PLATED FRONT SIDE METALLIZATION ON TRANSPARENT CONDUCTING OXIDE UTILIZING LOW-COST APCVD SIO2 INSULATING LAYER

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ABSTRACT: An important process step for galvanic metallization on transparent conducting oxide (TCO) is the preparation of a plating mask, which is an electrically insolating layer in the area where no metal deposition is desired. A polymer ink is often used for this purpose. A disadvantage, however, is that the front side of the solar cell is largely coated with polymer, hence large amounts of it must be recovered or, even worse, disposed of together with the solvents used in the later stripping process. To reduce costs, we take a different approach, namely screen-printing a polymer ink in the form of the later front metal grid, applying a full-area SiO_2 coating at room temperature and lift off. This way we obtain a SiO_2 instead of a polymer plating mask. At first glance, replacing polymer ink with SiO_2 coating does not seem to be cost-effective. However, we have used a new atmospheric pressure chemical vapor deposition (APCVD) technology developed by us that potentially has very low investment and operating costs. In this work, we investigated this approach and demonstrated the performance of the SiO_2 plating mask on heterojunction Si solar cells.

Keywords: Heterojunction, ITO, Metallization, Electroplating

1 INTRODUCTION

Interest in solar cells featuring heterojunction or passivated contacts is growing because they are the leaders in high energy conversion efficiency [1]. A transparent conducting oxide (TCO) often is applied to the front and rear sides of these cells because TCOs provide relatively low sheet resistance for low-loss lateral current transport on a-Si:H or polycrystalline Si and simultaneously act as an efficient antireflection or reflection coating, respectively. Indium tin oxide (ITO) is characterized by high electrical conductivity and low light absorption and is therefore a widely used TCO. In industry, the bench mark for front side metallization on ITO is screen printing of low-temperature cured silver paste. In recent years, the combination of fine-line screen-printing and multi-wire interconnection has resulted in good silver savings. Silver consumption can be further reduced or even eliminated by plated metallization on Cu basis. Ni/Cu/Ag or Ni/Cu/Sn metallization stacks are often used. A thin Ni layer provides low contact resistance and good adhesion to ITO, thick Cu acts as highly conductive layer and thin Ag or Sn protects Cu from oxidation. The plated metallization is characterized by a factor of about 2 lower line resistance compared to low-temperature cured silver paste [2] and thus enables more flexible contact grid designs with longer finger lines. A key process for electroplating on TCO is the preparation of a plating mask, i. e. an electrically insolating layer in the area where no metal deposition is desired. A polymer mask as described in [3-7] can be used for this purpose. In this process, the front side of the solar cells is largely coated with polymer. Hence, large amounts of organic material must be recovered from solvents used in the subsequent stripping process or have to be disposed together with the solvents.

There are several other ways to obtain plated metallization on silicon heterojunction (SHJ) solar cells described in [8-16]. They use vacuum tools for plasma-enhanced chemical vapor deposition or physical vapor deposition of thin films. In this work, we present a potentially cost-effective approach using our newly developed SiO_2 atmospheric pressure chemical vapor deposition (APCVD) technology [17, 18], which operates at room temperature without combustible gases such as SiH_4.

2 EXPERIMENTAL

Fig. 1 illustrates the sequence examined in this work for preparation of plated metallization on SHJ cells. The process steps are:

1) We start with *n*-type alkaline textured CZ SHJ solar cell precursors. The cells are coated on the front with ITO and metallized on the back with 500 nm thick evaporated Ag layer.

2) Screen-printing of a self-made paste of ethyl cellulose in the form of the contact grid on the front side of the cells. The viscosity of the paste has been

optimized in order to ensure sufficient masking of the ITO against SiO_2 deposition and to obtain a clearly-defined print image. The paste was dried at 50 °C for 1 min after printing.

3) APCVD of a SiO_2 film on the front side. A schematic cross-section drawing of the lab-type APCVD setup used is shown in Fig. 2. The device is made from plastic by 3D printing. Two gases are dosed through two separate openings into the deposition chamber. Depending on the gas flow rates, the deposition rate was 16 to 100 nm/min at room temperature.

4) Annealing at 200 ℃ for 1 minute. Annealing causes the solvent to evaporate and the polymer to shrink so that the oxide on top breaks, see Fig. 3. This is a prerequisite for the polymer paste to be stripped in the subsequent ultrasonic treatment in acetone for 10 minutes. Finally, the samples are rinsed in isopropanol and deionized water in order to remove polymer residuals and SiO_2 flakes.

