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54 **Solar cell device.**

57 A solar cell device comprises first and second photoactive materials (1, 2) deposited on opposite sides of a transparent insulating substrate (3). The first photoactive material (1) has a larger energy bandgap than that of the second photoactive material (2) and the first photoactive material is responsive to light of different wavelengths to those of the light to which the second photoactive material is responsive. A metal layer (4) formed on the second photoactive material reflects light back through the structure and may extend around the edge of the substrate to electrically connect the solar cell on one side of the substrate to the solar cell on the other side of the substrate. A metallic grid (5) forms an ohmic contact to the first photoactive material. The solar cells may be of the P-N junction or Schottky barrier types.

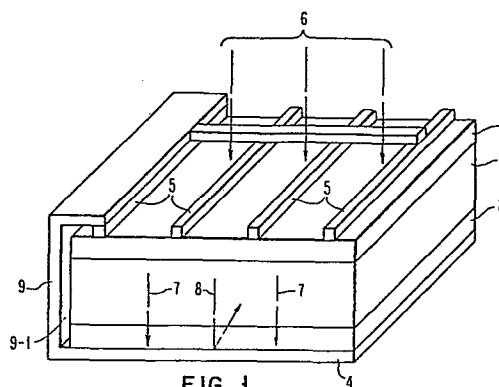


FIG. 1



SOLAR CELL DEVICE

This invention relates to solar cell devices, and more particularly to solar cell devices with a solar cell formed on each side of an insulating substrate.

H. Hovel, in "Novel Materials and Devices for Sunlight Concentrating Systems", IBM J. Res. and Dev., 22, 112, (1978), describes the advantages of "multicolour" solar cells. By using several materials with different energy bandgaps in optical series, the usual energy losses which limit solar cell efficiencies to less than 30% are overcome.

U.S. Patent 4,094,704 describes a solar cell device comprising first and second photoactive materials deposited on opposite sides of a transparent insulating substrate.

The invention seeks to provide an improved solar cell device which can have an efficiency approaching or exceeding 40%.

A solar cell device according to the invention comprises a transparent insulating substrate having a first photoactive material deposited on one side thereof and a second photoactive material deposited on the opposite side thereof, the second photoactive material being responsive to light of different wavelengths to those of the light to which the first photoactive material is responsive and is characterised by a reflective metallic layer being formed on the second photoactive material.

Semiconductors grown upon foreign substrates are generally polycrystalline in nature unless special conditions prevail. As an example, layers of GaAs, GaAlAs, GaAsP, Si, Ge and others are polycrystalline when grown upon quartz which is a transparent insulating material. Under special conditions in which the substrate is monocrystalline and the lattice parameters of the semiconductor are close to those of the substrate, and where the temperature and other growth conditions are carefully chosen, a monocrystalline epitaxial semiconductor layer can be grown upon a transparent insulating substrate. Polycrystalline layers on transparent insulating substrates can form the basis for low cost, moderately high efficiency tandem solar cells while monocrystalline layers on transparent insulating substrates can form the basis for higher efficiency structures which may be more costly but which can be used in concentrating systems where efficiency is more important than cost (see the Hovel article mentioned above).

The invention will now be explained by way of example, with reference to the accompanying drawings in which four different solar cell devices embodying the invention are represented in Figs. 1 to 4, respectively.

In a first embodiment of the invention (FIG. 1), semiconductor layers 1 and 2 are deposited upon a transparent insulating substrate 3. A reflective metal layer 4 covers the bottom layer 2, while a grid of metal 5 forms ohmic contact to the top layer 1. Light 6 enters through the top layer 1 which has a larger energy bandgap than layer 2. A portion of the light 7 whose photons have less energy than the energy bandgap of layer 1 is transmitted through the substrate to the semiconductor layer 2. A portion of the light 8 not absorbed by layer 2 on the first pass is reflected by the metal layer 4 and can be absorbed on the second pass. A metal layer 9 can be used to wrap-around the edges of the structure to ohmically

connect the two solar cells. Region 9-1 may be an actual physical separation between wrap-around metal 9 and the regions 1, 2 and 3, or it may be an insulator acting as a stand-off to separate metal 9 from the semiconductor layers 1 and 2. In cases where metal 9 forms a low leakage electrical contact to semiconductor layers 1 and 2, metal 9 may touch layers 1 and 2 (as well as substrate 3) and the region shown as 9-1 will be absent. The layers 1 and 2 may be polycrystalline in general, but if the substrate and semiconductor layers and growth conditions are appropriately chosen, they may be epitaxial and monocrystalline. Techniques for choosing such conditions and materials are well known to crystal growth specialists.

