FRONT CONTACT AND SERIES CONNECTION PROBLEMS OF a-Si:H SOLAR CELLS ON POLYMER FILM SUBSTRATES

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ABSTRACT: In this paper the authors present results of different investigations concerning the structuring and module fabrication of a-Si:H solar cells on polymer film substrates. More precisely, this paper will discuss the evaluation of ITO and ZnO as top contacts for n-i-p a-Si:H solar cell modules and the possibilities of implementing monolithic serial connections in a one step, post deposition process by using selective laser scribing.
These features were successfully implemented in a small solar module (4 cells) on a polyimide film (PI/Al/ZnO/n-i-p/ZnO/met). The following performance values were achieved: Active area: 4*9.2 cm^2, Voc = 3.42 V, FF = 62.3%, Isc = 12.34 mA/cm^2.

KEYWORDS: a-Si - 1: Laser scribing - 2: Polymer film - 3

1. INTRODUCTION

In the past, in most cases glass or metal sheets were used as substrate materials for amorphous silicon solar cells. Polymer films could in the future, however, turn out to be more suitable substrates, for the following reasons:

At the present state of development it looks as if the efficiency of industrially produced amorphous silicon solar modules will remain for the near and midterm future clearly below 10%, in a range from 6-9%. The only way to compete at this level with the dominating crystalline silicon technology is by offering radically lower costs and unique application advantages.

Regarding costs, only the use of polymer films allows one to combine both the roll-to-roll continuous fabrication process, and an easy possibility of direct monolithic series connection, both factors being key cost reduction elements. Neither glass nor metal substrates can offer this combination. In addition, the polymer substrate materials themselves can potentially be very inexpensive.

Regarding applications, polymer substrates, are light, allows for large area modules with electrical series connection, flexible, and unbreakable, offer additional unique advantages, in particularly in the domain of building integration, where they can be laminated without using glass onto low-cost metal facades or roofs.

In order to connect the cells together, it is necessary to separate the cells on the same substrate, then to connect the back contact of one cell to the top contact of its neighbour. To achieve this, the laser scribing is the usual technique [3-9] and the most common way needs a 3 step process of laser scribing: deposition and scribing, respectively of the back contact, of the n-i-p structure and of the top TCO. This process demands specialised equipment for the alignment of the different steps of the scribing process and can be very problematic in the case of the use of a plastic film as substrate.

Another solution which allows one to reduce the number of laser scribing steps to a single step, only, consists of depositing a metallic layer on the other side of the substrate and then collecting the current through holes made in the substrate [4].

Here, we propose an alternative method of laser scribing which allows one, also, to reduce the structuring process of the device to a single step.

2. EXPERIMENTAL

The solar cells were deposited with the VHF-GD technique at a plasma excitation frequency of 70MHz within a single chamber deposition system [1]. The two coplanar electrodes have a surface of 133 cm^2, the substrate is fixed face down to the upper electrode. The excitation frequency is applied on the lower electrode. The effective temperature was kept between 170ºC and 240ºC depending on the layer.

The metallization of the back contacts (Al) was deposited by evaporation. ZnO (back and top contact) and ITO (top contact) were deposited by Chemical Vapour Deposition (CVD) and by sputtering, respectively.

The structuring of the cells was performed with a doubled Nd-YAG pulsed laser (532nm), the beam was deviated with prisms onto a lens which was mounted on a micrometric screw. This allows one to control the focusing (or defocusing) of the beam as it arrives on a XY-table onto which the samples are fixed. The power of the laser and the speed of the table are controlled by a computer.

Up to now, the flexible isolating paste was manually deposited with a syringe. The series connection was performed with Cr-Ag deposited by e-beam and by Joule effect, respectively, through a mask.

The cells were characterised by measuring illuminated j-V curves; thereby, a two-source solar simulator was used. Voc and FF were determined from the j-V curves. The short circuit current (Isc) was determined by integration of the spectral response curve of a selected cell.

3. TOP CONTACT OF n-i-p a-Si:H DEVICES WITH LARGE AREAS

A proposed structure for a n-i-p device has been previously given by us [2]. Because the cell is directly exposed to light, the generated current must be collected through the top TCO (Transparent Conductive Oxide) (Fig. 1). It is well known that for a cell of a few square centimetres or more, the top TCO will behave as a serial resistance and may substantially decrease the FF (fill factor) of the cell.

