build crystalline semiconductor solar cells employing so-called “induced junction”. The “junction” is a depleted region in a p-type crystalline silicon induced by corona-charged electret externally applied to the cell body above the collecting electrodes (US Patent 4,435,610). One of the intrinsic disadvantages of the device is the screening of the field produced by the electret due to presence of conducting collecting electrode separating the electret and the region of photogeneration inside the device. The device also possesses all problems that are common for crystalline semiconductor solar cells.

Fabrication of crystalline semiconductor solar cells for power production is a well-established technological field. Recent crystalline solar cells are able to convert above a 40% of solar radiation to power. The only problem inhibiting wide use of those cells in power production is extremely high production price of crystalline materials of high degree of purity.

There is a large variety of solar cells based on amorphous materials such as amorphous silicon (a-Si and c-Si), CIGS (Cu/In/Ga/Se) thin film solar cells and a large variety of heterojunction solar cells such as ZnO/c-Si cell. Principle of operation of these cells is identical to crystalline cells: namely, photogenerated charge carriers separated due to electric field in vicinity of metallurgical junction between two materials.

Development of semiconducting polymers led to a new type of solar cells – bulk-heterojunction solar cells. The active material in this type of cells is a mixture of two semiconducting polymers (or polymer with inorganic material) with different electron affinity. The separation of photogenerated pairs occurs due to the difference of electrochemical potentials between the materials. The transport of free charge carriers is a field-driven transport, where the field is produced by the difference of electrochemical potentials of the contacts. Characteristic value of the field is 10^4-10^5 V/cm. The strength of the field is insufficient for complete separation of initial excitations and for preventing recombination of charge carriers.

Solar cells made of amorphous materials are much cheaper than the cells made of crystalline, but their power conversion efficiency is limited: ~10-13% for inorganic and ~3-5% for polymeric materials. The reason for low efficiency is a presence of morphological disorder, which produces trapping states for charge carriers. Trapping states make the carrier's transport less efficient and facilitate carrier losses during recombination.

The means to overcome the negative effects of amorphous materials would be a presence of strong electric field inside the device. It's known for a long time that the quantum efficiency increases with the increasing of the field from ~0.1 at fields with strength lower than 10^4 V/cm up to 1 at fields with strength of order 10^6 V/cm. Also known is that the mobility increases with the field (power-law dependence). Nevertheless it is not known to use this phenomenon for improving efficiency of solar cells despite there exist some reports on attempts to introduce the built-in electric field in polymeric solar cell devices.

In one case ["Effect of Molecular Orientation on Photovoltaic Efficiency and Carrier Transport in a New Semiconducting Polymer" V. Kazukauskas et. al. *ACTA PHYSICA POLONICA A,* Vol. **113** (No. 3) , pp.1009-1012 (2008)] new functionalized soluble poly(p-phenylene vinylene) derivative bearing polar molecules was used as active layer in photovoltaic cell. The device was poled by dc field of order $\sim 10^5$ V/cm to orient the polar moieties. improves the External quantum efficiency of the device with frozen polarization higher by 1.5-2 times in comparison with the device without the polarization. Unfortunately, the device was not compared with other device based on original (non-functionalized) poly(p-phenylene vinylene): changing of molecular structure may deteriorate the performance of the device. Another disadvantage of using fictionalized polymer is a limitation on the strength of the poling field due to polymer electric breakthrough. Using of polymeric materials limits a lifetime of the solar cell.

Another article ["Nanodipole photovoltaics" Diana Shvydka, V. G. Karpov *Appl. Phys. Lett.* Vol. **92**, 053507 (2008)] suggests mixing of a photoactive polymer (host matrix) with permanent dipole bearing elongated CdS nano-crystals (guest) oriented by poling external dc field. The CdS crystals supposed to create the field of order 3×10^4 V/cm in order to facilitate the separation of photo-generated pairs. Disadvantages of this scheme are: low strength of electric field insufficient for effective separation and prevention of recombination, limitation of poling field and low lifetime due to use of polymeric material.

Also known attempts to use internal electric field existing in ferroelectric materials for photovoltaic devices (such as US Patents 4,160,927) . For the best of our knowledge all the patents exploit well-known anomalous photovoltaic effect explored since 70's. Despite high output voltage photovoltaic devices based on ferroelectrics the output current was extremely low due to high internal resistance of ferroelectric materials.

In all cases were materials with unseparated function of photo-activity and transport from one side and generation of the field from another side. It causes limited efficiencies of the materials.

Aspects of the invention

Purpose of the present invention is to provide the new ways to build better photovoltaic devices based on amorphous photoactive materials. The goal is achieved by creating a built-in high electric field throughout the device. Providing of possible structures and methods to create such structures are objects of the present invention.

The main idea of the invention is a hybrid structure consisting of non-conductive field inducing component and photoactive component sandwiched between couple of collecting electrodes. There are two main distinct features of the proposed device structure: the 1st feature – both components (field inducing and photo-active) are located within the space between the collecting electrodes, the 2nd feature - field inducing and photo-active components are separated and located in certain locations relatively to each other. It should be emphasized that the photoactive component must have an electric contact with both collecting electrode to provide continuous conduction path between the two electrodes.

Due to the possibility of using high electric fields influence such high electric fields produced by the field inducing component, it is expected an increase in quantum and power-conversion efficiency of the photoactive component irrespective of the kind of amorphous material. The presence of a high field in the device also allows use of cheap, widespread, enviromently-friendly and simple in manufacture materials. Another positive aspect associated with the presence of the high electric field throught the device is a possibility to build a device with extremely large optical depth.

Brief description of figures

The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention.

Fig.1 1st embodiment of the device
Fig.2 Manufacturing of the 1st embodiment in bottom-up approach
Fig. 3 Manufacturing of the 1st embodiment in up-bottom approach
Fig. 4 2nd embodiment of the device
Fig. 5 Manufacturing of the 2nd embodiment
Fig. 6a and 6b Variation of 3rd embodiment of the device
Fig.7 4th embodiment of the device
Fig. 8 Manufacturing of the 4th embodiment
Fig. 9 Alternative manufacturing path of the 4th embodiment
Fig. 10 5th embodiment of the device
Fig. 11 Manufacturing the grid of insulated conductors
Fig. 12 Manufacturing of the 5th embodiment

Disclosure of the invention

It should be appreciated that the particular implementations shown and described herein are examples of the invention and are not intended to otherwise limit the scope of the present invention in any way.

Below we will give the determinations of main parts of the device

The field inducing component – is a spatial structure or set of spatial structures that produce the field inside the device due to bearing of sustaining polarization or due to bearing of sustaining spatial distribution of electrical charges or due to both of them. The component may be transparent or opaque. The component should allow direct electric contact between the photoactive material and the collecting electrodes.

In the case of field inducing component bearing sustainig polarization it could be maid of ferroelectric material or any other material capable to preserve polarization for a long time (so called "dipole electret"). Examples of ferroelectric materials are $BaTiO_3$ or polymeric ferroelectrics such as PVDF. An examples of materials suitable for dipole electret preparation can be named poly-carbonate, poly-vinyl-chloride, poly-methil-metacrylate and many others. The polarization may be directed in an arbitrary direction.

In the case of field inducing component bearing sustainig spatial charge distribution it could be maid of any material capable to preserve the distribution for a long time. It could be made of inorganic dielectrics such as SiOx, SiNx, organic dielectrics such as poly-silane resins or of poly(methyl methacrylate) (PMMA). An example of hybrid structure suitable for fabrication of the field inducing component capable to preserve the distribution for a long time is a grid of aconductors covered with insulating material.

Photoactive component – spatial structure or set of spatial structures supporting the processes of photo-generation of free charge carriers and transport of the charge carriers. This component must have a direct electrical contact with both collecting electrodes providing continuous conduction path between the two electrodes. The photoactive component consists of a photoactive material or any combination of such materials.

Non limited list of Photoactive material comprises semiconductors of group IV of periodic table such as Si and Ge or group III-V semiconductors such as GaAs or InP or group II-VI such as CdTe,CdHgTe etc. Photoactive polymers and their mixtures such as P3HT, C60, MEH-PPV and their derivatives may also be used as photoactive material.

Collecting electrodes – two conducting members applied to both sides of the device for collecting the charges produces by photogeneration in the photoactive component and delivering the charges outside of the device to an electric load. Each of two electrodes collect only one type of the charge carriers. The electrode collecting negatively charged carriers called anode, while the electrode collecting positively charged carriers called cathode The electrodes could be maid of any conducting material: metals, semiconductor, conducting polymers such as PEDOT/PSS or conducting oxides such as ZnO or ITO (indium-tin oxide). The electrodes may be transparent or opaque. The electrodes should have a direct electric contact with the photoactive component. The photoactive component must produce continuous conduction path between the two electrodes

During the device operation the electrodes are connected electrically via a load. The current flows through the load and the device when the device is illuminated/ irradiated. The illumination cause photogeneration of charge carriers pairs in the photoactive component. The charge carriers are separated and move to appropirate collecting electrodes under the influence of the electric field produced by the field inducing component and the difference of electrochemical potential between the collecting electrodes. In general the illumination can come through the field-inducing component or through one of collecting electrodes or through both collecting electrodes. Also it's possible that the illumination/irradiation is produced inside the device due to photochemical processes, radiation sources etc. which are located inside the device.