5) Light-induced plating (LIP) of a 150 nm thick Ni seed layer in the open area of the SiO_2 plating mask produced steps 1 to 4. This was followed by LIP of 4 – 10 µm thick Cu for good electrical conductivity of the finger lines and 200 nm thick Ag to protect Cu from oxidation.
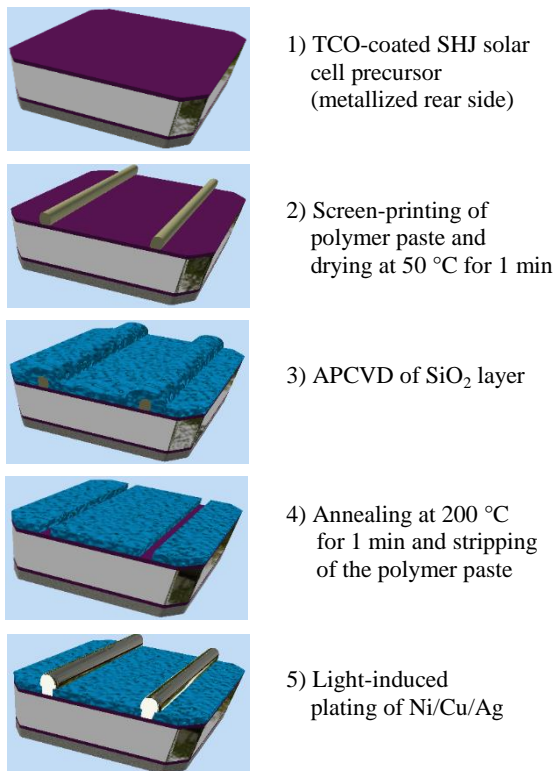

1) TCO-coated SHJ solar cell precursor (metallized rear side)

2) Screen-printing of polymer paste and drying at 50 °C for 1 min

3) APCVD of SiO_2 layer

4) Annealing at 200 °C for 1 min and stripping of the polymer paste

5) Light-induced plating of Ni/Cu/Ag

Fig. 1: Process sequence for the preparation of plated metallization on the ITO coated front side of SHJ solar cells.
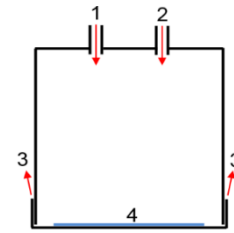

Fig. 2: Schematic cross-section drawing of the lab-type SiO_2 APCVD setup. 1) Inlet of gas 1, 2) inlet of gas 2, 3) exhaust, 4) solar cell.

APCVD SiO_2 mask
Polymer ink
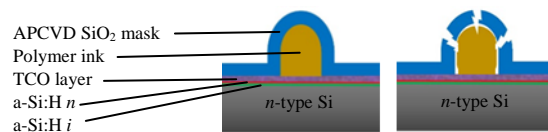TCO layer
a-Si:H n
a-Si:H i
n-type Si

Fig. 3: Schematic cross-section drawing of a polymer finger screen-printed on the front side of a SHJ solar cell and coated with a SiO_2 layer. Left: Before annealing. Right: After annealing at 200 C° for 1 min. The rear side is not depicted in this drawing.

The printed polymer finger lines were examined by confocal laser scanning microscopy. Secondary electron microscope (SEM) images were taken from the SiO_2 plating mask after stripping of the polymer paste and after LIP. Paste residuals on the ITO were analyzed by energy-dispersive X-ray spectroscopy (EDX). To assess the adhesion of the plated metallization on ITO, a 3M tape test was performed.

3 RESULTS AND DISCUSSION

3.1 Polymer mask

Fig. 4 shows optical microscope images of polymer fingers screen-printed on alkaline textured, ITO-coated front side of a SHJ solar cell. The image on the left was obtained for a paste with a too low viscosity. 1 – 2 µm high fingers with a width of 135 µm were found. The reason for this is extensive spreading of the paste on the textured surface. In contrast, the paste with higher viscosity delivered 12 µm high fingers, which are 45 µm wide, only 5 µm wider than the opening in the screen. In this case a low spreading was observed and no finger interruptions were found. Even after several days of storage of the printed sample at room temperature, the finger profile had not changed.
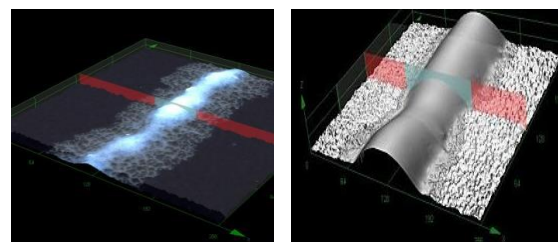

Fig. 4: Confocal microscope images showing the topography of two screen-printed polymer fingers on the front of a SHJ solar cell precursor. Left: Low viscosity

paste which reveals spreading. Right: Finger with high aspect ratio.

