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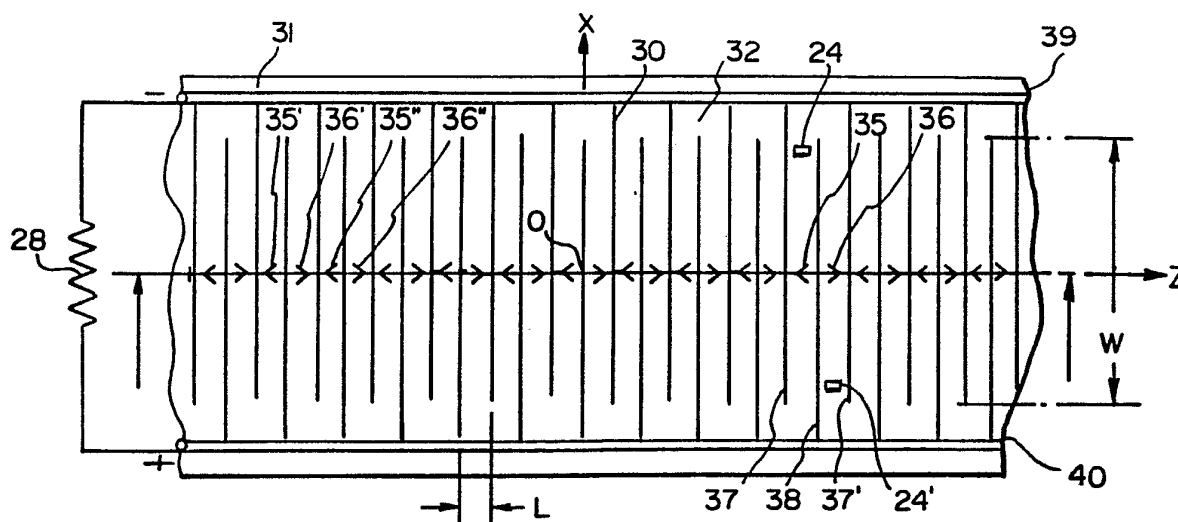
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(54) Title: LIGHT-POLARIZING ELECTRICALLY CONDUCTING FILM



(57) Abstract

A light polarizing electrically conducting film (32) includes a two-dimensional array of conductors stretch oriented in a polymer film. The orientation produces gaps in the conductors. The film also contains molecular diodes, called diads (24, 24'), which bridge a sufficient number of the gaps to permit conduction of electricity in the conductors when exposed to light. An interdigitated electrode array (37, 38) contacts the film. The diads are polarized by light and rotated by an electrostatic field (35, 36) applied through the electrode array before the polymer film is dried, whereby the diads provide unidirectional flow of electricity. The magnitude of the electrostatic field is increased, without electrical breakdown, by placing the portion of the film, whose diads are being polarized and rotated, in an atmosphere of a high-dielectric gas. A method for continuous production of the film is disclosed.

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LIGHT-POLARIZING ELECTRICALLY CONDUCTING FILM

FIELD OF THE INVENTION

The present invention relates to a polymeric light-electric power converting sheet comprising molecular antennae, diodes and electrode structure; a method, and
5 a device for its manufacture.

DEFINITIONS

Heteromonomer: A monomeric unit comprising various different structures chemically bonded to each other in a particular order.

Lepcomer: A heteromonomeric molecular unit which is capable of absorbing
10 a photon, and converting the photon energy to an increase in electric energy by motion of an electron charge in one direction toward one end of the molecule.

Lepcopolymer: A polymer chain comprising linked lepcomer units which is capable of absorbing one or more photons, and converting the photon energy to an increase in electric energy by a motion of electron charges in one direction. The
15 linkage may be by chemical bond, or by proximity.

LepconTM A trademark referring to a light electric power converter.

LumeloidTM A trademark referring to a light electric power converter which comprises a lepcopolymeric sheet.

Diad: An electrical diode of molecular dimensions in which an electron can
20 travel in only one direction. It comprises a substantially linear molecular complex containing groups of atoms specialized as an electron-donor group, an insulator-spacer group. An electron from the donor can tunnel across the insulating spacer to the acceptor, but not in the reverse direction.

Diad-Dipole: A diad in which an electron has moved to one end of the diad,
25 due to absorbing a photon of light. A diad-dipole in a suitable fluid is an electric dipole on which an electric field exerts a torque, rotating its long axis parallel to the field, and the negative end toward the positive electrode. In this manner,

diad-dipoles are aligned head-to-tail.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 shows a diagram of a randomly connected network according to the prior art.

5 Fig. 2 shows for a random network, a graph of the proportion of gaps in which connections have been made versus the conductivity of the network, according to the prior art.

Figure 3 shows experimental values of conductivity versus the molar percentage of Iodine in transpolyacetylene reported in the prior art. The
10 Percentage of Mass Concentration of Iodine has been calculated and is shown on the same graph.

Figure 4 shows a random network with parallel linear conductors with incident random photons and transmitted polarized photons.

Figure 5 shows a randomly connected network sheet with oriented diodes at
15 a proportion of connections.

Figure 6-9 inclusive uses a mathematical model of a light-electric power converting sheet according to this invention to compute an example of the relationships between the electrical variables with the conductivity δ as the major parameter; showing log log graphs of the conductivity σ in S/cm versus respectively:
20 Fig. 6 the electrical load, Fig. 7 current, Fig. 8 generated voltage, and Fig. 9 internal resistance.

Figure 10 shows a plan view in the XOZ plane, of a light/electric power converting sheet according to this invention.

Figure 11 shows a cross sectional view in the YOZ plane, of a light/electric
25 power converting sheet according to this invention.

Figure 12 shows a diagrammatic plan view of a production device for the continuous manufacture of light electric power converting sheets according to this invention.

Figure 13 shows a diagrammatic side sectional view through the YOZ plane

of a production device for the continuous manufacture of light electric power converting sheets according to this invention.

Figure 14 is an exploded perspective view of an assembly for the conversion of light to electric power, showing a series connection to an electrical load.

5 Figure 15 is an exploded perspective view of an assembly for the conversion of light to electric power, showing a parallel connection to an electrical load.

Figure 16 is log linear graph of the Conductivity in S/cm versus the % Total Iodine Solids of a light-polarizing electrically-conducting film according to this invention.

10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A prior art reference describes "percolation theory", relating to fluid of electric current flow through a random network; such as shown in Fig. 1, comprising a 2 dimensional square resistive wire lattice 1 connected between bus bars 2 and 3. The busbars 2 and 3 are connected to a voltage source 4 and ammeter 5. The
15 wire lattice has been cut at random in many places; for example at positions 6, 6, 6",....; a fraction p of the connections between the wires remains uncut. The graph 7 below the lattice shows current vs. p . The current flow is the same in both directions. For this 2 D lattice, the critical value of p is : P_C
= 0.5 For values of $p > 0.5$, the current increases rapidly with p ; for values of p
20 < 0.5 the current is zero.

Fig. 2 shows the curve 7 for the conductivity ratio σ/σ_0 vs. p is zero for $p < P_C$; but increases rapidly for $p > P_C$.

Fig. 3 shows prior art experimental data for polyacetylene doped with Iodine. The data are for bundles of fibrils of polyacetylene aligned by stretching, in a sheet
25 which is black, opaque and not optically continuous; and which scatters and absorbs incident light. Nevertheless the data is useful. The curve 9 shows $\log \sigma$ vs $\log y$; and $\log C$; where σ is the conductivity of the doped polyacetylene; y is the mol fraction of iodine, and C is the Weight fraction of iodine in the polymer. The midpoint 10 on the curve 9, is at coordinates $\log \sigma^*$ $\log y_0$; or, $\log C_0$. The

significance of the curve and its midpoint is explained below in the description of Fig. 5.