The first possible embodiment is depicted on the Fig. 1 (exploded view). The device consists of field inducing component 101 possessing persistent polarization (the direction of polarization is shown by arrow), set of photoactive components 102, and collecting electrodes 103 and 104. The device is shown in work with electric load 105 connected between the collecting electrodes. The field inducing component have the shape of a slab; a plurality of channels opened from both sides are made in the slab, the channels filled by rod-shaped photoactive component that have direct electric contact with both collecting electrodes producing conductive path between the two electrodes.

There is no limitation on channel cross-section shape. It could be circle, hexagonal, rectangular or any other shape. Channel should penetrate the matrix approximately perpendicular to lateral dimension. The photoactive component may be a homogeneous bulk photoactive material or a homogeneous mixture of such materials. The inner arrangement of photoactive component may possess an arbitrary inner spatial structures such as layered core-cladding cylinders, super-lattices or interpenetrating networks

Approximate spatial dimensions of the device are as follows: thickness of order 0.5 – 5 microns, lateral dimensions are limited by manufacturing considerations only and may vary from millimeters up to several tens of centimetrs. Channel characteristic lateral cross-section dimension is 10-100nm. Lateral inter-channel distance should be of order of channel lateral cross-section dimension. There is no limitation on channel cross-section shape. It could be circle, hexagonal, rectangular or any other shape. Channel should penetrate the matrix approximately perpendicular to lateral dimension.

Inverted spatial structure is also possible. It means that the material of field inducing component fill the channels, while the photoactive material form the "walls" of the channel. In this case lateral spatial dimensions of the channels is expected to be a little larger, than prescribed above.

Bottom-up exemplary fabrication path is depicted in Fig.2. In bottom-up approach the fabrication starts from nanorods of inorganic photoactive material (Fig 2,a). As used herein, the term "nanorod" generally refers to any elongated particle conductive or semiconductive material (or other material described herein) having an aspect ratio (length:width) 100-10. The length of the nanorods defines the device thickness and should be of order 0.5 – 5 micron as prescribed above. The lateral dimensions should be of order 10-100 nm. The nanorods could be obtained by any known in the art method such as template-assisted deposition, free solution synthesis or grown on subtsrate by liquid or chemical vapor deposition. As already mentioned the nanorods can be maid of homogeneous bulk materials or to have arbitrary inner spatial structures such as layered core-cladding cylinders, super-lattices or interpenetrating networks

- The nanorods 201 embedded in melted sacrificial dielectric polymer 202 such as PMMA or PVAl. The polymer with the nanorods is deposited and spreaded on a sacrificial substrate 203 as flat layer by doctor-blade or spin-coating (Fig 2,a).
- The substrate with melted polymer-nanorod layer on it is inserted between the auxiliary electrodes 204 and 205. It may be a gap or buffer layer between the auxiliary electrodes and the polymer-nanorod layer. The nanorods are vertically aligned by externally applied high electrical field between the auxiliary

electrodes. The field is produced by high-voltage source 206 connected to the electrodes. Characteristic local field inside the sacrificial polymer layer should be of order $10^6 - 10^7$ V/cm After the sacrificial polymer cooled down for solidification the field is turned off. Finally we get solid sacrificial polymer matrix with aligned nanorod inside it (Fig 2,b).

- The uppermost layer of the sucrificial polymer 202 is dissolved up to partial exposure of the nanorods 201 (Fig 2,c).
- The first collecting electrode 207 is deposited on the exposed part of nanorods. The contact may be maid of metals (Pt, Au, Al etc.), conducting oxides such as ITO or ZnO. The electrode may be created by evaporation, by sputtering, by electroplating, by electroless deposition, by melting nanopowdered materials, by sol-gel deposition or by any other deposition method providing good electrical contact between the connecting electrode and the nano-rods. (Fig 2,d).
- After the first collecting electrode deposition the remaining part of sacrificial polymer layer can be dissolved, burned or removed by any other appropriate method leaving free-standing comb-like structure 208 of nanorods partly embedded in the first collecting electrode (Fig 2,e).
- The comb-like structure formed by aligned nanorods partly embedded in the first collecting electrode is filled by material of field-inducing component 209 by any appropriate method. For example, $BaTiO_3$ can be deposited by sol-gel method with subsequent annealing, while PVDF or polycarbonate or other polymer materials may be deposited by spin-coating from solution and dried. It should be emphasized, that after the deposition the tips of the nanorods must remain free of the deposited material and to be able to produce an electric contact with the second collecting electrode. After the deposition the material of field-inducing component is poled in high electric field in the manner described above (Fig 2,f).
- Manufacturing of the whole device 211 is accomplished by deposition of the second collecting electrode 210. The second collecting electrode should be deposited by any method listed for the first electrode (Fig 2,g).

Up-bottom approach exemplary fabrication path is depicted in Fig.3. In up-bottom approach the fabrication starts from field-inducing component made of inorganic material

- Sacrificial commercially-availiable polymer track-etched polymer membrane 301 used as a template for deposition.The channels of the membrane can be filled with inorganic ferroelectric material 302 such, for example, as $BaTiO_3$ by sol-gel deposition (Fig 3, a)
- After subsequent annealing and the template membrane burning-out we get freestanding field inducing component spatial structure 303. In this case we get "inverted spatial structure". (Fig 3 b).
- The field inducing component have to be poled in external electric field as described above and its channels should be filled with photoactive material 304 by any method appropriate for the chosen material: electrodeposition, sol-gel, dipping etc. (Fig.3, c).
- After the channels are filled, the collecting electrodes 305 and 306 are deposited by any appropriate method described above (Fig.3, d).

For technological reasons deposition of one of the electrodes can be effected before the deposition of photoactive material

The second possible embodiment is depicted on the Figure 4 (exploded view). As before the device consists of field inducing component 401 made of material ,which is capable to bear persistent polarization (the direction of polarization shown by arrow) and penetrated by channels open from both sides filled with photoactive material 402 filling the channels named above, collecting contacts 403 and 404. The device is shown with electric load 405 connected between the collecting electrodes. Spatial dimensions of the device, materials etc. are identical to those descibed in the first embodiment. In the contrary to the first embodiment the channels are not perpendicular to device's lateral dimension, but chaotically penetrate the field inducing component, producing net-like structure of photoactive component connecting both sides of the device.

The manufacturing of the device in accordance with the second embodiment we start from the manufacturing of photoactive component in the form of porous spatial structure of inorganic photoactive material with chaotically oriented channels and voids.

- Such structure can be manufactured using sacrificial porous polymeric membrane 501 commercially available or produced by any known method. The photoactive inorganic material 502 can be deposited into the pores of the sacrificial membrane by electrochemical, chemical or sol-gel method (Fig 5,a)
- The material of sacrificial membrane should now be dissolved, burned out, etched by acid or removed by any other appropriated method remaining free-standing chaotic porous structure 503 maid of photoactive material 502. (Fig 5,b).
- Porous spatial structure spatial structure made of the photoactive material is filled with the material of field inducing component 504.(Fig 5,c). For example, $BaTiO_3$ can be deposited by sol-gel method with subsequent annealing, while PVDF or polycarbonate or other polymer materials may be deposited by spin-coating from solution and dried. It should be emphasized that the field inducing component material deposition must preserve the possibility of direct electrical contact between the photoactive component and the collecting electrodes. In order to expose covered tips of photoactive component special steps should be taken such as dissolition or plasma etching of outmost layer of the field inducing component material.
- The material of field inducing member should be poled in external electric field produced between two auxiliary electrodes 505 and 506 by high-voltage source 507 as shown (Fig 5,d). The applied voltage should provide local field with strength of order 10^6-10^7 V/cm.
- Device fabrication is accomplished by deposition of collecting electrodes 508 and 509 as described above (Fig 5,e)
- The fabrication path described above is applicable with slight changes for fabrication of "inverted structure" device: instead of starting with deposition of photoactive material into the sacrificial membrane it can start with the deposition

of field inducing component material and subsequent filling of the produced structure with photoactive material.