If an ITO (Indium Tin Oxide) top contact is used, the optimal thickness, from the optical point of view, is lower than 100 nm due to the fact that the ITO is usually flat and the optimisation of the thickness depends on interferometric effects.

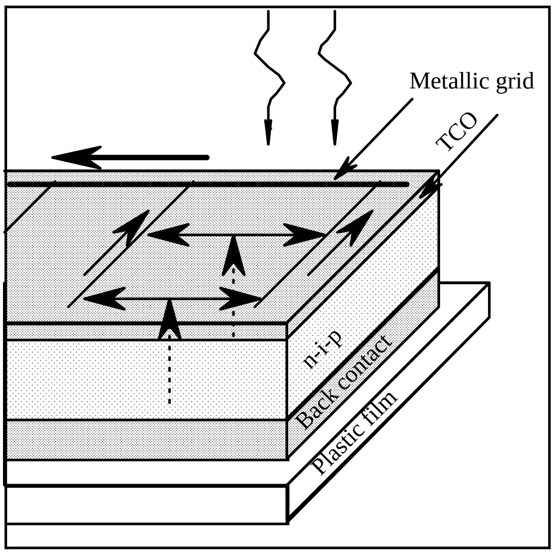

FIGURE 1: Structure of a n-i-p device. The photogenerated current is collected through the top contact.

In this case, for distances more than about 1 or 2 mm, the ITO layer is not thick enough to carry the current of a single cell without significant losses due to the serial resistance of this material. In other words, this means that it becomes very rapidly necessary to use a metallic grid with fingers to collect this current at the surface; however, the shadow effect of such a metallization will reduce the effective surface (i.e. the active area).

Another solution consists of using ZnO (Zinc Oxide) which has a higher conductivity than ITO, the thickness of such a TCO can be increased (1 to 2 µm) due to its high optical transmission coefficient. In this case, the losses in the top TCO are much lower than in the case of ITO. The distances between the metallic fingers can be increased, or the latter even be removed.

From this point of view, the ZnO top contacts clearly appear to be a more advantageous solution.

4. SELECTIVE STRUCTURING BY LASER SCRIBING

In our case, we tried to reduce to only one step of laser scribing the structuring process of the device. The function required is to separate the unit cells electrically, not to make series-connection. Figure 2 resumes the different kinds of laser scribing processes needed to perform this.

One should distinguish between:

· 1 <u>Total structuring</u>: all the layers are removed as far as the substrate. This structuring allows one to separate the cells deposited on the same substrate.

· 2 <u>Deep structuring</u>: the top TCO and the n-i-p structure are removed but not the back contact. The sweeping of a small surface with such a deep structuring method allows one to "open a window" as far as the back contact.

· 3 <u>Top structuring</u>: only the top TCO is removed. This kind of structuring can be used to define the area of each cell.

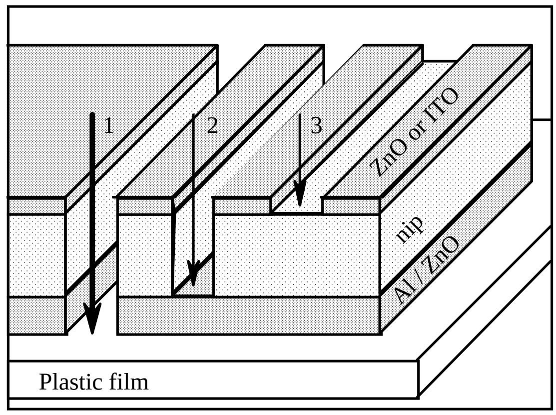

FIGURE 2: Selective laser scribing processes implemented with a 532nm laser (Nd-YAG frequency doubled). 1: <u>Total structuring</u>, all the layers are removed. 2: <u>Deep structuring</u>, the top contact and the n-i-p device are removed. 3: <u>Top structuring</u>: only the top TCO is removed.

