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(54) Amorphous silicon photovoltaic device

(57) Series connected solar cells comprise a metal film substrate 1, e.g. stainless steel or Fe—Ni—Cr alloy, an insulating film 2 of heat resistant resin, e.g. polyimide, or of chromium oxide, electrodes 3, 5 and an amorphous silicon film 4. Insulating film 2 may be formed by selective oxidation of substrate 1 or by sputtering, vapour deposition, or coating, and may be of double layer construction.

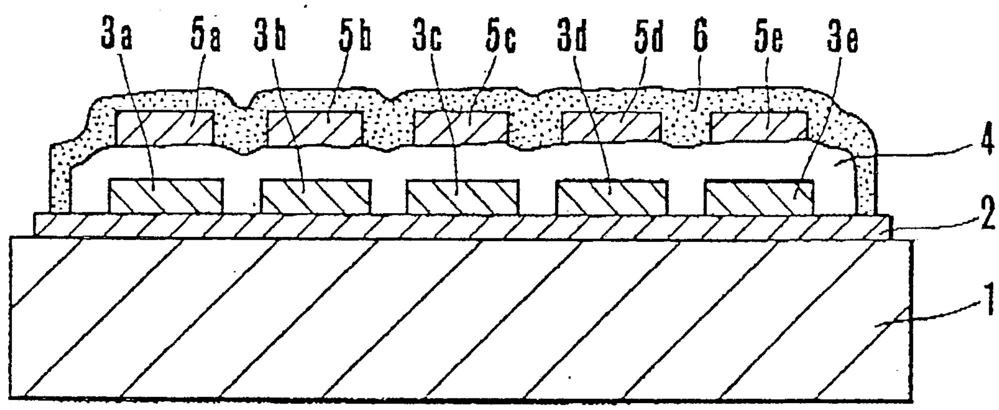

FIG.2

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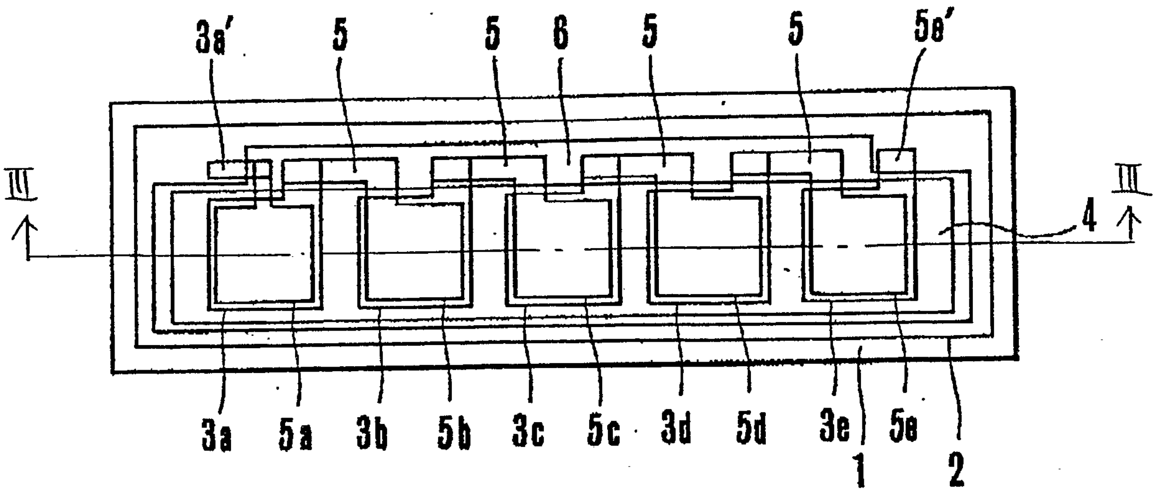