The third embodiment is depicted on the Fig. 6a and Fig. 6b. The third embodiment is actually a modification applicable to the first and to the second embodiments. As before the device includes porous matrix 601 with channels filled with photoactive material 602 and the contacts 603 and 604. The device is shown in work electric load 605 connected between the collecting electrodes In the previously described embodiments the field was produced by persistent polarization of dipole moieties of field inducing component. On the contrary in the third embodiment the field is produced by "frozen" charge spatial distribution 606 produced just beneath the surface of charge-retaining material. We will not describe the manufacturing of the device deliberately but will rather emphasize the differences with the first and the second embodiments.

The field inducing component material in the present embodiment should be able to absorb and to keep injected charges for a long time (instead of persistent polarization in the previous embodiment). The technology of production of "frozen" space charge distribution is known for a long time and used to manufacture the membranes for so called electrets microphones. Organic materials that are suitable for field inducing component are, for example, polycarbonate or PMMA. As examples of suitable inorganic materials we can name SiO_2 and SiN. The injection of the charges into the materials of field inducing component is performed by well-known corona charging process.

As example of possible manufacturing path we can choose modification of up-bottom approach of the second embodiment. Instead of poling the material of field inducing (Fig. 5, d) we perform two-sided corona-charging process charging opposite sides of the membrane with charges of opposite sign, remaining the rest of steps as before.

The fourth possible embodiment is depicted on the Fig. 7. The photoactive component is slab of photoactive material 701, the field-inducing component 702 consists of insulating grids or isles of insulating material or thin porous insulating layers bearing "frozen" charges of opposite signs, and collecting electrodes 703 and 704. An external electrical load 705 is connected to the collecting electrodes. It must be an electric connection between the collection electrodes and the photoactive component through the voids in the field-inducing component (charge bearing layers named above). Spatial dimensions are as follows: photoactive material slab thickness 0.5 – 5 micron, thickness of the field-inducing component 100-150 nm, characteristic pore size – 100nm, characteristic distance between the pores – 100-150 nm. Possible manufacturing path is depicted on the Fig. 8.

- In the case of inorganic photoactive material the manufacturing starts from free-standing layer of the photoactive material 801 (Fig. 8, a). The layer may be produced by variety of methods. For example, Si layer may be manufactured by electrochemical deposition on sacrificial substrate ["Electrochemical reduction of silicon chloride in a non-aqueous solvent" Y. Nishimura, Y. Fukunaka, *Electrochimica Acta,* Vol. **53**, pp.111–116(2007)]
- The second step is to produce field-inducing component 802 as described above (Fig. 8, b). The layer may be manufactured by evanescent wave nano-lithography or block-copolymer lithography with subsequent deposition of the field inducing component material into the determined structure or by using the defined structure as is. Another method that may be usefull for Si and is a nano-anodization producing isles of SiO2 on the Si slab ["Nanoelectrode lithography", A. Yokoo and H. Namatsu, *NTT Technical Review*]
- After that the layer is charged by corona-charging process (Fig. 8, c). Opposite sides of the slab should be charged with charges of opposite signs, i.e. the coronas should be produced by high-voltage sources of opposite signs 803 and 804
- The collecting electrodes 805 and 806 can be applied by any appropriate method providing electrical connection between the collecting electrodes and the photoactive component material (Fig. 8, d).

- Another possible manufacturing path applicable mostly in the case of polymeric photoactive material or any other photoactive material implying solution or melted phase deposition starts from the collecting electrodes 901 and 902 (Fig. 9, a).

- The second step is to produce the field inducing component 903 on both future collecting electrodes (Fig. 9, b). The layer may be manufactured by evanescent wave nano-lithography or block-copolymer lithography with subsequent deposition of the field inducing component material into the determined structure or by using the defined structure as is.
- After that the layer is charged by corona-charging process (Fig. 9, c). Field inducing component on the oppositing electrodes should be charged with the charges of opposite signs, i.e. the coronas should be produced by high-voltage sources of opposite signs 904 and 905
- The photoactive material layer 906 should be deposited above one of the contacts by simple spin-coating (Fig. 9, d)
- with consequent application of the second contact (Fig. 9, e) on the photoactive material layer.

The fifth possible embodiment is depicted on the Fig. 10 (exploded view). The device's photoactive component consists of the slab of photoactive material 1001, the device's field inducing component consists of two grids of insulated conductors 1002 and 1003 from both sides of the slab 1001, two collecting electrodes 1004 and 1005 connected electrically to the slab of photoactive material through the voids in the grids 1002 and 1003. Any points on the conductor in the grid connected electrically to any other point on the conductor of the same grid (fully connected graph). The grids have electrical exits 1006 and 1007 insulated from the collecting contacts and photoactive material for connection to high voltage sources outside the device. The device is shown with electric load 1008 connected between the collecting electrodes Spatial dimensions and materials are identical to those used in the embodiment four.

In order to make the device ready for operation the conducting insulated grids 1002 and 1003 should be connected to opposite poles of external high voltage source by means of electrical exits 1006 and 1007. After the grids are charged with charges of opposite signs the high-voltage source is disconnected from the grids. Charges on the grids produce the electric field in the photoactive component (the photoactive slab)

The key technological objective of the present embodiment is the production of the grids of insulated conductors. Requirements to be met: spatial dimension and connectivity. The dimensions must be as follows: thickness of order 10-100 nm, voids characteristic diameter – 10-100 nm, inter-void distance is of order of the voids diameter.
For devices with external irradiation it's preferable to have transparent field-inducing component. As possible fabrication path for transparent conducting mesh we can use electrochemical deposition of transparent conducting oxide ZnO inside opal structure produced by polystyrene spheres (Hongwei Yan , Yingling Yang , Zhengping Fu , Beifang Yang , Linsheng Xia ,Shengquan Fu , Fanqing Li "Fabrication of 2D and 3D ordered porous ZnO films using 3D opal templates by electrodeposition" Electrochemistry Communications 7, pp. 1117–1121, (2005)).

Here we describe alternative possible fabrication path (method) using detachable (separable) forms for electrochemical deposition. The method is the part of the invention. The method is depicted on the Fig. 11.

- Polymeric or inorganic slab patterned with pits and channels 1101 (Fig. 11, a) is covered by
- another slab 1102 with smooth surface and pressed against. Prior to application an additional sacrificial or detaching-promoting layer 1103 may cover the slab's surfaces (Fig. 11, b).
- The conductor 1104 (metal, conducting oxide, doped semiconductor) is deposited in the voids of the structure produced by two contacting slabs (patterned and un-patterned) (Fig. 11, c) by any appropriate method. For example, the metal can be deposited by electrolysis.
- After the conductor deposition the slabs are detached or dissolved remaining the conductor's grid as freestanding structure 1105 (Fig. 11, d).

The freestanding conductor's grid will be covered by insulator. For example, insulating perylene layer can be deposited by chemical vapor deposition. . Also insulation of conducting mesh may be accomplished by electroless liquid phase deposition of SiOx from solution of H_2SiF_6 by addition of H_2O. This method provides thin films with breakdown field up to ~8 MV/cm (Ching-Fa Yeh, Shyue-Shyh Lin and Ching-Lin Fan "Thinner Liquid Phase Deposited Oxide for Polysilicon Thin-Film Transistors" IEEE Electron Devices Letters, 16(11) pp.473- 475 (1995)).

In order to make the process continuous the forming slabs may be posed on two opposed rotating cylinders pressed to each other.

The manufacturing path of the device described on the Fig. 10 may be as follows (Fig. 12):

- The manufacturing starts from one of the collecting electrodes 1201 covered by the grid of insulated conductors 1202 described above. (Fig. 12, a). For better adhesion of the grid special measures such as substrate heating may be taken
- The photoactive component deposited on the collecting electrode covered by the grid in form of slab of the photoactive material by any appropriate method (Fig. 12, b). For example, polymer photoactive material may be deposited by spin-coating from solution, while inorganic material such as Si may be deposited by electrochemical method as described above.
- The second grid 1204 is deposited on the surface of the photoactive component (Fig. 12, c)
- Manufacturing of the whole device is accomplished with the deposition of the second collecting electrode 1205 by any appropriate previously mentioned method for contact deposition.