5. RESULTS ATTAINED AND DISCUSSION ABOUT LASER SCRIBING

<u>Total structuring</u> is possible with both ITO or ZnO as top contact (see Fig. 4). We note that, for an appropriate power, all the layers are removed without damage of the plastic film. Nevertheless, the n-i-p structure is strongly deteriorated in the borders of the path of the scribe. This deterioration is due to the spallation and crystallisation of the material [5,7].

This structuring is appropriate for a separation of the back contacts of the cells but needs an other structuring process to define the area of each cell.

On Fig.4, the borders of the path (in black) show that the structure of the cell is deteriorated. The white region is the back contact (Al / ZnO) and, in the middle of the path, the plastic film.

<u>Deep structuring</u> shows the same effect (a deterioration of the n-i-p structure).

In Figure 5, the borders of the path (in black) show that the structure of the cell is damaged. The white region is the back contact of Al-ZnO.

No damage of the n-i-p structure were observed after the <u>top structuring</u> of an ITO top contact. This can be explained by the thin thickness (• 70nm) of this layer and the low energy needed to remove it.

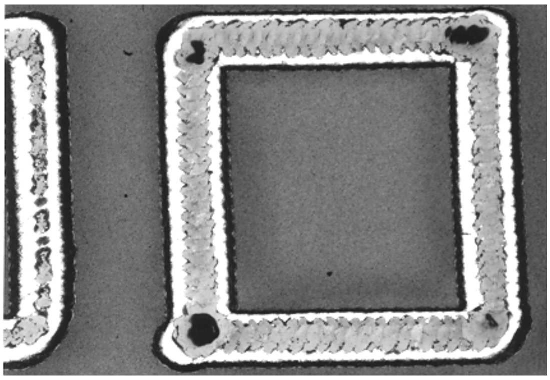

FIGURE 4: Photography (optical microscope) of a total scribe of the device PI / Al-ZnO / n-i-p / ZnO. The length of a side is 1 mm.

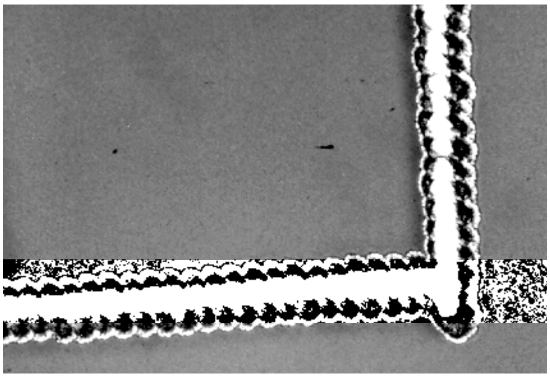

FIGURE 5: Photography of a deep scribe of the structure PI / Al-ZnO / n-i-p / ITO.

FIGURE 6: Photography of a top scribe of the structure PI / Al-ZnO / n-i-p / ZnO

Top structuring of ZnO is more problematic. On one hand, the wavelength of 532nm is inappropriate because the ZnO is highly transparent at this wavelength; therefore the ablation of this layer is performed by a local increase of the pressure in the a-Si:H layer. On the other hand, the thickness of the ZnO top contact is 2 to 3 time higher than the thickness of the cell, so that the power needed for its "top structuring" must be increased with respect to the power needed for ITO "top structuring". Such a power can lead to the deterioration of the a-Si:H structure (Fig. 6). We observed that the laser scribing of ZnO can generate certain "micro-shunts" all along the scribing path; however, the micro-shunts can be removed with a soft chemical etching step [6].

6. RESULTS OF SELECTIVELY LASER-SCRIBED SOLAR CELLS ON PLASTIC FILM SUBSTRATES

Figure 7 shows the design of the serial connection of the cells deposited on a plastic film and structured with the technique of selective scribing. Note that the thicknesses of the different layers are deliberately increased in the figure and the width of the scribes are relatively decreased.