FIG.1

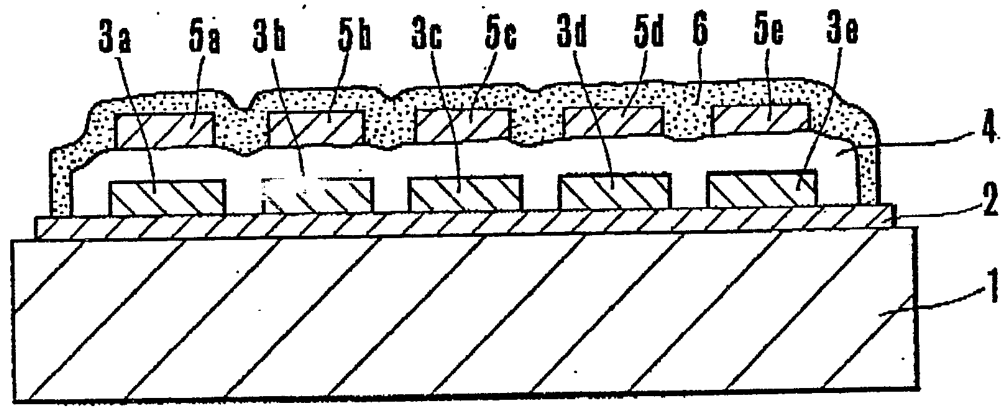

FIG.2

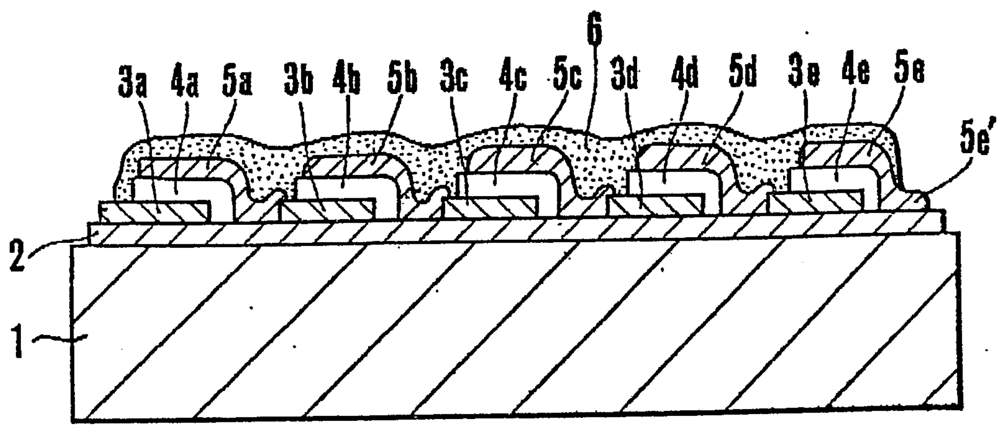

FIG.3

SPECIFICATION

Amorphous silicon photovoltaic device

This invention relates to an amorphous silicon photovoltaic device and more particularly, to a structure of an insulating film on a substrate surface, on which an amorphous silicon film is formed.

Recently, there is increasing interest in photovoltaic devices, especially a solar battery as a new source of energy. Among various solar batteries, particularly those using amorphous silicon are thought to be promising. One reason for this is that the solar energy is harnessed free from pollution problems and will never be exhausted. Another reason is that while the conventional solar battery, for instance one consisting of single crystal silicon, is very expensive and is used only in special fields, the amorphous silicon solar battery can be produced at a greatly reduced cost.

Hitherto, the substrate of the amorphous silicon solar battery has been chiefly formed of a transparent glass plate or a stainless steel plate. The glass or stainless steel plate, when used as the substrate of the amorphous silicon solar battery, has many excellent features.

The glass or stainless steel plate, however, is not always desirable as the substrate of the amorphous silicon solar battery from the standpoint of its cost.

One of the grounds for the possibility of cost reduction of the amorphous silicon solar battery is that it is possible to form an amorphous silicon film having a large area continuously and automatically. To make use of this advantage, it is desired to use a long and thin film web which can be rolled continuously.