Claims

1. A photovoltaic device configured as a sandwiched structure comprising a bulk portion concluded between collecting electrodes, said bulk portion comprises a photo-active component and an electric field-inducing component wherein at least a fraction of said photo-active component being in electrical contact with said collecting electrodes such that a continuous electrical conduction path is provided between the collecting electrodes.
2. The photovoltaic device of claim 1, in which said electric field-inducing component comprises a material capable to retain spatial charge distribution
3. The photovoltaic device of claim 8, in which said inorganic dielectric materials are selected from the group of materials having formula SiO_x, SiN_x, and their combinations
4. The photovoltaic device of claim 2 or 8, in which said photoactive component comprises a semi conductive material.
5. The photovoltaic device of claim 10, in which said collecting electrodes are made of at least partially electrically conductive material selected from the group consisting of metals, semiconductors, conductive polymers, conductive oxides and their combinations.
6. The photovoltaic device of claim 11, in which said bulk portion is configured as a slab consisting of the electric field-inducing component and there are voids within the slab in which said photoactive component reside.
7. The photovoltaic device of claim 12, in which said voids are configured as rectilinear channels, which are directed parallel to each other.
8. The photovoltaic device of claim 12, in which said voids are configured as non-rectilinear channels, which are chaotically distributed within the bulk portion.
9. The photovoltaic device of claim 11, in which said bulk portion is configured as a slab consisting of the photoactive component and said electric field-inducing component is accommodated within a plurality of discrete locations provided on those surfaces of said slab, which are adjacent with the collecting electrodes.

10. The photovoltaic device of claim 11, in which said field-inducing component as at least one electrically conductive grid having plurality of openings, said grid being located between the slab and at least one of the collecting electrodes, while the grid is electrically insulated from the adjacent collecting electrode.
11. A method of producing a photovoltaic device, which is configured as a sandwiched structure comprising a bulk portion concluded between collecting electrodes, said bulk portion comprises a photo-active component and an electric field-inducing component, said method comprising the following steps:
    a) providing of field-inducing component configured as a flat layer defined by a first and by a second surface
    b) delimiting of plurality of discrete locations on the first and the second surface
    c) deploying of the field-inducing component in the discrete locations delimited on the first and the second surface
    d) applying an external electrical field to render spatial charge distribution of the filed-inducing component by corona-charging process
    e) arranging collecting electrodes on the first and the second surface.

12. A method of producing a photovoltaic device, which is configured as a sandwiched structure comprising a bulk portion concluded between collecting electrodes, said bulk portion comprises a photo-active component and an electric field-inducing component, said method comprising the following steps:
    a) providing a first and a second collecting electrode
    b) delimiting plurality of discrete locations on a surface of the first and the second collecting electrode
    c) deploying of the field-inducing component in the discrete locations delimited on the surface of the first and the second collecting electrode
    d) applying an external electrical field to render spatial charge distribution of the filed-inducing component by corona-charging process
    e) depositing of the photo-active component on the surface of the first and the second collecting electrode

f) coupling the first electrode with the second electrode such that the surface of the first electrode with deployed thereon field-inducing component and deposited photo-active component and the surface of the second electrode with deployed thereon field-inducing component and deposited photo-active component would constitute the bulk portion of the photovoltaic device.

13. A method of producing a photovoltaic device, which is configured as a sandwiched structure comprising a bulk portion concluded between collecting electrodes, said bulk portion comprises a photo-active component and an electric field-inducing component, said method comprising the following steps:
    a) providing a first collecting electrode
    b) depositing the first grid of insulated conductors on the surface of the first collecting electrode
    c) depositing of the photo-active component on the surface of the first collecting electrode covered by the grid of insulated conductors
    d) depositing the second grid of insulated conductors on the surface of the photoactive component
    e) depositing the second collecting electrode on the surface of the photoactive component covered by the grid of insulated conductors

14. A method of producing of grid of insulated conductors, said method comprising the following steps:
    a) providing a first polymer slab patterned with the surface patterned with channels determining the form of the grid
    b) covering the patterned surface of the first polymer slab by the second slab with smooth surface
    c) the grid of conductors is produced by depositing of the conducting material in the voids created between the first and the second polymer slabs
    d) depositing of insulator material on the grid of conductors.