Referring to Fig. 4, the sheet 12 is an electrical conductor and a light polarizer. In the sheet 12, conductors 11, 11',... which may comprise lengths of linear conducting molecular chains, are disposed at random substantially parallel to the OY axis, supported in the transparent matrix sheet 12. The linear conductors 11, are long and thin and may wander somewhat from being parallel, enabling contact with other linear conductors displaced a small distance $\pm \delta_x$ and $\pm \delta_z$ along the OX axis, in zigzag connections 13,13" ...; thus providing a few or many connecting paths 14, 14'.. between the electrodes 15, 16. The voltage source 4 may be AC or DC. The current flow, which may be measured by ammeter 5, is the same in both directions. Light source 17 emits light photons 18, 18',... in a light beam having rays 22, 22'..., which are incident on the sheet 12. The electric vectors 19, 19' of the photons 18, 18' are normal to the incident light rays, and disposed at random angles about the rays. The sheet 12 has a length L between electrodes 15 and 16, and a width W parallel to the electrodes; the area exposed to light is $A=LW$. A transmitted beam 23 is strongly polarized along a vector 21.

Fig. 5 is the same as Fig. 4 except that is a light-electric power converting sheet containing molecular diodes, or diads 24,24'... dissolved in the composition and aligned head-to-tail as indicated by the arrows. A molecular diode, also known as a "diad" is a donor-insulator-acceptor complex. A Diad 24 is illustrated diagrammatically in the upper left portion of Fig 5. It comprises a donor molecule 25, an insulating spacer molecule 26, and an acceptor molecule 27. diads are usually rigid elongated molecules. When a diad is exposed to light it may absorb a photon, the photon energy is transferred to an electron which is moved to one end of the diad, to a higher electric potential, thus producing an electrical dipole. The functions of the diads 24, 24'.... are; to transmit an electron charge in one direction only; and to provide an insulating barrier for the potential difference between adjacent linear conducting chains. The insulating spacer molecule 26 provides a tunnel junction between the donor molecule 25 and the acceptor molecules 27; the diad as a whole functions as a molecule diode. The molecular

diodes 24, 24'.. function as one-way connectors between the linear conducting molecules.

During the process of manufacture described in Figs 12 and 13, just after the stretching step, enough solvent remains in the film to permit the diad to rotate. An electric field applied between the electrodes 15, 16 produces torques on the diad dipoles 24, 24'... rotating them into a head-to tail configuration.

In Fig. 5, the diad 24 comprises a donor molecule 25, an insulator molecule 26 and an acceptor molecule 27. The insulator molecule 26 is a short nonconducting linear molecular chain. The chemical composition of the insulating spacer molecule 26 may be, for example, a linear polyalkyl chain $-(CH_2)_x-$, where $3 > x > 15$; the length of the insulator chain is chosen to facilitate the tunnelling of the electron in substantially one direction only; the length of the insulating spacer molecule 26, or the spacing between the donor molecule 25 and the acceptor molecule is about 5 to 25 Å.

The voltage buildup between electrodes 15, 16 across the load resistance 28 is a dynamic process. An incident photon 18 causes an electron in the linear conductor 11 between diads 24, 24' to increase its voltage potential. This happens because the absorbed photon 18 increases the orbital energy of the linear conductor 11 by about 2.5 eV. As a result, the molecular orbital in the conductive antenna chain, usually a conjugated carbon chain, goes from a π orbital to a π^* orbital. This energy can be transmitted only in one direction through an adjacent diad to the next antenna. For less than a saturation flux of photons, there may be numerous antenna-diads at zero potential, because no photon had arrived to excite it to an increased potential. The potentials in adjacent antenna-diads are additive in voltage steps. Hence the potential difference between electrodes 15, 16 depends on the photon flux time-rate of charge production on the series antenna-diads which induces a voltage between the electrodes; vs. the current, or time-rate of charge flow drawn by the load 28. The voltage generated as measured by a voltmeter 29 in parallel with the load 28, is the sum of all the voltages generated by the series antenna-diads. This depends on the dynamic balance of the rate of charge production by the incident photons absorbed by the antenna-diads, and the rate of

charge removal by current through the load. When a photon flux pulse is applied the voltage between the electrodes 15, 16 builds up exponentially. When the photon flux pulse suddenly drops to zero the voltage across the electrodes decreases exponentially to zero. The peak voltage generated across the electrodes 15, 16 is less than the maximum voltage generated by the saturation flux. With a saturation photon flux the voltage generated between the electrode is proportional to the number of diads between the electrode times the voltage generated per photon absorbed by each antenna-diad.

Returning to Figs. 1, 2, and 3, and more particularly the significance of point 10 on Curve 9 in Fig. 3, assume that most of the cut connections 6, 6', 6''... in Fig. 1, are replaced by diodes such as 24, 24',... For the forward current the diad acts like a good connection, hence the bond fraction p and the conductivity σ are increased; vice versa, for the reverse current the diad acts like a cut or open connection, hence the bond fraction p and the conductivity σ are decreased. Further, because the linear conductors 11, 11'.. in Fig. 5 are oriented in one dimension, instead of in 2 dimensions as in Fig. 1, the curve 9 in Fig. 3 is shifted to the left of the curve 8 in Fig. 2, and the system is more sensitive to small changes in composition; specifically in this case, the % Concentration of Iodine.

The graphs shown in Figs. 6-9, inclusive, were plotted from equations utilizing reasonable physical values for distances between the electrodes 15, 16 of $L=10, 100, 1000 \mu\text{m}$; respectively. The central parameter is the forward conductance of the film. Equations can be derived utilizing this parameter to compute corresponding values of the voltage V across the electrodes; the current I per strip of film between the electrodes, the Load Resistance R , the forward film resistance per strip r_1 ; and the reverse film resistance per strip r_2 .

The Design Criteria utilized were:

1. the forward resistance r_1 of the film is negligible compared to the load; for example, $r_1 = 0.02 R$; and
2. the reverse resistance r_2 of the film is large compared to the load; for example, $r_2 = 50 R$; and
3. The electric field strength V/L between electrodes is

less than the electric field strength between electrodes

for spark breakdown in air $E = V_1/L$

Criteria 1, choosing L , $W = 1\text{m}$, D the known film thickness, and the forward conductivity $\sigma_1 = 5 \times 10^{-6} \text{ S/cm}$, enables calculations for a strip: Load
5 Resistance R ; voltage V ; Current I ; forward resistance r_1 , and reverse resistance r_2 .
For these design values, and using respectively $L = 10, 100, 1000 \mu\text{m}$; $W = 1\text{m}$, and $D=2, 8, 8 \mu\text{m}$; the calculated values of voltages are respectively: 1225, 125 and 25 volts.

Figs. 10 and 11 show a preferred embodiment of an electrode structure 30
10 on a substrate supporting sheet 31 in contact with a light-electric power converting polymeric film, or lepcopolymer film 32. A protecting cover sheet 33 may be laminated to the film 32. An example of the composition and manufacture of film 32 is described herein.

Referring to Fig. 10, OZ is the stretch axis of the film 32. Just after
15 stretching, the film 32 is applied while partially fluid onto the support sheet 31. The molecular diodes or diads 24, 24'.. are dissolved in the film composition 32 and are initially in random directions. During processing, the diad 24 is illuminated by light ray 34, and subjected to a strong electric fields: 35 and 36. The light ray 34 causes the electric charge in the molecular structure to flow toward one side of the
20 diad, which becomes an electric dipole. The electric dipole is then oriented in a head-to-tail direction parallel to the stretch axis OZ by the applied electric field, in the -OZ direction by field 35; or in the +OZ direction by the field 36. For simplicity, only two diads are shown, but it is understood that there are many diads which are oriented head-to-tail as described. The head-to-tail directions of the diads
25 are reversed in adjacent areas where the electric field directions reverse. The electric fields 35 and 36 are applied between electrodes 37-38 and 38-37', respectively. Busbars 39 and 40 are deposited parallel to the axis OZ, along the opposite edges of substrate sheet 31. Electrodes 37, 37', 37''... are connected to busbar 39; and electrodes 38, 38', 38''... are connected to busbar 40. The advantage
30 of this structure is that substantially all of the surface area of the lepcopolmer sheet 32 is utilizable for light-electric power conversion. In the prior art structure, the

orientation of the diads were all in one direction, with an intermediate spaced area which served as an insulator, but which could not be utilized for power conversion. The electrodes 37, 37'... and 38, 38'... and busbars 39, 40 are deposited on the surface of substrate supporting sheet 31 by any suitable means, such as photolithography. The electrodes have a width L_1 , and are spaced a distance L apart; and $L_1 \ll L$; for example $2 \mu\text{m}$ and $100 \mu\text{m}$ respectively. the Lepcopolymer film has a thickness D usually from $2 \mu\text{m}$ to $10 \mu\text{m}$. The active width of the sheet is W , herein taken as 1m . Hence the active power converting area on the sheet between electrodes is $A = LW$.