3.2 Microstructure of the APCVD SiO₂ layer

Fig. 5 shows a SEM image of a cross section of an about 90 nm thick APCVD SiO_2 layer on top of an alkaline textured ITO coated front side of a SHJ solar cell. It's the oblique flank of a pyramid to see. The ITO layer is relatively rough and voids have been found in the film. In contrast, the APCVD SiO_2 film is smooth and dense without voids, pinholes or cracks. It forms a conformal coating on the rough ITO layer
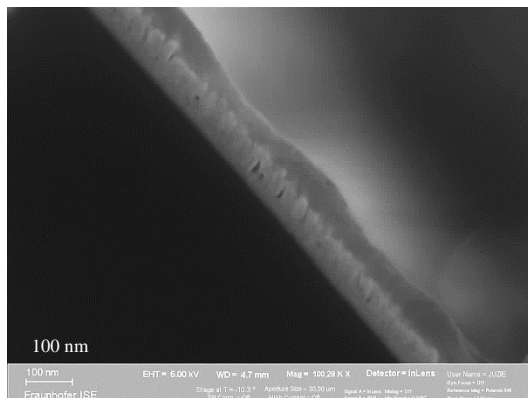

Fig. 5: SEM picture of a cross-section of a SHJ solar cell front side coated with ITO and an about 90 nm thick APCVD SiO_2 layer on top.

The deposition rate has a large influence on the microstructure of the SiO_2 layer. For deposition rates > 70 nm/min we found parasitic plating when using alkaline electrolytes, which is probably due to pores and cracks in the SiO_2 film. Therefore, we have used deposition rates from 15 to 50 nm in the following experiments.

3.3 Structure of the SiO_2 mask after polymer stripping

As described in paragraph 2, the annealing of the samples at 200 °C for 1 min facilitated the stripping of the polymer paste under the SiO_2 top layer by induced cracks in the SiO_2. A photo of the resulting SiO_2 plating mask on a SHJ solar cell is shown in Fig. 6 on the left. Due to the minimized spreading when using the highly viscous polymer paste, the edges of the finger openings in the SiO_2 layer were well defined, see Fig. 6 on the right. The width of the openings was about the same as the width of the printed polymer finger, i. e. about 45 µm.
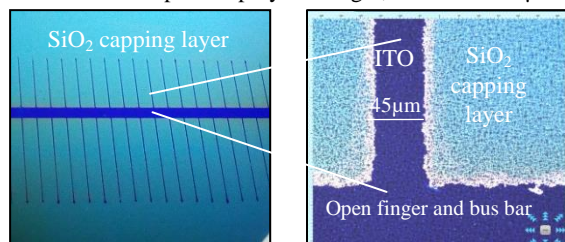

Fig. 6: Photo (left) and optical microscope picture (right) of an APCVD SiO_2 plating mask on a SHJ solar cell after polymer stripping showing open-fingers and bus bar.

SEM and EDX investigations were performed after stripping of the polymer paste to investigate whether polymer residuals were present in the open areas of the SiO_2 plating mask, see Fig. 7. The numbers in the EDX spectrum represent the mass fraction of each element detected. We found no large agglomerates of polymer paste in the SEM, but 1.6 wt% carbon was detected with EDX, indicating that the paste was not perfectly removed. Besides C there are In, O and Si. Due to 300 nm penetration depth of the electron beam and an ITO thickness of 75 nm, Si is also visible. The Sn content was below the detection limit of EDX.
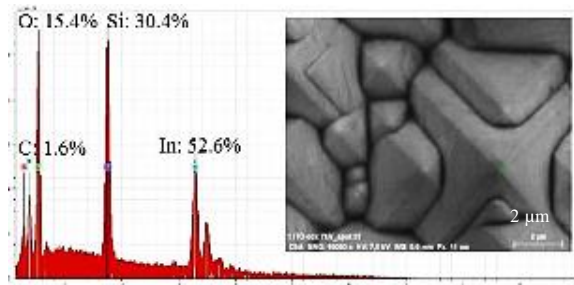

Fig. 7: SEM image (right) and EDX spectrum (left and in the background) of the ITO layer after polymer stripping.