The output voltage of the amorphous silicon solar battery cell is usually below 1 volt. In practical use, however, the voltage of a power source is required to be above 1 volt. Usually, therefore, a plurality of solar battery cells are used in series connection. From the standpoint of effecting cost reduction, it is essential to be able to form them integrally on the same substrate.

Therefore, there has been proposed an amorphous silicon solar battery which uses a stainless steel film as a substrate on which amorphous silicon is formed.

Where the stainless steel film is used as the substrate, however, the following problems arise. In order to form a plurality of solar battery cells in series connection on a substrate, electrodes of the same polarity as the solar battery cells must be electrically isolated from one another. Where the solar cells are formed directly on the substrate of a stainless steel film, however, electrodes of the same polarity as the cells are electrically connected, that is, they cannot be connected in series, because stainless steel has high electric conductivity. In order to attain the series connection of a plurality of amorphous silicon solar battery cells formed on a stainless steel film, therefore, it is necessary to electrically isolate the amorphous silicon solar battery cells from the stainless steel film by forming an insulating layer on the surface of the stainless steel film prior to the formation of the amorphous silicon solar battery cells.

By the present invention it is possible to provide an amorphous silicon solar battery capable of providing sufficiently high electrical insulating resistance for the formation of the solar battery.

By the present invention it is possible to achieve sufficiently high electrical insulation and smoothness for the formation of the solar battery.

It is also possible to achieve sufficiently high electrical insulation and dense formation of the solar battery.

According to one aspect of the invention, an amorphous silicon solar battery has a substrate of a stainless steel film and a thin heat-resistant resin film is formed on the substrate. A metal electrode is formed on the heat-resistant resin film, an amorphous silicon film is formed on the metal electrode, and an electrically conductive and transparent electrode is formed on the amorphous silicon film.

According to another aspect of the invention, an amorphous silicon solar battery has a substrate of a stainless steel film and a chromium oxide film is formed on the substrate. A metal electrode, an amorphous silicon film and an electrically conductive and transparent electrode are formed on the chromium oxide film in the order mentioned above.

Fig. 1 is a plan view showing the essential part of one embodiment of an amorphous silicon solar battery according to the invention;

Fig. 2 is a sectional view of the solar battery shown in Fig. 1; and

Fig. 3 is a sectional view, taken on line III—III in Fig. 1, showing another embodiment of the amorphous silicon solar battery according to the invention.

Referring to Figs. 1 and 2, a substrate 1 is a stainless steel substrate of about 100 m thickness, for example, having a flexibility and heat resistance. It is polished so that its surface is flat within 0.1 μm, for example. A thin high polymer resin film 2, for example, of polyimide, most suitably polyimide isoindroquinazolinedione, having a thickness of approximately 5 μm is formed on the polished surface of the stainless steel substrate 1.

The film is formed by uniformly coating the resin in the liquid phase by means of a spinner, spray or dipping, or roller coating process and by sintering it at a high temperature of approximately 350°C. Metal electrodes 3a to 3e having a thickness of approximately 2,00 nm and spaced apart from each other at a predetermined distance, are then formed by sputtering stainless steel on the thin resin film 2 formed on the stainless steel substrate 1. An amorphous silicon film 4 including layers of different conductivity types is then formed in the order of conductivity types of p, i and n or n, i and p using the plasma

CVD with the substrate temperature set to approximately 250°C, thus covering the metal electrodes 3a to 3e. Electrically conductive transparent metal electrodes 5a to 5e are then formed on the amorphous silicon film 4 such that they face the metal electrodes 3a to 3e and extend up to one end portion of adjacent lower electrodes 3a to 3d by sputtering In_2O_3—SnO_2 to a thickness of approximately 80 nm. Finally, a SiO_2 passivation film 6 of a thickness of approximately 200 nm is formed to cover the upper electrodes 5a to 5e by sputtering SiO_2. In the above way, a solar battery having five series-connected amorphous silicon solar battery cells is completed. In this case, interconnection 5 for the five amorphous silicon solar battery cells is formed simultaneously with the formation of the electrode pattern of the upper electrodes 5a to 5e. Further, lead terminals 3a' and 5e' for output voltage are formed on one end portion of the metal electrode 3a and one end portion of the upper electrode 5e.