10 The electric breakdown field strength in air is $E_1 = 3 \text{ v}/\mu\text{m}$, or 300 v between electrodes $100 \mu\text{m}$ apart.

It is a feature of this invention to momentarily apply a much greater electric field strength between electrodes to align the diad-dipoles 24, 24'...; that is : $E_2 = 27 \text{ v}/\mu\text{m}$ or 2700 v between electrodes $100 \mu\text{m}$ apart. This is accomplished by using an atmosphere of sulphur hexafluoride (SF_6), which is a harmless nontoxic gas. Sulphur hexafluoride increases the electric field breakdown relative to air, by a factor of $9x$. Since the aligning torque on the diad-dipole is proportional to E , the torque is increased by $9x$.

A forward conductance of the film $\sigma_1 = 5 \text{ E}^{-6} \text{ S/cm}$ is easily obtained with the light-polarizing electrically-conducting film composition according to the invention. This value results in a generated voltage V less than the spark breakdown voltage in air: $V_1 = EL = 3 \times 10^6$; which is, for $L = 10, 100$, and $1000 \mu\text{m}$: $V_1 = 30, 300$ and 3000 volts, respectively. For comparison, the generated voltages between the electrodes are $25, 125$, and 1225 volts, respectively. The generated voltage V is less than the spark breakdown voltage in each instance. A smaller value of forward conductivity of the film may result in breakdown. A further calculation shows that the minimum values of forward conductivity at incipient spark breakdown are, respectively: 3.33×10^{-6} , 8.33×10^{-7} , and $8.33 \times 10^{-7} \text{ S/cm}$. These values are all smaller than the chosen value of forward, conductivity, i.e.: $5.0 \times 10^{-6} \text{ S/cm}$.

The continuous conversion of precursor polyvinyl alcohol (pva) film to a

copolymer with polyvinylacetylene (pa), to make a light-polarizing electrically-conducting film and/or the light/electric converting film known as Lumeloidtm, requires a casting belt surface insoluble in the solvents and inert to the chemicals used in the composition, and stable to a temperature of at least 100°C. Mylartm film (Dupont tm) is clear, transparent, and meets these requirements. Mylar film may be used for the casting belt. Mylar film may also be lithographed with conducting lines and busses, and used for the substrate film in a feed roll during manufacture.

The steps in the process for making a light-electric power converting polymer and substrate composite sheet are:

- (i) Deposit a conducting line electrode structure on the film substrate; for example, by lithography; and wind on a roll for use in the manufacturing device described herein.
- (ii) Prepare a polymer solution containing having a small proportion of medium boiling range residual solvent and diad material dissolved therein.
- (iii) Cast the polymer solution (ii) onto a moving casting belt.
- (iv) Partially dry the solution (ii) to form a precursor film on the casting belt, and stretch orient the film onto the conducting line structure on the clear film substrate.
- (v) Simultaneously illuminate the film (iv), and apply an electric voltage between the electrodes on the substrate to align the diads to align head-to-tail in the film.
- (vi) Evaporate the residual solvent to fix the orientation of the diads.
- (vii) Heat the film-substrate structure to a temperature and for a time sufficient to eliminate residual solvent.

Fig. 12 shows a linear layout on a plan view, and Fig. 13 a side view, of an example of a manufacturing device 41 for the continuous production of a light-electric power converting sheet according to this invention, illustrating the steps of manufacture. Figs 12 and 13 are approximately to a 1:100 scale. The manufacturing device 41 produces a light-electric power converting sheet 1/2m

(50cm) wide. A chemically inert first belt 48, such as Mylar, is mounted on Rollers 43, 44, 45, and 46. Variable speed motor 42 is connected to roller 43, which drives the first belt 48. The roller 46 is immersed in lepcopolymer solution 47 in the trough 49. The first belt 48 is continuously passed through the fluid 47 in trough 5 49, and applied as coating 50 onto the belt surface 48'. The first belt 48 moves with a velocity U_1 . The coating 50 is partially dried; for example, at 50°C for 6 min in a length of 6m at a velocity of 1m/min in a First Chamber 51, which has a hot air inlet 52, and air-vapor exhausts 53 and 54 at each end.

The partially dried film 32 exits from the first chamber 51 where the belt 48 10 turns around roller 44. At this point the partially dried film 32 is pulled away from the belt 48 and stretched at location 55 onto the surface 56' of the second belt 31a at roller 57. The second belt comprises a continuous substrate sheet 31 supplied from a wound Roll 58. The substrate sheet 31 has the electrodes 37,37'..., 38,38'..., and busbars 39 and 40 preformed thereon, as previously described in Figs. 10 and 15 11. In this example, the coating velocity on the surface 48' of the first belt 48 is $U_1 = 0.01667$ m/s (1 m/min= n ; 60 m/hr), and the stretch ratio is 6 x. Then the velocity U_2 of the second belt 31a is:

$$U_2 \approx 6 U_1 \approx 0.1\text{m/s (6 m/min; 360 m/hr)}.$$

The initial width of the film on the belt 48 is 1 m. After stretching at 20 location 55, the film 32 is about 1/2 its initial width, or 1/2 m; with the same solid volume its thickness is about 1/3 its initial thickness. After stretching film 32 onto sheet 31 at roller 57, the film composition retains enough solvent for the diad-dipoles 24,24'.. to rotate. It is a property of a diad that light causes an electron to move to one end of a diad, making it an electric dipole, herein termed a diad- 25 dipole. An electric field exerts a torque on a diad-dipole. Consequently, diad-dipoles are rotated and aligned head-to-tail by the electric field, in a direction along the stretch axis. The electric fields 35, 35'..., 36, 36'... and lights 59, 59'.. are applied in a second chamber 60 for about 30 sec in a distance of 3 m, at a temperature of about 40°C. This step aligns the diad-dipoles and removes enough solvent from the 30 film composition to permanently fix this alignment.

A harmless nontoxic gas 61 sulfur hexafluoride SF_6 at 1 atmosphere pressure

is provided in the second chamber 60. The SF₆ gas 61 enters the second chamber 60 via the inlet pipe 62 and exits via the pipes 63 and 64 at each end. The presence of SF₆ gas enables a high electric field to be maintained without electric spark breakdown in the second chamber 60. The high electric breakdown field results in a maximum alignment of the diads. In the presence of SF₆ gas the maximum electric field is about 9 x, compared to that of the electric breakdown field in air. (A breakdown voltage of 2700 v in sulphur hexafluoride compared to 300 v in air for a 100 μm distance between electrodes). The high electric field is applied by voltage source 65 via sliding contacts 66 and 67 made to busbars 39 and 40, respectively, on sheet 31.

Under the given conditions, the second chamber 60 has a total length of (1+3+1) = 5 m. The purpose of the extra 1 m length at each end of the second chamber 60, is to prevent the momentarily applied high voltage from shorting out by sparking across the gap between the electrodes in the presence of air outside second chamber 60 and damaging the film 32. To avoid this, one of the busbars 39 is disconnected periodically; for example, once for each meter length, by a break in its continuity while remaining protected by the presence of SF₆ in the second chamber 60. The other busbar is unbroken and remains connected to ground at 68. Subsequently contacts along busbar 39 may be restored in any suitable manner.