The necessary devices made on layers 1 and 2 can be formed with Schottky barriers, p-n homojunctions, or heterojunctions. FIG. 2 shows an example of a structure using two Schottky barriers. Semiconductor layers 11 and 12 are deposited upon transparent insulating substrate 10. These semiconductor layers may be, for example, n-type conducting layers. Schottky barriers are formed by metal layers 13 and 14. Layer 14 is very thin, 60 to 200 Angstroms thick, so it is highly transparent to visible light. A grid 15 makes contact to the thin layer 14. The output electrodes are 16 and 17. Electrode 17 makes an ohmic contact to semiconductor 12 while wrap-around metal 18, shown connected to metal layer 13 at 18-3, makes ohmic contact to semiconductor layer 11. Region 18-1 may be an actual physical separation between wrap-around metal 18 and the substrate 10, and the layers 11 and 12 or it may be an insulator acting as a stand-off to separate metal 18 from the semiconductor layers 11 and 12. Metal 18 touches and makes ohmic contact to layer 11 at point 18-2. In cases where metal 18 forms a low leakage electrical contact to semiconductor layer 12, metal 18 may touch layer 12 (as well as substrate 10 and layer 11) and the region shown as 18-1 will be absent. Layer 13 is a thick optically reflective metal layer. An anti-reflection layer 19 can be used to maximize the transmittance of light through the thin metal layer 14.

Slightly different configurations for practice of this invention can be utilized, if desired. FIG. 3 shows an example of a tandem structure which utilizes opposite conductivity-type semiconductors with Schottky barriers. N-type semiconductor 21 and p-type semiconductor 22 are deposited on opposite sides of transparent insulating substrate 20. Reflective metal layer 23 forms a Schottky barrier to layer 22 while thin semi-transparent metal layer 24 forms a Schottky barrier with layer 21. A metal grid 25 contacts the metal layer 24 while electrodes 26 and 27 lead to the electrical load. Wrap-around metal layer 28 makes ohmic contact to both semiconductor layers 21 and 22, and may touch substrate 20. An anti-reflection coating 29 is shown covering layer 24 and grid 25.

The structure of FIG. 3 can be made using p-type silicon as layer 22 and n-type GaAlAs or GaAsP as layer 21. Metal layer 23 is Al and layer 24 is Au. Grid 25 can be made with Au and wrap-around metal 28 is made with Ti/Ag. Anti-reflecting layer 29 is made with TiO_2 . The substrate 20 is Al_2O_3 .

An example of a structure utilizing p/n junctions is shown in FIG. 4. Transparent insulating substrate 30 has semiconductor layers 31 and 32, and 33 and 34 on respective sides. Semiconductor layers 31 and 32 form a p/n junction and semiconductor layers 33 and 34 form another p/n junction. Reflective metal 35 forms an ohmic contact with layer 34 and a metal grid 36 makes an ohmic contact with layer 32. A wrap-around contact 38 is used to connect the two p/n junctions into electrical series. Region 38-1 may be an actual physical separation between wrap-around metal 38 and the regions 30, 31 and 33, or it may be an insulator acting as a stand-off to separate metal 38 from the semiconductor layers 31 and 33. In cases where metal 38 forms a low leakage electrical contact to semiconductor layers 31 and 33, metal 38 may touch layers 31 and 33 (as well as substrate 30) and the region shown as 38-1 will be absent. Metal

layer 38 may touch regions 34 and 32. An anti-reflection layer 37 covers the top surface. Electrodes 39 and 40 make ohmic contact to layers 31 and 33, respectively.