With the above construction, in which the top surface of the stainless steel substrate 1 is polished and the thin heat-resistant resin film 2 is formed on that surface, sufficient smoothness for the substrate of the solar battery cells can be obtained, and also the stainless steel substrate 1 and amorphous silicon film 4 can be perfectly insulated from each other. It was shown that an open-circuit voltage of approximately 3.1 volts and a short-circuit current of approximately 18 A could be obtained under approximately 200-lux fluorescent lamp illumination. In this case, the open-circuit voltage per cell (with light-receiving area of 1 cm^2) was approximately 0.62 volts, and no loss due to defective insulation between adjacent cells occurred. The amorphous silicon solar battery constructed in the above manner was tested by bending them 10^5 times to a radius of curvature of approximately 60 mm. The results of the test showed that the deterioration of energy conversion efficiency was less than 5%.

While the above embodiment has used the stainless stell substrate of a thickness of approximately 100 μm as the flexible and heat-resistant substrate on which the amorphous silicon film is formed, this is by no means limitative and the same effects as described above can be obtained by replacing this stainless steel substrate with a metal substrate, for instance, an Fe-Ni alloy substrate of about 100 μm thickness, or by using as the heat-resistant film, "Capton" (a trade name) composed of polyimide resin, for example. The thickness of the substrate is not limited to 100 μm.

Further, while in the above embodiment the thin heat-resistant resin film formed on the substrate has a thickness of approximately 5 μm, this thickness will vary depending upon the thickness of the substrate, and it ranges from 0.1 to 100 μm. If the thickness is below 0.1 μm, sufficient insulation cannot be obtained. If the thickness exceeds 100 μm, on the other hand, the film will be peeled off when the solar battery is bent. Thus, the suitable thickness range is 0.1 to 100 μm. The best range is 2 to 10 μm in consideration of the film characteristics, productivity and other factors.

As has been described in the foregoing, according to this embodiment of the invention, the thin heat-resistant resin film is formed on the flexible and heat-resistant substrate on which the amorphous silicon film is formed. Thus, high surface smoothness and insulating property can be obtained, so that it is possible to obtain a highly reliable, high quality and high performance amorphous silicon solar battery, which has high bending strength and is free from defective insulation between adjacent cells.

Reference is now made to Fig. 3 illustrating, in sectional form, another embodiment of the present invention. A stainless steel substrate 1 is made as a rolled substrate of a thickness of approximately 0.1 mm from a thin metal web containing Cr. It is heated in hydrogen of a dew point of 0°C, which is held at approximately 850°C, for 30 minutes, whereby only Cr contained in the substrate 1 is selectively oxidized to form a thermally oxidized chromium oxide insulating film 2 on the substrate 1. Stainless steel is then sputtered on the thermal oxide film 2 to form lower electrodes 3a to 3e of approximately 200 nm thick and spaced apart from each other at a predetermined distance. An amorphous silicon film 4 including layers of different conductivity types is then formed on the respective lower electrodes 3a to 3e by depositing amorphous silicon in the order of conductivity types of p, i and n, or n, i, and p to approximate thickness of 30 nm, 500 nm and 15 nm, respectively, using the plasma CVD process with the substrate held at a temperature of approximately 250°C. Transparent upper electrodes 5a to 5e are then formed on the respective amorphous silicon film 4 so as to extend up to an exposed end portion of adjacent lower electrodes 3b to 3e by sputtering In_2O_3—SnO_2 to a thickness of approximately 80 nm. An SiO_2 passivation film 6 is then formed to cover the upper electrodes 5a to 5e by sputtering SiO_2 to a thickness of approximately 200 nm. Thus, a solar battery having five amorphous silicon solar battery cells connected in series is obtained. In this case, interconnection for the five amorphous silicon solar battery cells is formed simultaneously with the formation of the electrode pattern of the upper electrodes 5a to 5e. Further output voltage terminals 3a' and 5a' are formed respectively on an end portion of the lower electrode 3a and an end portion of the upper electrode 5e.