The evaporation of the residual solvent in film 32 is accomplished by passing the film 32 on the substrate 31 through a third chamber 70, which is about 36 m long, for about 6 minutes at a temperature of about 85°C, at a velocity of $U_2 \approx 6$ m/min. The completed sheet 71 is then wound into a roll 72, ready for use. A drying gas enters centered inlet 73 and exits at end exhausts 74 and 75.

A light-polarizing electrically-conducting film made on manufacturing device 41 with a composition according to the present invention has a conductivity of about 10^{-4} S/cm. This composition may be diluted with an insulating polymer solution, such as polyvinyl alcohol in a water-alcohol solvent, to obtain a smaller conductivity such as 10^{-6} S/cm. It has a transmittance to ordinary light of 40 to 45%; to parallel polarized light of 80 to 90%, and to perpendicular polarized light less than 0.03%.

A single such film with suitable diads is capable of converting about 40% of incident light power to electric power. The transmitted component is polarized light comprising 40% of the incident light-power.

Figs. 14 and 15 are exploded perspective views of composite panel 84 comprising panels 82 and 83 laminated or assembled together with a single pair of electric outlet terminals connected to load 85. Panels 82 and 83 each comprise a lepcopolymer film 32 incorporating aligned diads mounted on a substrate supporting sheet 31 with electrodes and busbars, as above described. The XOZ planes of the panels 82 and 83 are normal to a common OY axis, and their axes OZ_1 and OZ_2 are disposed orthogonally.

Light-power ray 77 along the OY axis may be incident on the first panel 82. The electric vector E_{Z1} of the resolved incident light 78, contains 50% of the incident light-power 77. The first panel 82 converts 80% of the resolved incident light-power 78 to electric power. Thus, the first panel 82 converts $50\% \times 0.8 = 40\%$ of the total incident light-power 77 to electric-power supplied to the load 85. About 80% of the remaining 50%, or 40% of the resolved incident light power 77 is transmitted as polarized light-power ray 79, having the electric vector $E_x = E_{Z2}$, which is incident on the second panel 83, which further converts 80% to electric power. Therefore $40\% \times 0.8 = 32\%$ of incident polarized light-power 79 is converted to electric power in the second panel 83. The total electric power converted by the two panels 83 and 84, connected in series or in parallel, is $40 + 32 = 72\%$.

If the peak sunlight power is 600 watts/m^2 , then the peak converted electric-power supplied to the load 85 by the two panels is $600 \times .72 = 432 \text{ watts/m}^2$. The daily available average incident sunlight power is about $1/2$ of peak, or 216 watts/m^2 . The first panel 82 converts 40% of $1/2 \times 600$ peak power or 120 watts/m^2 . The second panel 83 converts an additional $0.32 \times 1/2 \times 600 = 96 \text{ watts/m}^2$. The total average electrical output power for the two panels is: $120 + 96 = 216 \text{ watts/m}^2$.

Using two panels 83 and 84 of 1 m^2 area with the parallel electric connection shown in Fig. 15, the total generated electric power output is 432 watts/m^2 . For

electrode spacing $L = 1000, 100, \text{ and } 10 \mu\text{m}$, respectively, the voltages are 1225, 125, and 25 volts. The total currents are 0.3527, 3.46, and 17.2 amp/m²; and, the load resistances are: 3431, 36.1, and 1.45 ohms.

Having described preferred embodiments of the invention with reference to
5 the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

What is claimed is:

1. An electrically conductive sheet comprising:
a transparent resin sheet;
said sheet having been unidirectionally stretch oriented;
5 a first plurality of conductors in said sheet;
characterized in that
said first plurality of conductors having been drawn into a generally parallel
relationship while said sheet was oriented;
a proportion, less than all, of said first plurality of conductors contacting
10 others of said first plurality of conductors;
a second plurality of gaps in said first plurality of conductors;
a third plurality of connections across said second plurality of gaps; and
said third plurality of connections being in sufficient proportion to said
second plurality of gaps to provide an electric current flow between first and second
15 points spaced apart in a direction of orienting of said sheet.
2. Apparatus according to claim 1 wherein a plurality of said gaps are 20 Å,
whereby said electric current flows at least in part by tunnelling through said gaps.
3. Apparatus according to Claim 1, characterized in that said first plurality
of conductors comprise an antenna array;
20 said antenna array having dimensions and spacing effective to resolve incident
photons and about half are transmitted and polarized.
4. Apparatus according to claim 1, characterized in that said connections are
diodes having a substantially unidirectional current flow in a head to tail direction,
a plurality of said diodes being located at said gaps and aligned parallel to a
25 direction of flow of said electric current, whereby an electric current flows only in
said head to tail direction.
5. Apparatus according to claim 4, characterized in that said diodes are
linear conducting polymer molecules and said sheet is an insulating linear polymer.
6. Apparatus according to claim 5, characterized in that said sheet has an
30 electrical conductivity of at least 10^{-7} S/cm.

7. Apparatus according to claim 4, in which said conductors are linear conducting polymer molecules, and said diodes are diads.

8. Apparatus according to claim 7, wherein said diads are molecular donor acceptor complexes.

5 9. Apparatus according to claim 5, wherein said linear conducting polymer molecules are diad molecules oriented in said sheet head to tail parallel to said electric current flow, whereby said electric current flow is substantially unidirectional, and about half of incident photons are transmitted polarized.

10 10. Apparatus according to claim 1, further comprising a second sheet, the first-mentioned sheet comprising a film of polymer stretch-oriented along an axis, said second sheet being transparent, said first-mentioned sheet being supported on said second sheet, said first sheet being an electrical conductor and antenna array, whereby about half of photons incident on said polymer film are transmitted and polarized.

15 11. Apparatus according to claim 10, further comprising:
a plurality of electrodes in said sheet normal to an axis of said unidirectional stretch;

said electrodes having a width L_1 and spaced apart a distance L ;

first and second bus bars along opposed edges of said sheet;

20 said first bus bars contacting a first plurality of said electrodes;

said second bus bars contacting a second plurality of said electrodes;

said first and second pluralities of electrodes being interdigitated;

at least some of said connections being diads;

25 substantially all of said diads between an adjacent pair of electrodes of said first and second pluralities of electrodes being aligned head to tail in the same direction; and

a direction of said diodes being reversed between a next pair of electrodes, whereby about half of photons incident on said sheet are converted to electric power and connected to said first and second bus bars for application to an
30 external load, and the remaining photons are transmitted through said sheet and polarized.

12. Apparatus according to claim 11, wherein:

said electrodes and bus bars are on a surface of a second sheet;

said sheet is supported on a surface of the first-mentioned sheet;

said first sheet having a thickness D , in which

5 $D \approx L_1$ and $L \gg L_1$

where L is the distance between adjacent electrodes, D is a thickness of said sheet, and L_1 is an average length of said gaps.

13. Apparatus according to claim 12, further comprising:

a duplicate of said first-mentioned and second sheet;

10 axes of polarization of said first-mentioned and second sheets and said duplicate being orthogonal, whereby polarized light transmitted through said first sheet is intercepted by said second sheet, whereby substantially all of incident light energy is converted to electric power.

14. A polymer film characterized in that the film comprises a reaction
15 product of polyvinyl alcohol, hydriodic acid, and iodine.

15. A polymer film according to claim 14, having range of solid compositions relative to 1 mol of polyvinyl alcohol as follows: hydriodic acid - 0.1 to 1.5 mols; and iodine - 0.1 to 1.0 mols.

16. A process for the continuous manufacture of electrically conducting light
20 polarizing polymeric film comprising:

dissolving a precursor conductive linear polymer in a solvent to produce a polymer solution;

characterized in that

coating said polymer solution onto a nonreactive belt moving at a velocity
25 U_1 ;

partially drying said coating to form a film on said belt;

stretching orienting said film by pulling it at a velocity U_2 ; and

further drying and solidifying said film;

17. A process according to claim 16, further comprising affixing said film to
30 a substrate moving at said velocity U_2 .