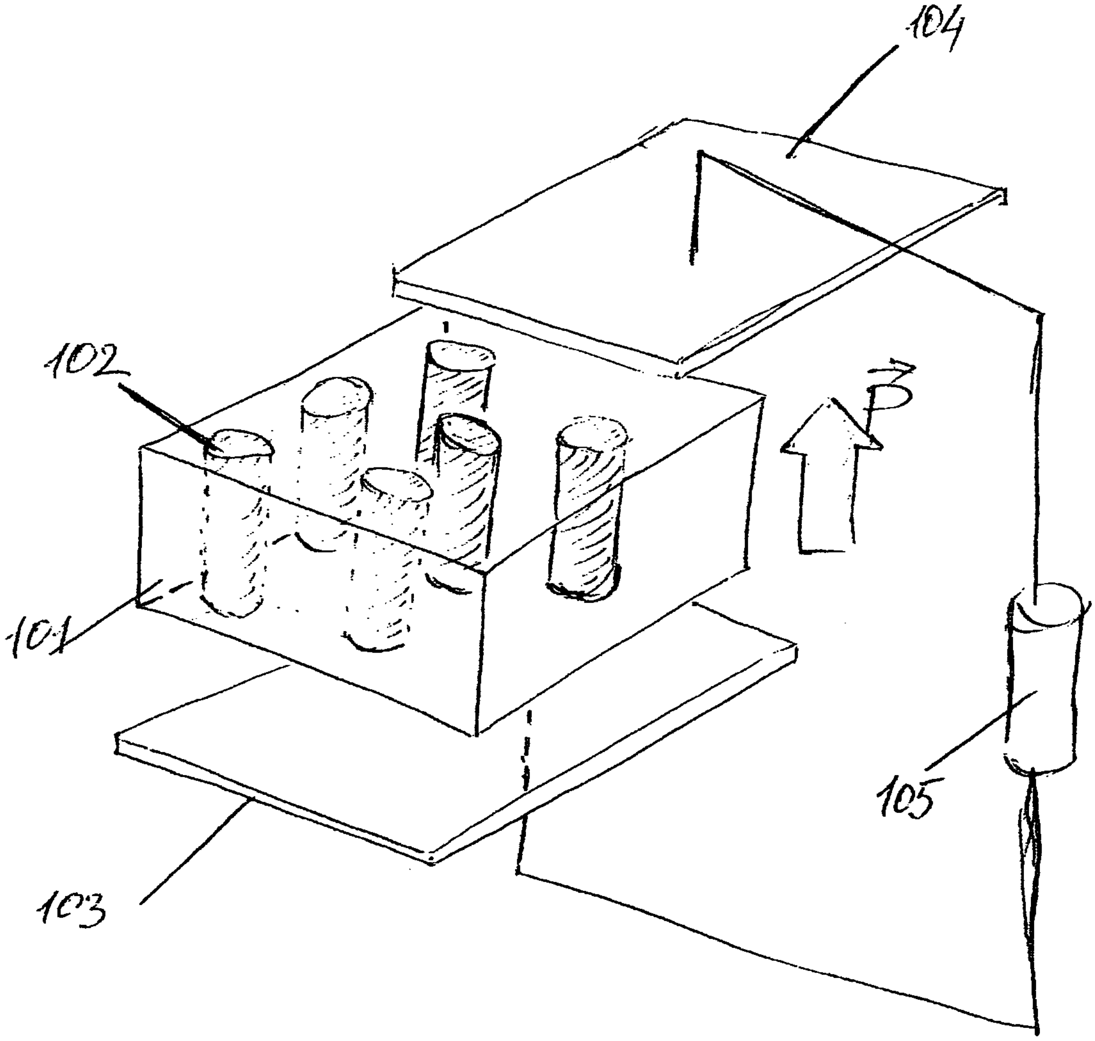


Fig. 1

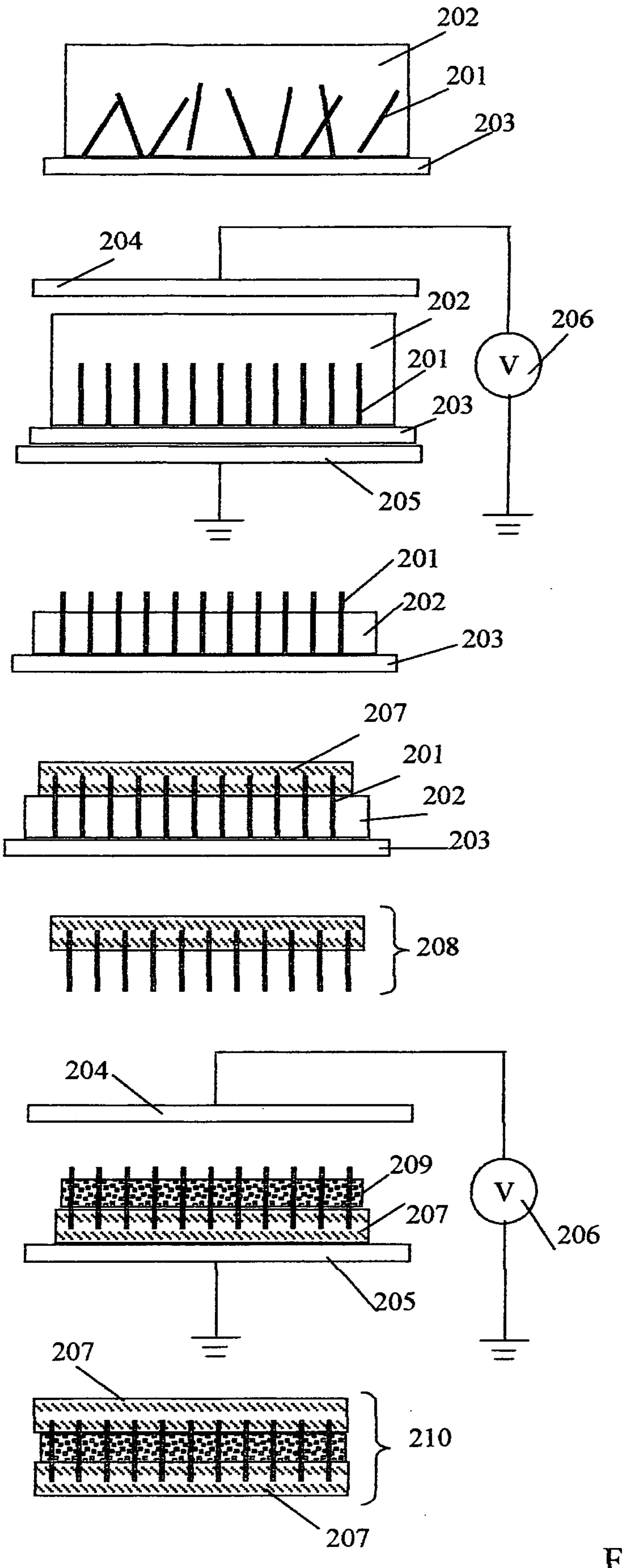


Fig 2,a

Fig 2,b

Fig 2,c

Fig 2,d

Fig 2,e

Fig 2,f

Fig 2,g

Fig. 2

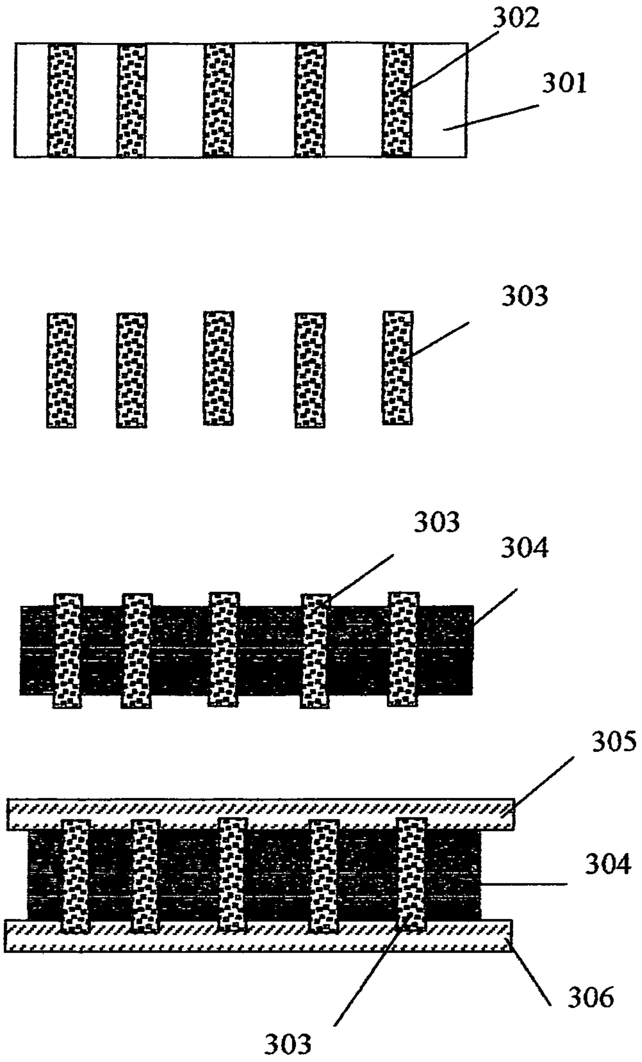


Fig 3, a

Fig 3, b

Fig 3, c

Fig 3, d

Fig. 3

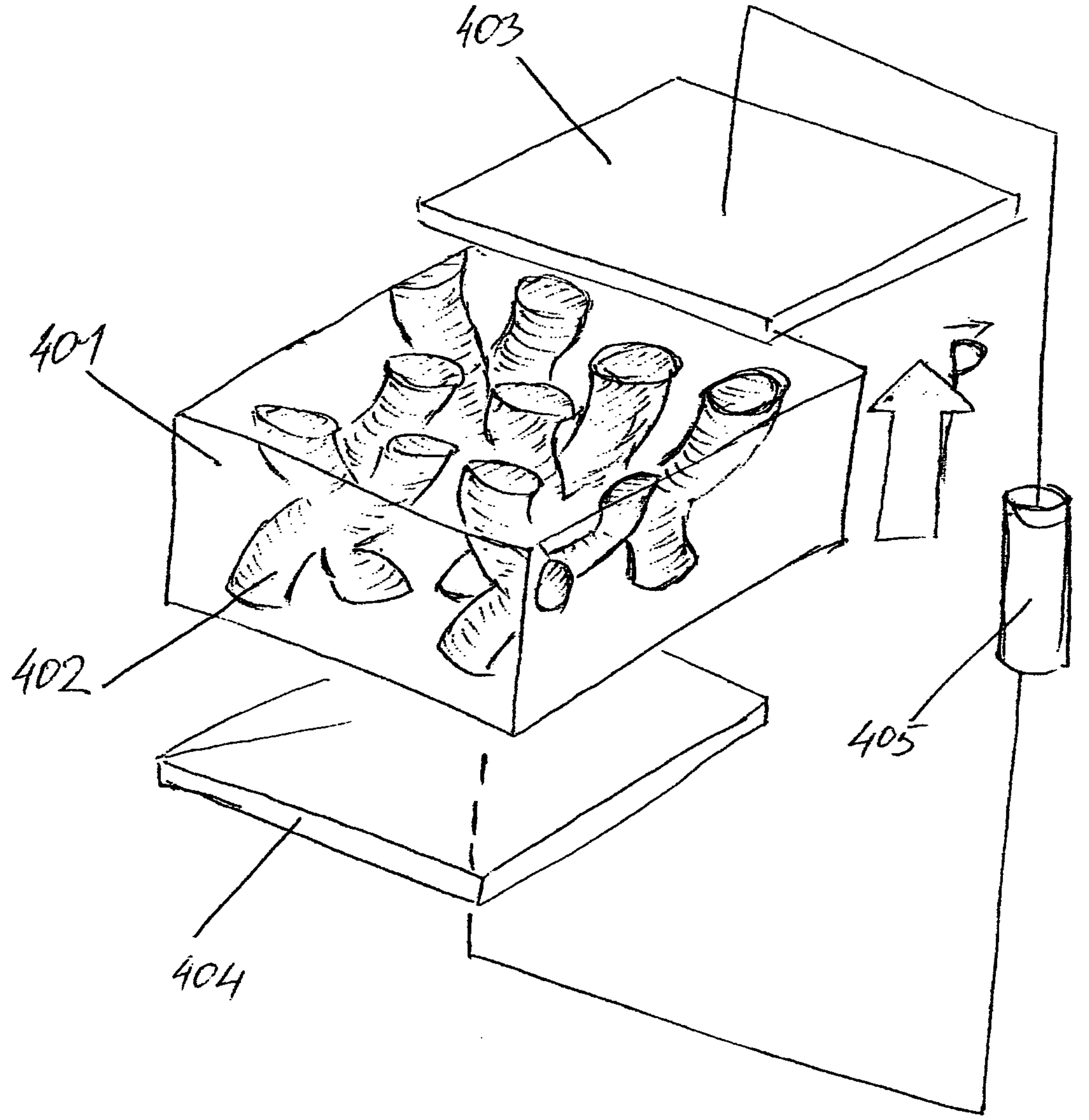


Fig. 4

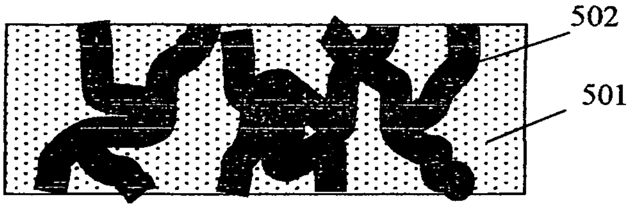


Fig 5, a

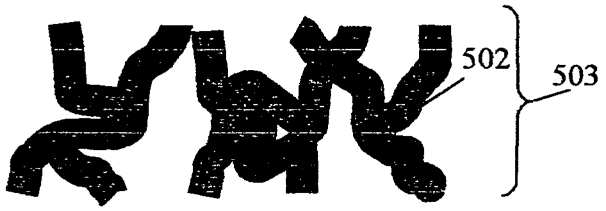


Fig 5, b

Fig 5, c