With the amorphous silicon solar battery, the open-circuit voltage measured under light illumination was five times as high as the voltage obtainable with a single amorphous silicon solar battery. For the sake of comparison, amorphous silicon solar battery samples were prepared under the same conditions with only exception that the insulating layer between the amorphous silicon solar battery cells and stainless steel substrate was formed by sputtering SiO_2 to a thickness of approximately 500 nm, and the open-circuit voltage was measured under light illumination. With most of the amorphous silicon solar battery samples thus prepared, the measured voltage was less than five times the voltage obtainable with a single amorphous silicon solar battery, with the voltage of a few samples reaching the value which is five times as high as that of the single amorphous silicon solar battery. It was confirmed that with these solar batteries, the insulation between the lower electrodes and stainless steel substrate was insufficient so that there was more or less leakage. With the method of manufacture of the amorphous silicon solar battery described above, in which the rolled thin stainless steel substrate 1 (thin stainless steel substrate fed from a roll of thin stainless steel web) of a thickness of 0.3 mm or less is used and only Cr contained in the stainless steel substrate 1 is selectively oxidized to form the chromium oxide film 2, it is possible to form a pinhole-free dense insulating film uniformly and continuously over a large area.

As a modification of the second embodiment, it is of course possible to form a double-layer insulation structure by forming a film of such material as SiO_2 and Al_2O_3 on the chromium oxide film 2. In this case, the insulating property can be further improved and surface smoothness of the insulating film can also be improved.

As a further modification, the chromium oxide film 2 may be formed by externally depositing only chromium oxide by means of sputtering or vapor deposition on the stainless steel substrate 1. In this case, the same effects as described above can be obtained.

While the above embodiment has concerned with the use of stainless steel as the metal containing Cr, this is by no means limitative, and entirely the same effects as described above can be obtained using Fe-Ni-Cr alloys, F-Cr alloys and Ni-Cr alloys.

As a still further modification, Cr or a metal containing Cr may be deposited by means of sputtering or vapor deposition on a thin metal sheet removed of Cr, and only Cr may be selectively oxidized in H_2 containing H_2O to form the insulating chromium oxide film. Further, the same effects may of course be obtained by depositing only chromium oxide by means of sputtering or vapor deposition on a thin metal sheet removed of Cr, thereby forming the chromium oxide film.

As has been described in the foregoing, according to second embodiment of the invention, a chromium oxide film is formed on a metal substrate on which amorphous silicon solar batteries are formed. Thus, a totally pinhole-free dense insulating film can be uniformly formed over a large area, so that it is possible to obtain highly reliable, high quality and high performance amorphous silicon solar batteries with high productivity.

Claims

1. An amorphous silicon solar battery comprising a substrate of a metal film, a thin heat-resistant resin film formed on said substrate, a lower electrode formed on said thin heat-resistant resin film, an amorphous silicon film formed on said lower electrode, and an upper electrode formed on said amorphous silicon film.

2. The amorphous silicon solar battery according to Claim 1 wherein the thickness of said thin heat-resistant resin film is set in a range of 0.1 to 100 μm.

3. An amorphous silicon solar battery comprising a metal film substrate, a chromium oxide film formed on said metal substrate, a lower electrode formed on said chromium oxide film, an amorphous silicon film formed on said lower electrode, and an upper electrode formed on said amorphous silicon film.

4. An amorphous silicon solar battery according to any preceding claim, wherein said metal film substrate is a stainless steel substrate of a thickness of 0.3 mm or less.

5. An amorphous silicon solar battery according to Claim 3, wherein said metal film substrate is made of a metal material containing chromium, and said chromium oxide film is formed by heating said substrate in H_2 containing H_2O.

6. An amorphous silicon solar battery as claimed in Claim 1 and substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

7. An amorphous silicon solar battery as claimed in Claim 3 and substantially as hereinbefore described with reference to Figure 3 of the accompanying drawings.

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