18. A process according to claim 16, further comprising:

applying a first set of electrodes connected to a first bus bar on a substrate;
applying a second set of electrodes, interdigitated with said first set of
electrodes, connected to a second bus bar on said substrate; and

affixing said film to said substrate with said electrodes contacting said film
5 after stretch orientation thereof.

20. A process according to claim 16, further comprising:

the step of dissolving a precursor polymer including providing at least some
materials in said precursor polymer capable of being diads;

exposing said diads to light before the step of further drying and solidifying,
10 whereby said diads become polarized;

applying an electrostatic field to the polarized diads to turn them in preferred
directions head to tail; and

performing the step of further drying and solidifying while holding said diads
in said preferred directions, whereby said diads are locked in said preferred
15 directions.

21. A process according to claim 20, wherein the step of applying an
electrostatic field includes:

forming a first plurality of electrodes parallel to each other across said film;
connecting first ends of said first plurality of electrodes to a first bus bar;
20 forming a second plurality of electrodes parallel to each other across said
film;

said first and second pluralities of electrodes being interdigitated; and

applying a voltage between said first and second bus bars to perform the step
of applying an electrostatic field;

25 22. A method according to claim 21, further comprising breaking said first
bus bar at intervals, whereby said electrostatic field is isolated to a portion of said
first and second pluralities of electrodes between adjacent breaks in said first bus
bar.

23. A method according to claim 22, further comprising:

30 exposing said film to a high dielectric constant gas during the step of applying
an electrostatic field, whereby said voltage may be increased to a value exceeding

a breakdown voltage in air.

24. Apparatus according to claim 1, wherein said third plurality of connections each includes a diad.

25. Apparatus according to claim 24, wherein a polarity of said diad is
5 controlled, whereby unidirectional current flow is permitted.

26. Apparatus according to claim 1, further comprising:

a first conductor passing across said sheet normal to a direction of said first plurality of conductors and passing through said first point;

a second conductor passing across said sheet normal to said direction of said
10 first plurality of conductors and passing through said second point; and

means for connecting said first and second conductors to said first plurality of conductors, whereby an electric current is enabled to pass between said first and second conductors through said first plurality of conductors.

27. Apparatus according to claim 1, wherein;

15 said sheet polarizes incident light, and permits a proportion, less than half, of said incident light to pass through said sheet; and

said proportion is strongly polarized.

28. A photoelectric device comprising:

a generally transparent, light-transmitting sheet;

20 said sheet including means for polarizing light;

said means for polarizing, in combination with said sheet, being effective to transmit therethrough a transmitted beam containing substantial proportion, less than half, of light incident thereon;

said transmitted beam being polarized;

25 characterized in that

said sheet further including means for at least one of a) generating electricity in response to incident light and 2) producing light in response to an electric input; and

means for making electrical connection to said photoelectric device whereby
30 electricity may be conducted to and from said electric sheet.

29. Apparatus according to claim 28, further comprising a second

photoelectric device identical to the photoelectric device in claim 28, and said second photoelectric device being stacked parallel to the photoelectric device of claim 28 and rotated in a direction having a polarization vector perpendicular to a polarization vector of said transmitted beam, whereby, the two photoelectric devices, 5 in combination, absorb substantially all of said incident light.

30. Apparatus comprising:

a first plastic resin sheet;

first and second conductive bus bars along first and second opposed edges of said plastic resin sheet;

10 a first plurality of conductive electrodes having first ends connected to said first bus bar and extending toward said second bus bar;

a second plurality of conductive electrodes having first ends connected to said second bus bar and extending toward said second bus bar;

15 said first and second conductive electrodes being interdigitated with a predetermined distance between each of said first plurality of conductive electrodes and its neighboring second plurality of conductive electrodes;

a second plastic resin sheet;

characterized in that

20 said second plastic resin sheet including a surface layer having a plurality of generally parallel linear conductors thereon;

some of said linear conductors making electrical contact with others of said linear conductors, whereby a two-dimensional matrix of linear conductors is formed;

a plurality of gaps in said linear conductors;

a substantial number of said gaps being bridged by diodes;

25 said first and second pluralities of conductive electrodes contacting said linear conductors, whereby electricity is connectable between said linear conductors and said first and second bus bars; and

those of said diodes between each of said first conductive electrodes and one of its neighbors being polarized in the same direction, whereby unidirectional flow 30 of electric current is enabled.

31. Apparatus according to claim 30, wherein said diodes are diads.

32. Apparatus according to claim 30 further comprising breaks in said first bus bar.

33. A method for making a photoelectric sheet comprising:

applying a conductive pattern on a first resin sheet;

5 said conductive pattern including first and second bus bars along opposed edges of said first resin sheet, a regularly spaced first plurality of conductive electrodes extending from said first bus bar toward said second bus bar, and second plurality of conductive electrodes interdigitated with said first plurality of conductive electrodes and extending from said second bus bar toward said first bus bar;

10 a spacing between each of said first plurality of conductive electrodes and its neighboring second plurality of conductive electrodes being a predetermined distance;

characterized in that

15 applying a liquid material to a second plastic resin sheet to form a conductive layer;

 said conductive layer including conductive strands therein in a two-dimensional array;

 orienting said second plastic resin sheet sufficiently to draw said conductive strands into substantial parallel relationships with each other;

20 the step of orienting also creating a plurality of gaps in said conductive strands;

 the step of applying including supplying a material in said liquid from which diads may be formed;

25 affixing said first and second resin sheets together with said first and second pluralities of conductive electrodes making electrical contact with said conductive strands;

 before said liquid is fully cured, exposing said second resin sheet to optical energy sufficient to polarize said diads while applying an electric field between said first and second pluralities of conductive electrodes;

30 said electric field being sufficiently large to rotate a substantial portion of said diads between an adjacent pair of first and second conductive electrodes into the

same polarity; and

curing said liquid while holding said diads in a polarized condition, whereby said diads remain fixed in said polarized condition.

34. A method according to claim 33, wherein the step of applying a
5 magnetic field includes immersing said first and second resin sheets in a high-dielectric material, whereby a higher electric field can be maintained than in an air atmosphere.

35. A method for orienting diads in a conductive layer comprising:

forming an interdigitated array of first and second parallel conductors on a
10 first resin sheet;

forming a first bus bar contacting an end of each of said first parallel conductors in said array;

forming a second bus bar contacting an end of each of said second parallel conductors in said array;

15 characterized in that

contacting said array with a conductive layer, containing said diads, on a second resin sheet;

passing said first and second sheets into a chamber containing a high-dielectric constant gas; and

20 applying a voltage in said chamber between said first and second bus bars sufficient to orient said diodes.

36. A method according to claim 35, wherein:

said first and second resin sheets are long resin strips;

the step of passing includes passing a first portion of said long resin strips
25 through said chamber with at least a second portion of said long resin strips remaining outside said chamber; and

forming spaces in at least said first bus bar at a regular spacing short enough that the step of applying a voltage in said chamber does not result in a substantial electric field between those of said first and second parallel conductors on said
30 second portion.

37. A method according to claim 36 wherein said chamber has a length that

is at least three times said regular spacing.