The two p/n junctions in FIG. 4 formed by layers 31/32 and 33/34 may be p/n homojunctions or p/n heterojunctions or one of each. For example, layers 33 and 34 may be of the same semiconductor material to form a homojunction while layers 31 and 32 may be of different semiconductor materials to form a heterojunction. Both materials 31 and 32 must then have larger bandgaps than the material comprising layers 33 and 34.

One embodiment of the structure of FIG. 4 would start with a substrate 30 of Al_2O_3 upon which there is deposited by vapour growth a region 33 of p-type Ge and a region 34 of n-type Ge. On the opposite face of the Al_2O_3 a layer 31 of n-type GaAs and a layer 32 of p-type GaAlAs would be deposited. Layers 35, 36, 38, 39 and 40 can all be made with Ti/Pd/Ag, which makes an ohmic contact to each semiconductor layer. Anti-reflecting layer 37 is made with TiO_2 .

Each of the FIGS. 1 to 4 has shown a wrap-around contact which electrically connects the two solar cells. This wrap-around connector can be left off if desired and the two solar cells operated in separate circuits. The use of an insulating transparent substrate ensures that complete electrical isolation can be achieved. If the two solar cells are operated in separate circuits, each solar cell must have two electrodes.

Suitable transparent substrate materials include spinel, quartz, beryllium oxide, zinc sulfide, sapphire, alumina, and glass. Suitable semiconductor materials include Ge, crystalline Si, GaSb, InP, GaAs, GaInAs, GaAsP, GaAlAs, CdS, CdSe, CdTe, amorphous Si and GaP.

Each of the structures of FIGS. 1-4 can be made with either polycrystalline or monocrystalline semiconductor layers. For highest efficiency of conversion of solar energy to electrical energy, single crystal layers are desired with electrical properties as close to bulk properties as possible. A crystal perfection accommodation region may then be desirable between the substrate and the active semiconductor layer. Crystal perfection accommodation regions are described in U.S. Patent 4,202,704. The crystal perfection accommodation region may be a wide bandgap semiconductor which "grades" the lattice properties of the substrate towards those of the active semiconductor layer and therefore reduces the defect density that would occur in the active layer.

CLAIMS

1. A solar cell device comprising a transparent insulating substrate (3) having a first photoactive material (1) deposited on one side thereof and a second photoactive material (2) deposited on the opposite side thereof, the second photoactive material being responsive to light of different wavelengths to those of the light to which the first photoactive material is responsive, the solar cell device being characterised by a reflective metallic layer (4) being formed on the second photoactive material.
2. A solar cell device as claimed in claim 1, in which the first photoactive material has a larger energy bandgap than that of the second photoactive material.
3. A solar cell device as claimed in claim 1 or claim 2, in which the reflective metallic layer extends around the edge of the substrate and makes contact with a portion of the first photoactive material so that the solar cell on one side of the insulating substrate is electrically connected to the solar cell on the other side of the substrate.
4. A solar cell device as claimed in any of the preceding claims, in which a transparent metallic layer is formed on the first photoactive material so as to form a solar cell having a Schottky barrier.
5. A solar cell device as claimed in claim 4, in which the reflective metallic layer forms a Schottky barrier with the second photoactive material.
6. A solar cell device as claimed in claim 3, in which P-N junctions are formed in each of the first and second photoactive materials.

7. A solar cell as claimed in any preceding claim, in which the transparent insulating substrate is of material selected from Al_2O_3 , Spinel, Quartz, BeO, Glasses and Aluminas.

8. A solar cell as claimed in any preceding claim, in which the first photoactive material is selected from GaAs, GaAlAs, GaP, amorphous Si, GaAsP, CdS, CdSe and CdTe.

9. A solar cell as claimed in any preceding claim, in which the second photoactive material is selected from crystalline Si, Ge, GaSb, GaInAs, and InP.