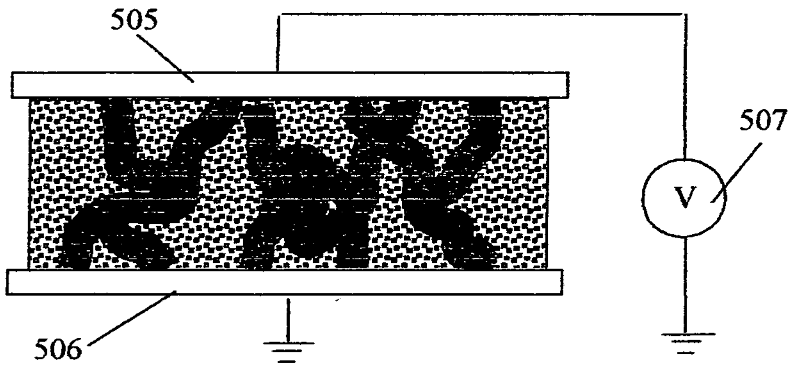


Fig 5, d

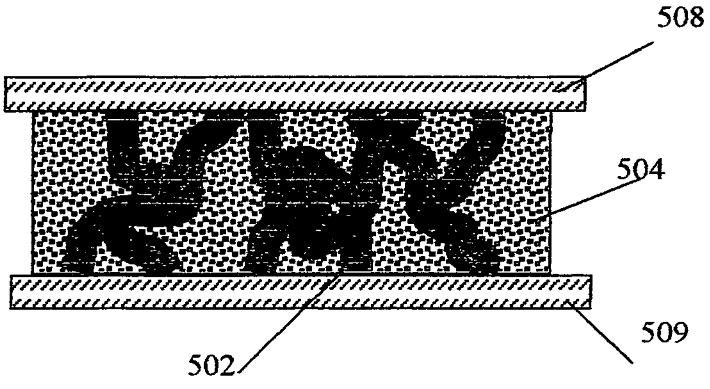
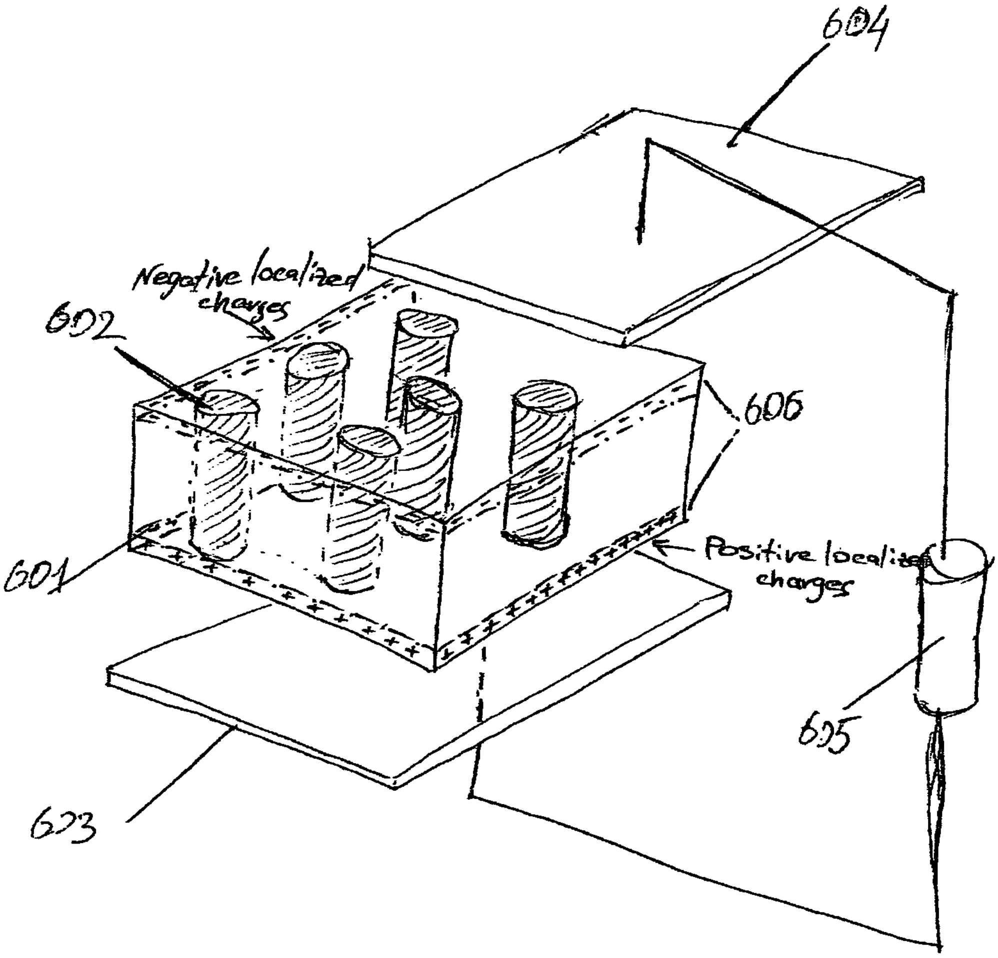


Fig 5, e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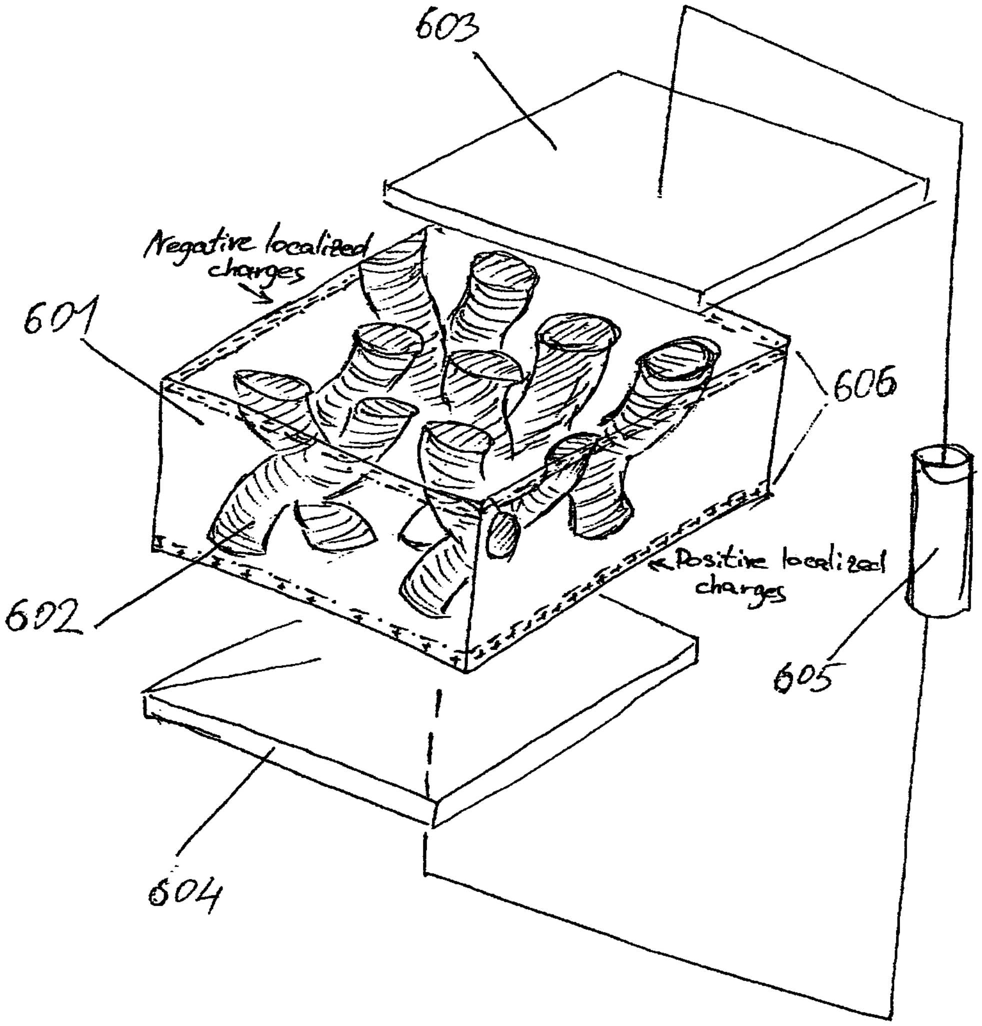
Negative localized charges
602
606
601
Positive localized charges
605
603

Fig. 6a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Positive localized charges
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Fig. 6b