38. A method according to claim 35 wherein said high-dielectric constant gas includes SF₆.

FIG. 1
PRIOR ART

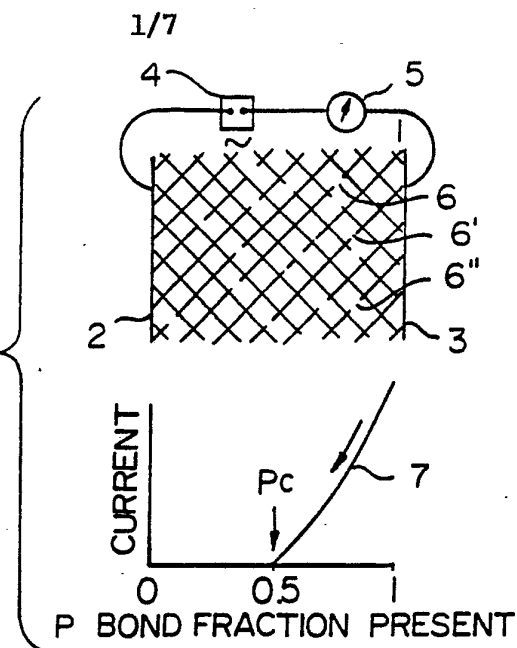


FIG. 2
PRIOR ART

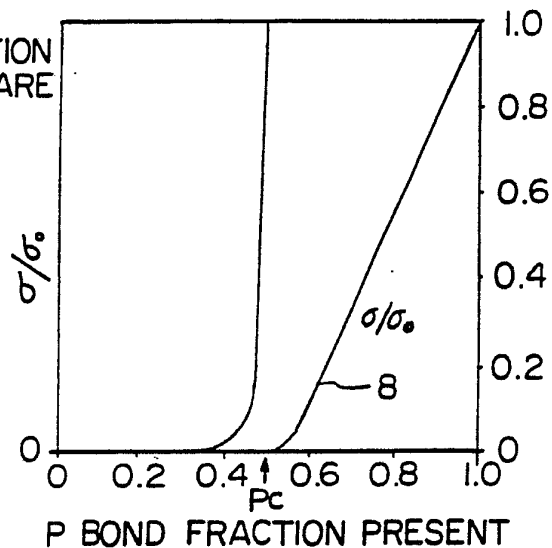


FIG. 3
PRIOR ART

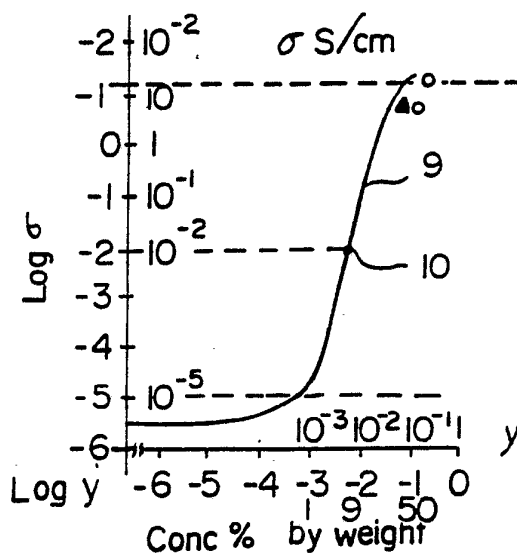


FIG. 6

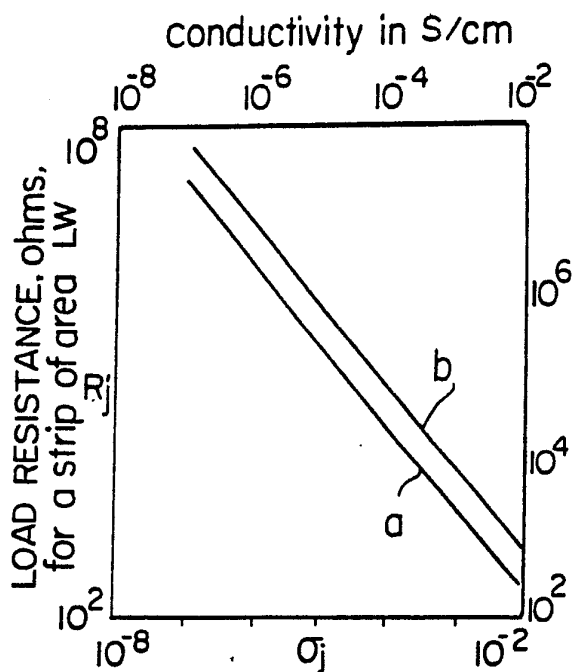


FIG. 7