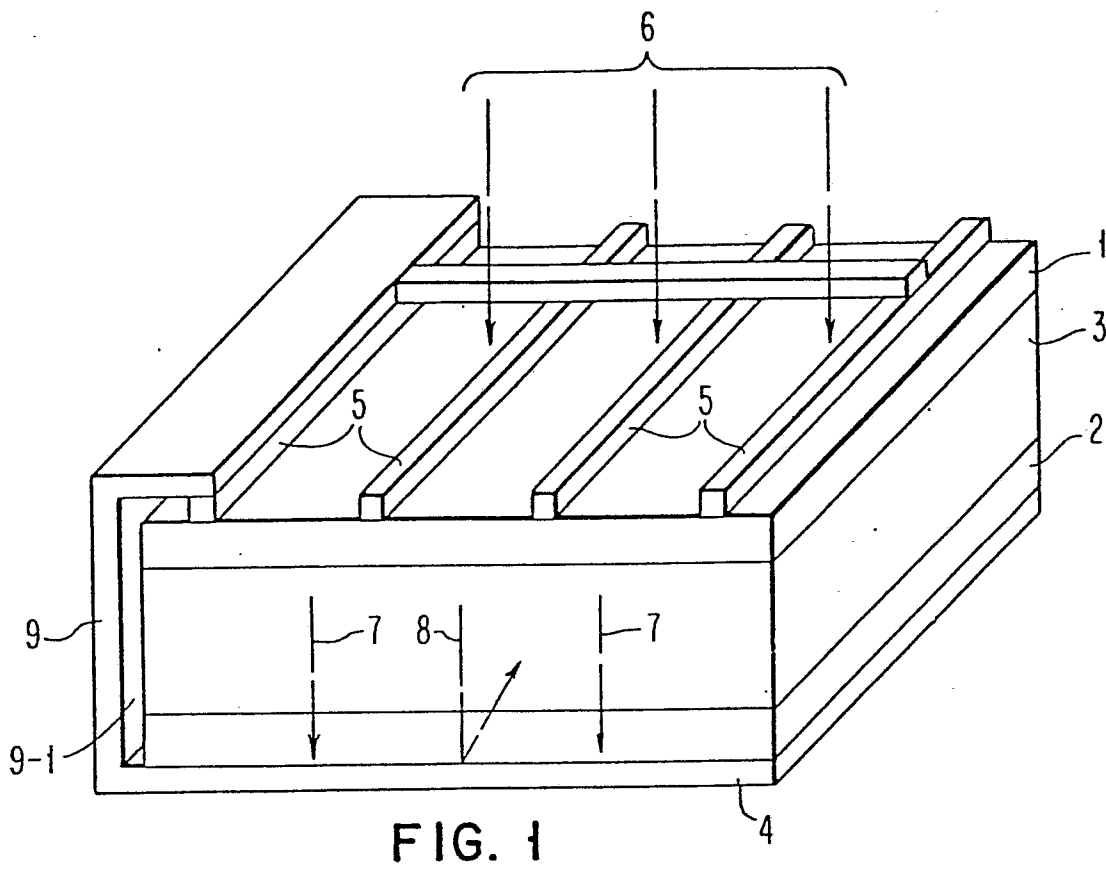


FIG. 1

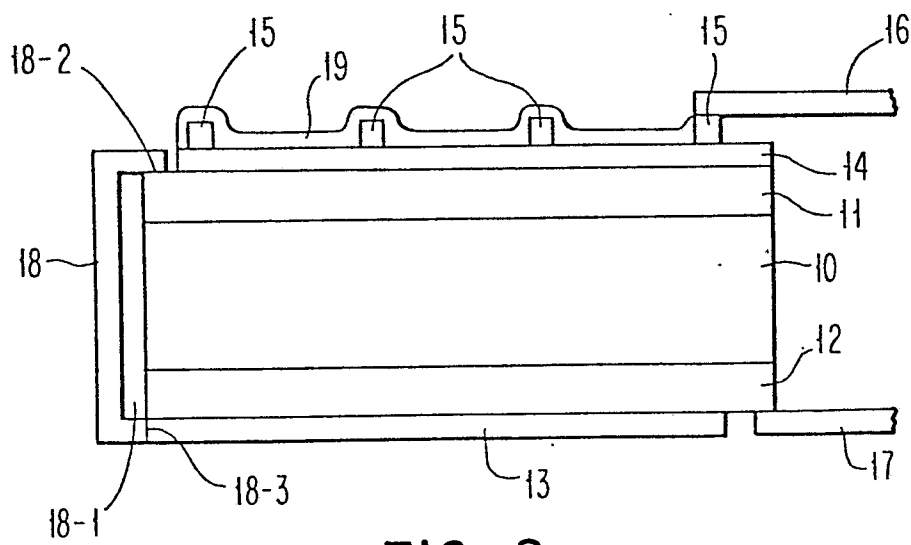


FIG. 2