3.4 Performance of the SiO_2 plating mask

The SEM study of a 70 nm thick APCVD SiO_2 layer on an alkaline textured ITO coated front side of a SHJ solar cell revealed 10 – 40 nm wide pinholes, see Fig. 8 at the top. As a result, metal is deposited at these locations during LIP, as shown in the SEM image in Fig. 8 at the bottom.
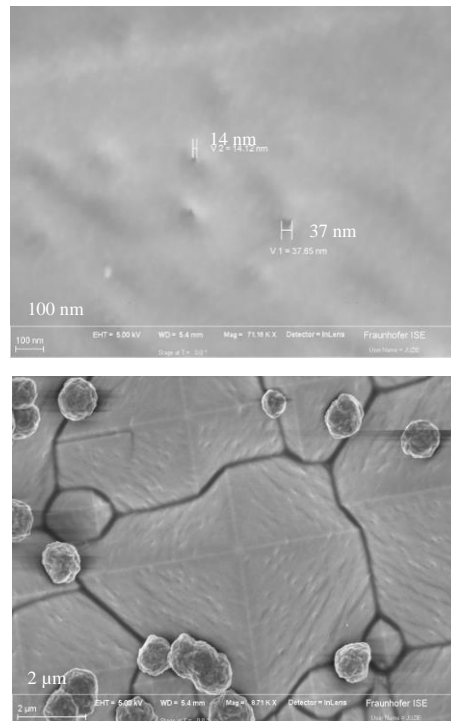

Fig. 8: SEM pictures of the alkaline textured ITO-coated front side of a SHJ solar cell after APCVD of about 70 nm SiO_2 (top) and after the subsequent LIP (bottom).

Already in section 3.2 it was proven that a 90 nm thick SiO_2 film completely covers the ITO. Fig. 9 shows a photo (top) and an SEM image (bottom) of a 90 nm thick APCVD SiO_2 layer on an alkaline textured ITO-coated front side of a SHJ after LIP of Ni, Cu and Ag. It can be seen that there is no parasitic plating as intended. In addition, there are no finger interruptions. In a performed tape test the metal fingers did not peel off. We conclude that the small amount of residual polymer as detected by EDX has no negative effect on the adherence or structure of the plated metallization.
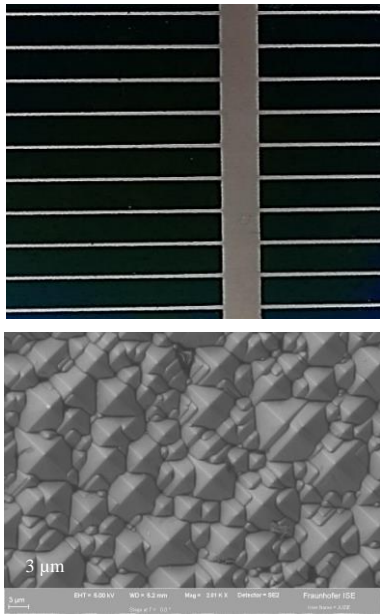

Fig. 9: Photo (top) and SEM image (bottom) of a SHJ solar cell after LIP of Ni, Cu and Ag.

4 CONCLUSION AND OUTLOOK

We have shown that the SiO_2 layer produced with our newly developed APCVD system can be successfully used as a plating mask on SHJ solar cells. Before SiO_2 deposition, we screen-printed a polymer mask in the form of the contact grid and locally removed the polymer and the oxide in a stripping process using solvents. A SiO_2 thickness of at least 90 nm was sufficient to prevent parasitic plating. There were no interruptions in the plated fingers and a tape test was passed demonstrating good adherence of the metal to the ITO.

The processing sequence described above is potentially a cost-effective route to galvanically metallize SHJ solar cells. It is characterised by the use of low-cost APCVD SiO_2, inexpensive polymer paste and low Ag consumption. Since the screen-printing of the polymer can easily be replaced by alternative printing technologies such as dispensing, finger lines narrower than 45 μm can probably be obtained in future developments.

5 AKNOWLEDGMENT

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