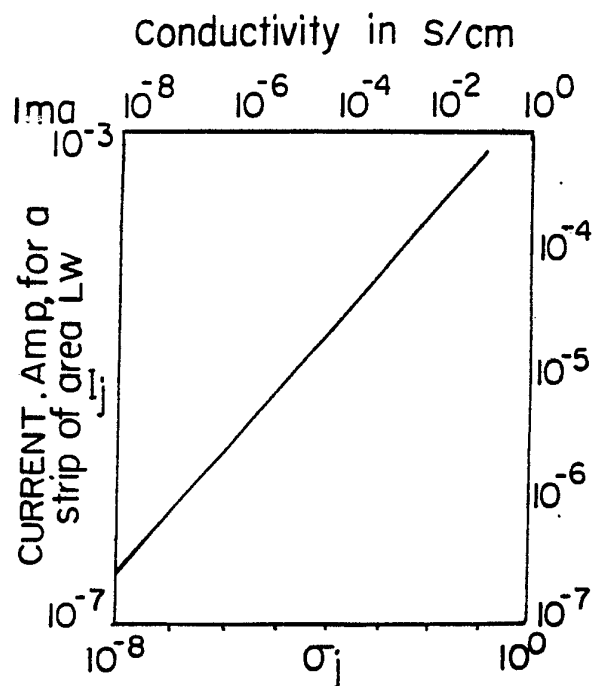


FIG. 8

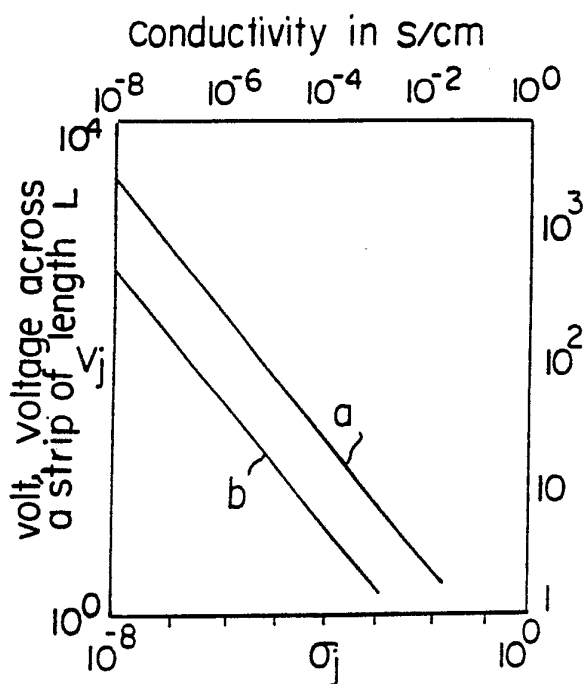


FIG. 9

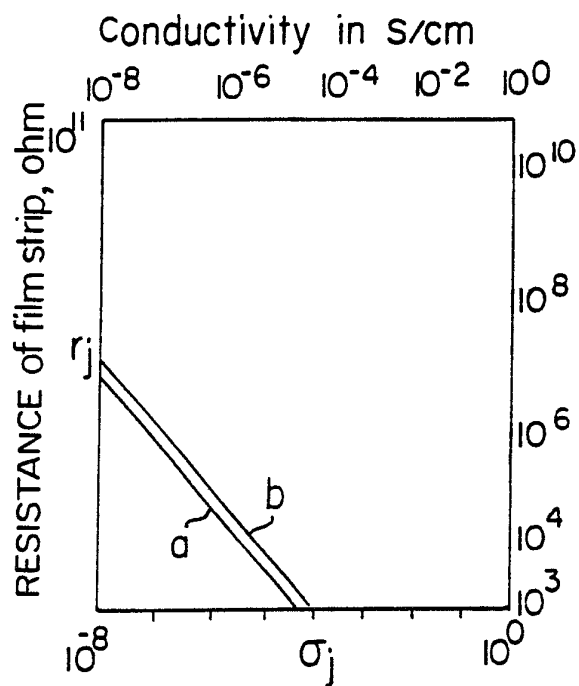


FIG. 12

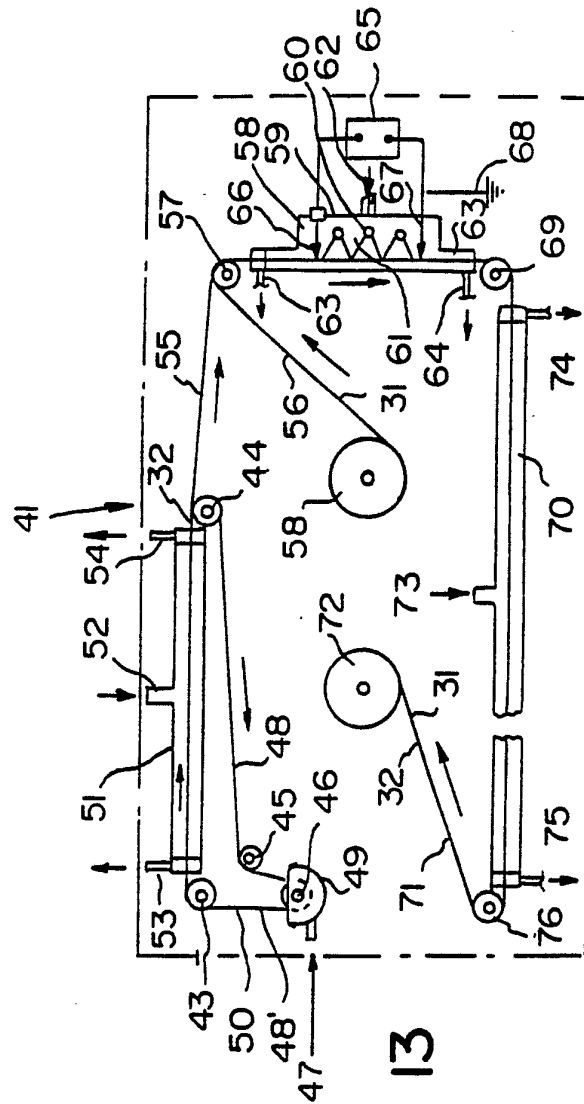
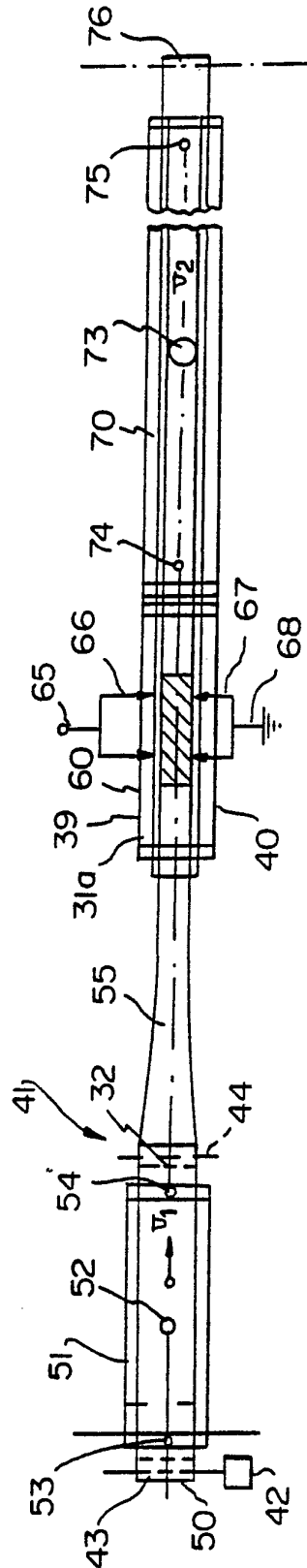


FIG. 13

FIG. 10

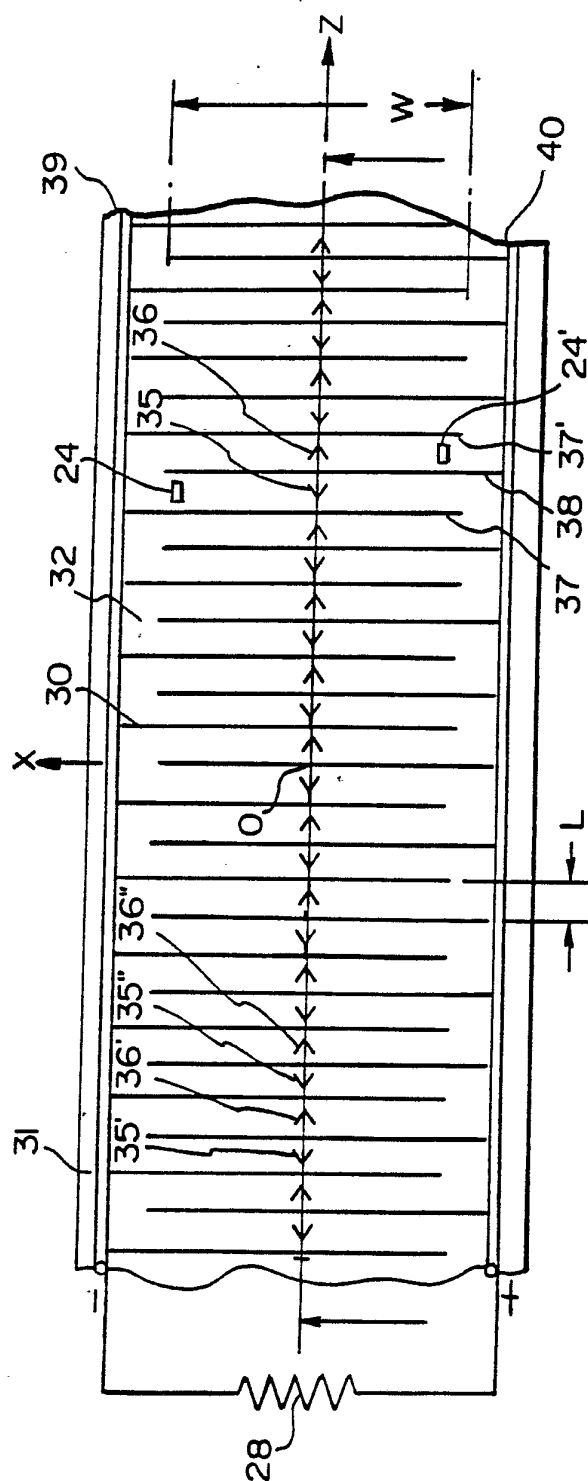
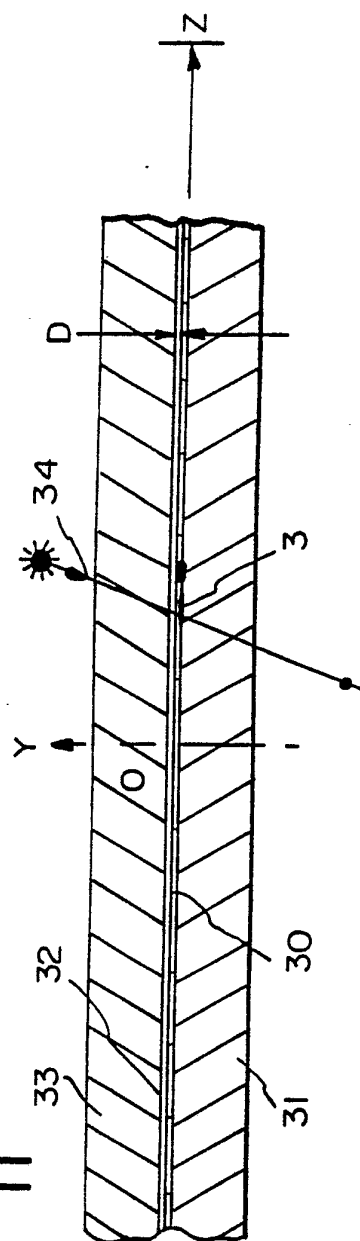