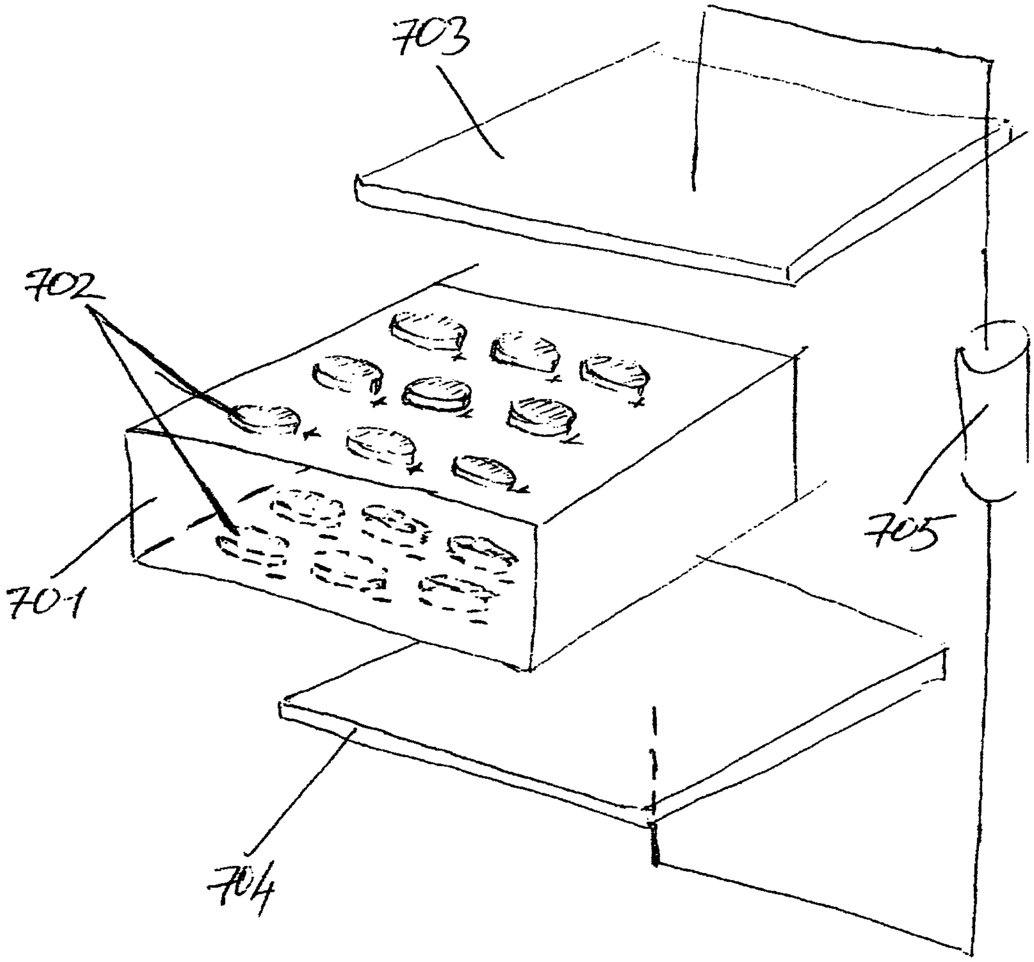

Fig. 7

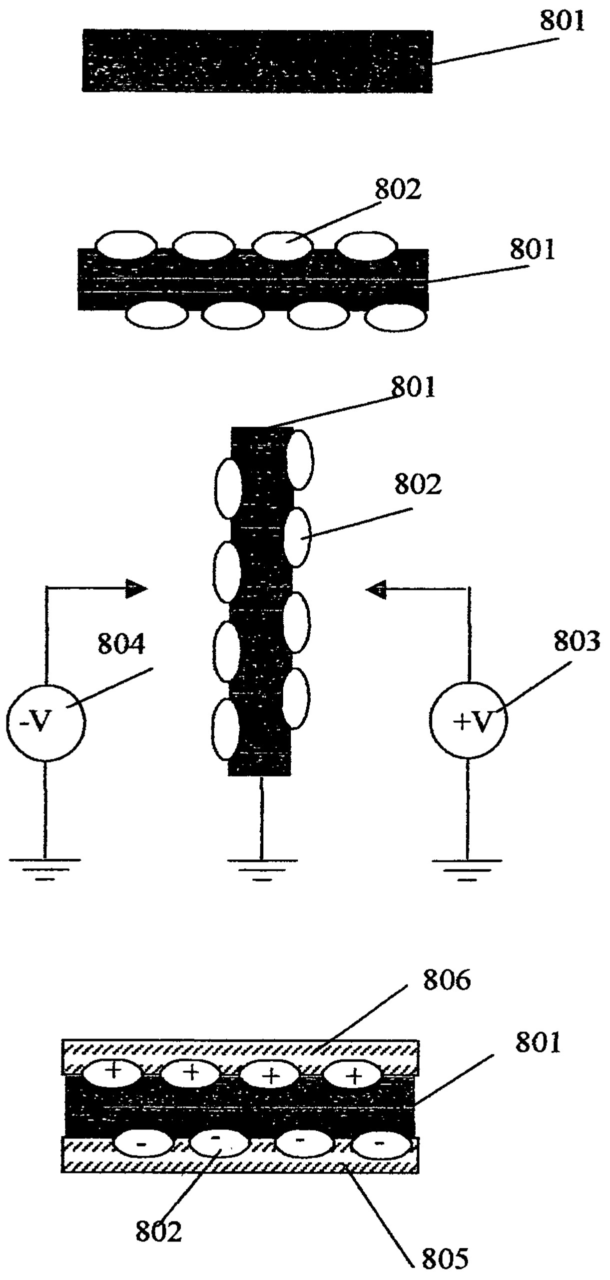

Fig. 8, a

Fig. 8, b

Fig. 8, c

Fig. 8, d

Fig. 8

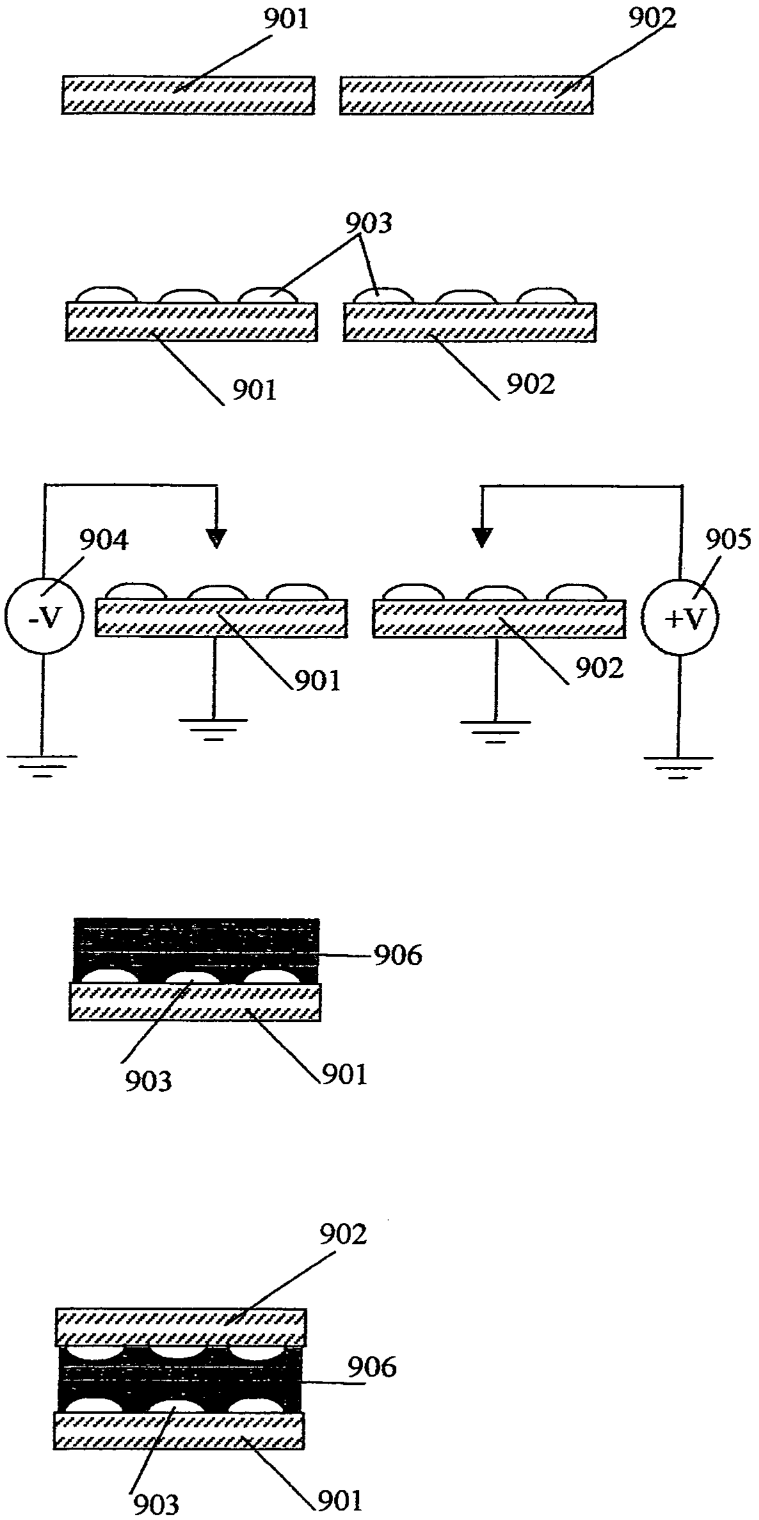

Fig. 9,a

Fig. 9,b

Fig. 9,c

Fig. 9,d

Fig. 9,e

Fig. 9

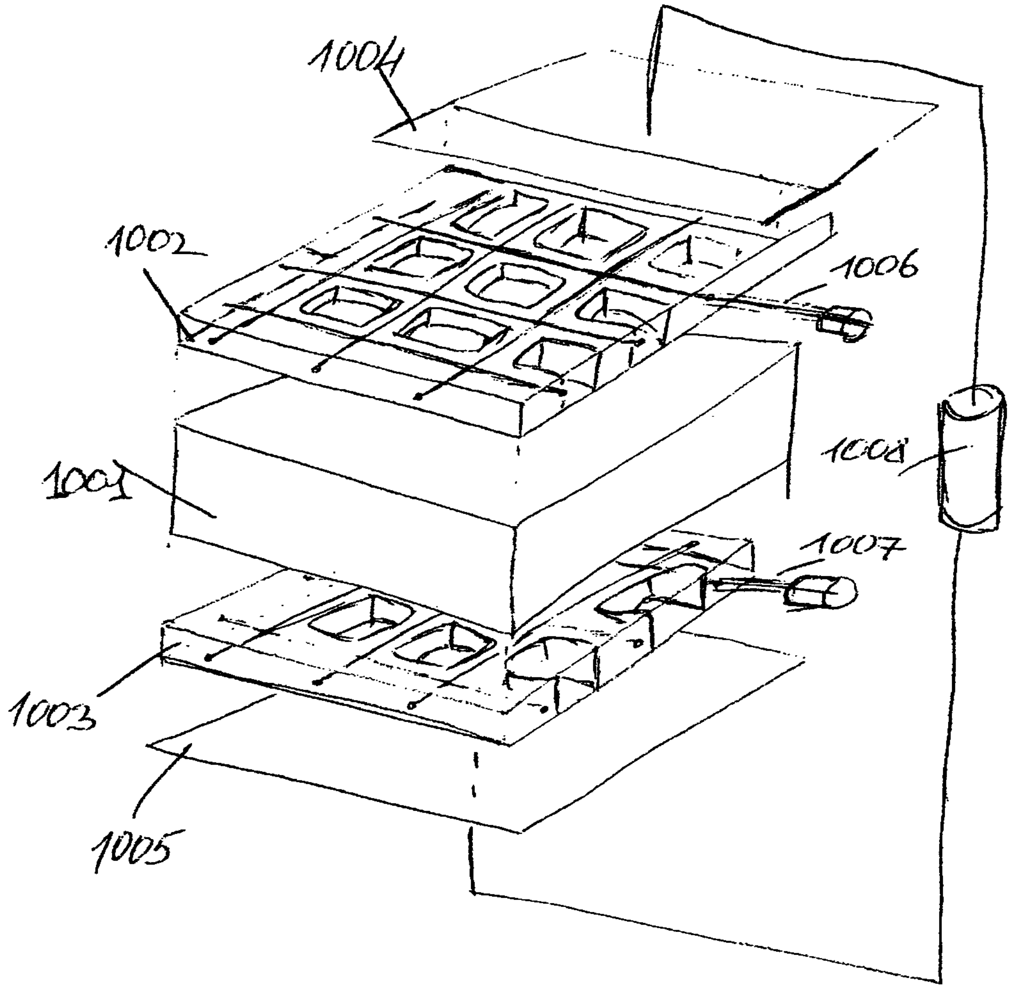

Fig. 10

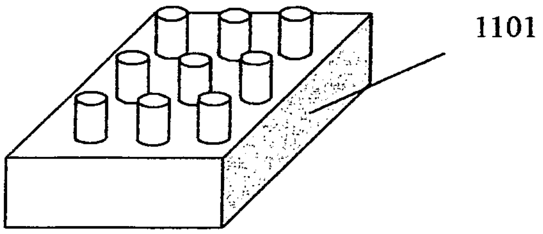

Fig. 11, a

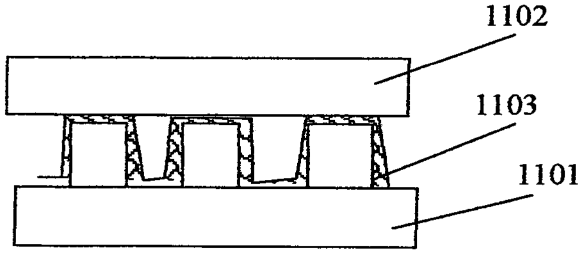