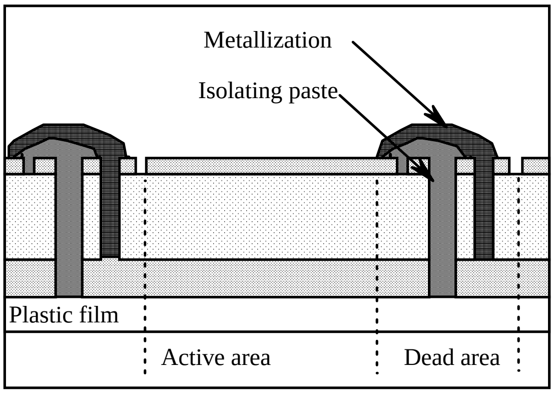

FIGURE 7: Monolithic serial connection of a n-i-p solar cell with the selective laser scribing process.

Figure 8 shows the process flow of the cells deposited on a plastic film. Note that all the depositions of the layers are performed before the laser scribing step. A substantial economic advantage of this method is that no special alignment is required for the different steps.

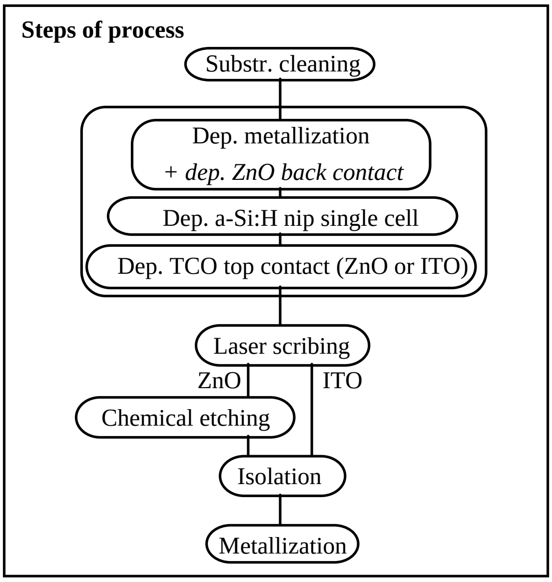

FIGURE 8: Process flow for a n-i-p solar cell deposited on a plastic film with the selective laser scribing process. Note the "one-step process" used here for laser scribing.

Figure 9 shows a prototype fabricated by our laboratory: the module consists of 4 single n-i-p cells according to the process flow previously described (see Fig.8). The area of each cell is about 11.5 cm^2 with an active area of 9.2cm^2

per cell. The active area can be increased with the automatization of the deposition of the isolating paste (manually performed up to now) and a reduction of the gaps between the different scribes (see Fig. 7). The characteristics of this module are: Voc = 3.42 V, FF = 62.3%, Isc = 12.34 mA/cm^2.

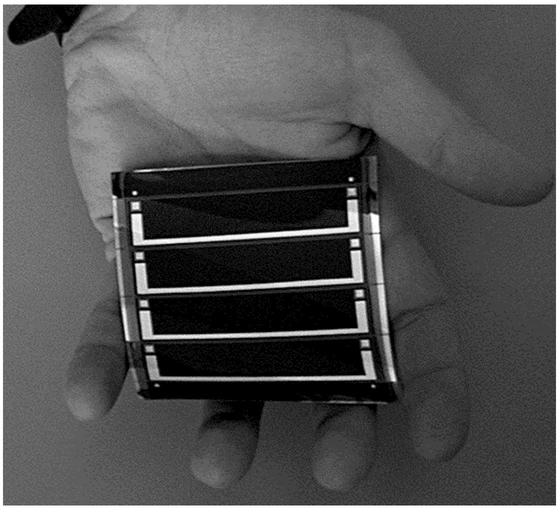

FIGURE 9: Cells deposited on plastic film. The structure is PI/Al-ZnO_{CVD}/n-i-p/ZnO_{CVD}.
The structuring is performed in a single pass, using the selective laser structuring process. The dimension of each cell are 7cm * 1.5cm.

7. CONCLUSIONS

We propose a new "one-step" laser scribing process for a-Si:H solar cell deposited on polymer films. First, we deposit all the different layers (back contact-n-i-p solar cell-top contact) then we selectively scribe the different layers with a frequency doubled Nd-YAG (532nm) laser. The interest of this method resides in the fact that there is no special alignment needed anymore between the different laser scribe steps, as was the case for the "conventional" process flow chart. We were able to implement a small module made up of 4 single cells of 9.2cm^2 each; the power is approximately 250mW under AM1.5.

8. ACKNOWLEDGMENTS

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