FIG 11



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FIG. 14

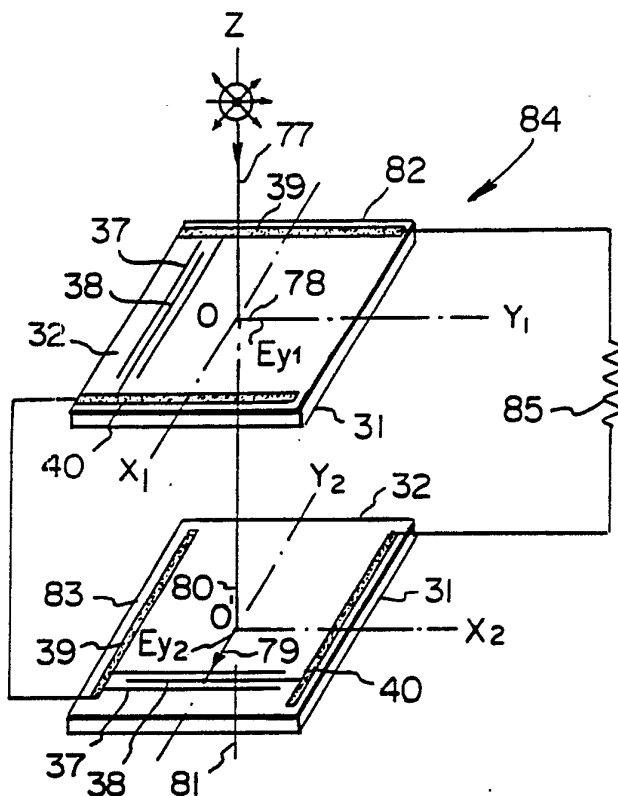


FIG. 15

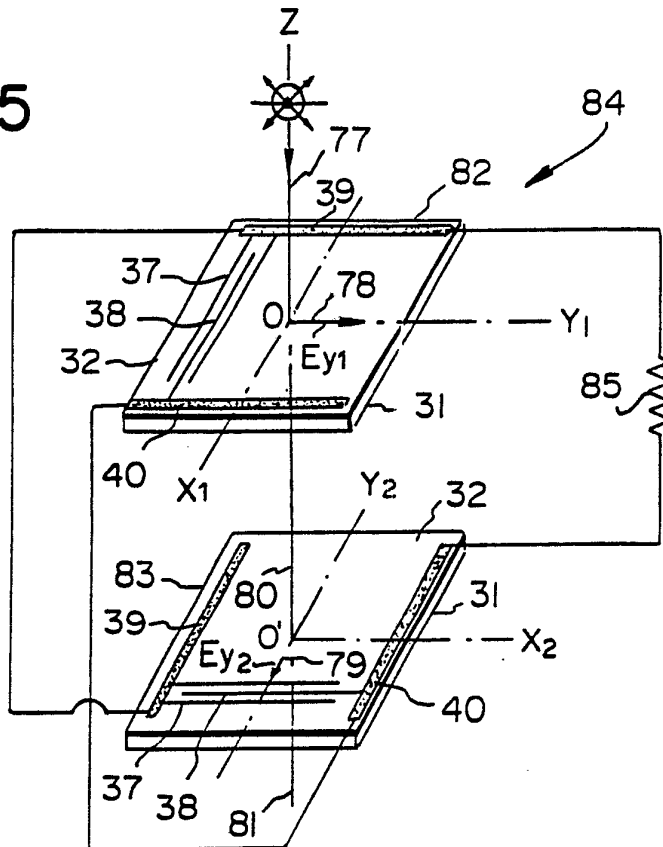
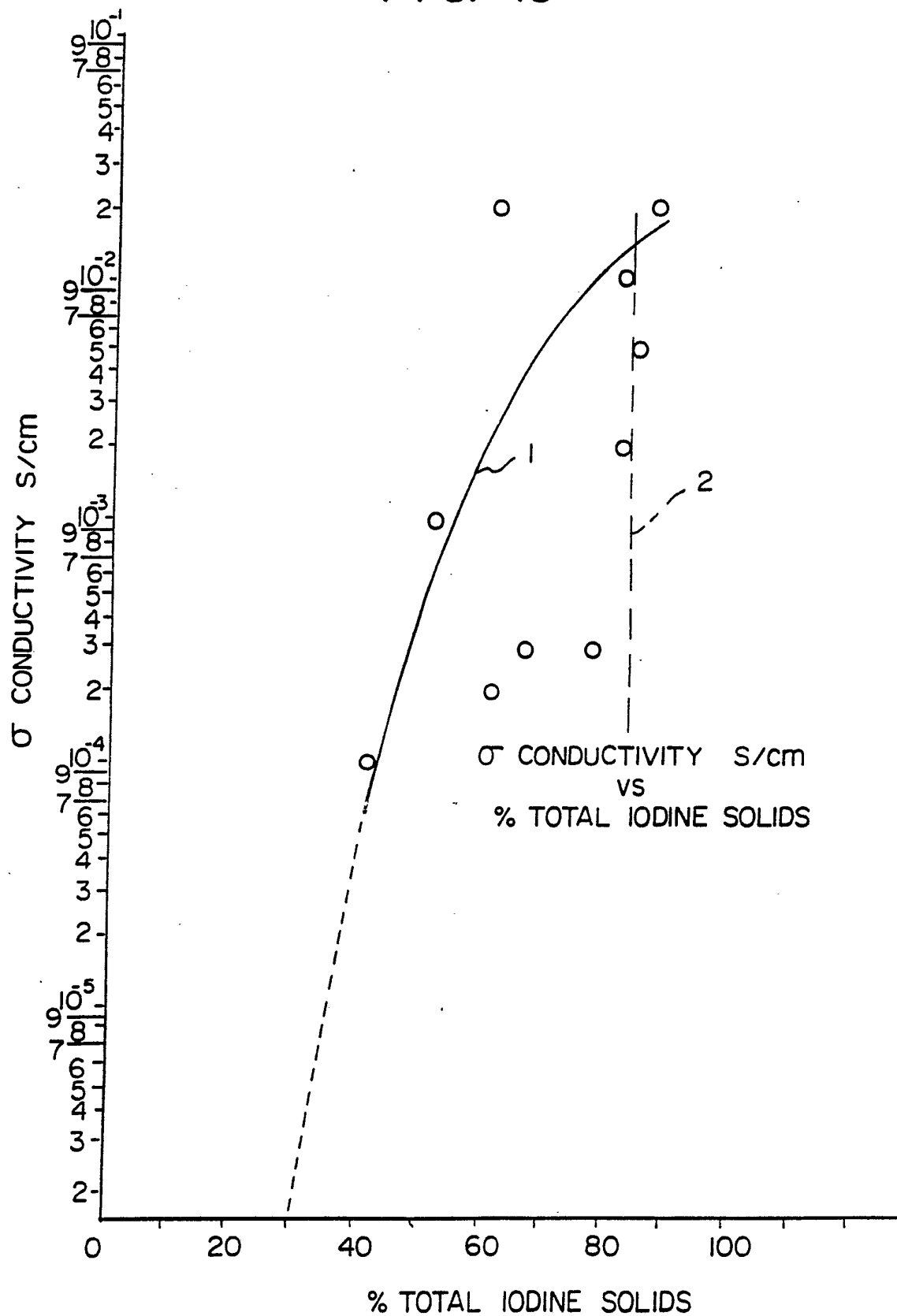
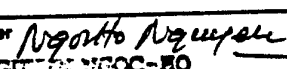


FIG. 16



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/07326

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *		
According to International Patent Classification (IPC) as to both National Classification and IPC IPC (5) H01L 29/28, 27/14, 29/88, 27/12, 23/48, 31/00 U.S.Cl.: 357/8,30,12,4,58; 136/263		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S.	357/8,30,12,4,68; 136/263	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4,574,161 (MARKS) 04 March 1986 See Figs. 1-5 and columns 3-8.	1-38
A	JP, A, 56-130976 (AGENCY OF IND. SCI. TECH.) 14 October 1981.	
A	JP, A, 62-222669 (TOSHIBA K. K.) 30 September 1987.	
A	JP, A, 02-001168 (TOSHIBA K.K.) 05 January 1990.	
* Special categories of cited documents: ¹⁰ "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "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		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
30 January 1992	18 FEB 1992	
International Searching Authority	Signature of Authorized Officer	
ISA/US	 William Mintel INTERNATIONAL DIVISION	