Fig. 11, b

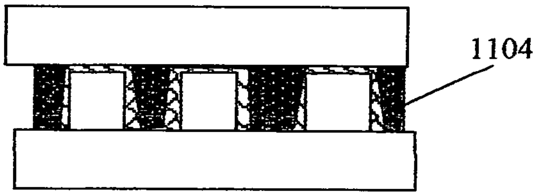

Fig. 11, c

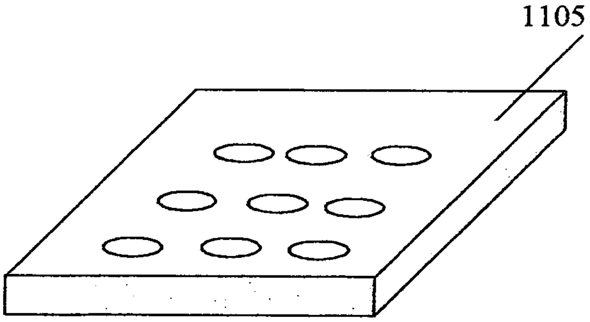

Fig. 11, d

Fig. 11

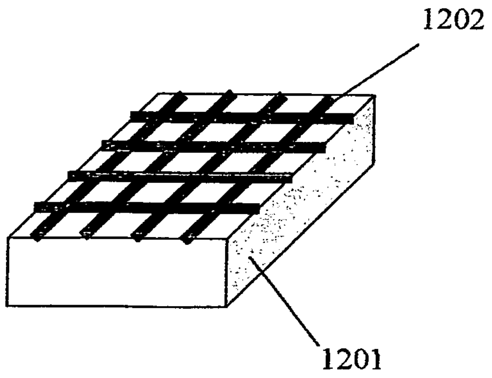

Fig. 12, a

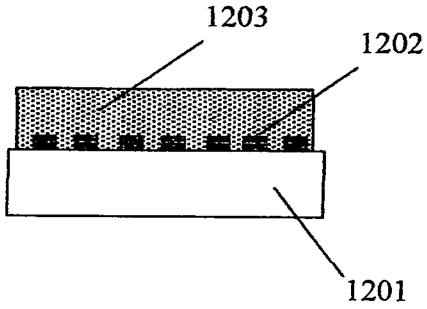

Fig. 12, b

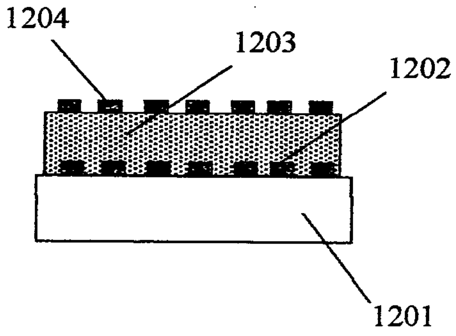

Fig. 12, c

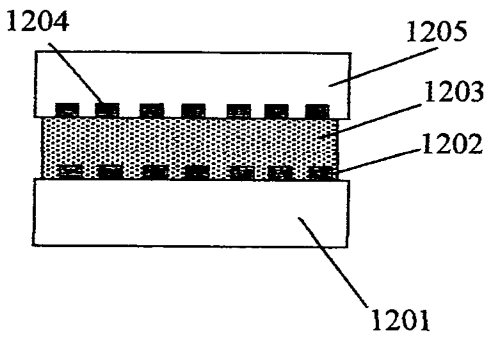

Fig. 12, d

Fig. 12