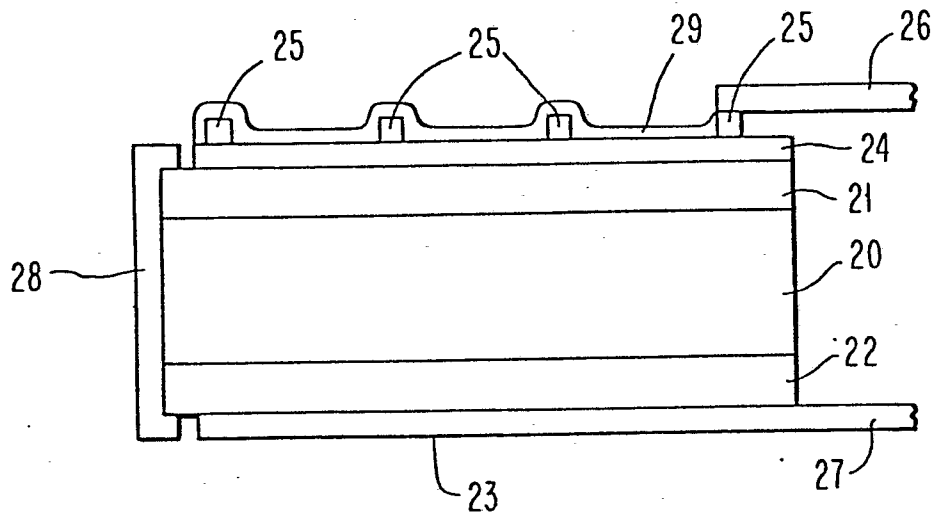


FIG. 3

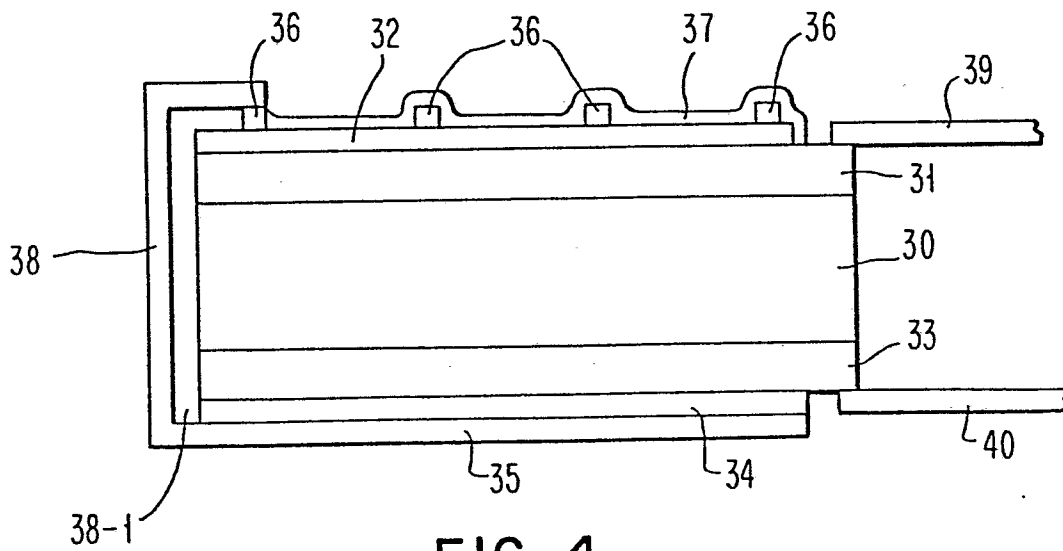


FIG. 4