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FORMATION OF A CONDUCTIVE GRID ON THIN FILM MODULES GLASS BY LASER-PATTERNING

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ABSTRACT

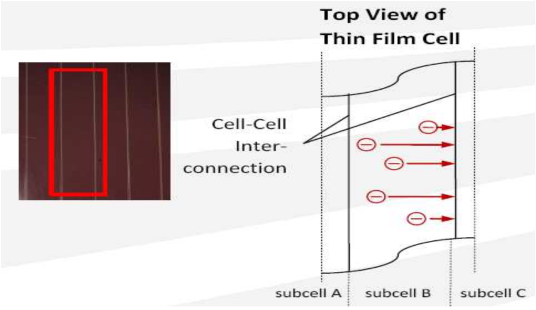
In thin film solar modules, transparent conductive oxides (TCOs) are commonly used as a front contact. The limited electrical conductivity and optical transparency of TCOs reduce the efficiency of thin film modules, so a compromise must be achieved between low-light absorption and good electrical conduction. In this work a new method for increasing the electrical-conductivity of TCO films and maintaining high optical transparency in solar modules by creating micron-sized metalized grooves in the substrate is presented. The grooves were machined into the glass substrate using a 266 nm pulsed UV laser and a relevant optical setup. Initial results show that ultra-fine gridlines down to 10 µm width with fully metalized sidewalls can be achieved. This is a factor of ten smaller than the gridlines produced by screen-printing. This paper presents the procedures for masking, laser processing and metallization and analyzes the impact this technique would have on solar cell performance.

INTRODUCTION

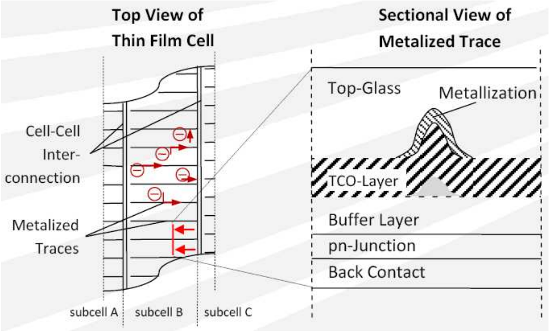
Thin film photovoltaic (PV) modules have two layers for lateral conduction of the electrical current generated - one on the front-side facing the sun (emitter side) and the other on the back-side (back contact). On the back-side of, a thin film module a metal with good electrical conductivity can be used, while the front-side layer must be both electrically conductive and optically transparent. For this purpose so called transparent conducting oxide (TCO) film [1, 2] are used.

Common TCO materials are tin doped indium oxide (ITO), fluorine doped tin-oxide (FTO) and aluminum doped zink oxide (AZO). The desired qualities of a TCO layer are high transparency to sunlight and high electrical conductivity to minimize electrical losses due to high series resistance. It is very challenging to obtain both properties in one TCO layer. To decrease lateral series losses, the TCO doping can be increased. Higher TCO doping, while leading to lower TCO sheet resistance, also leads to higher free carrier absorption in the near infrared, which increases photocurrent losses. Thus, the overall module design is a trade-off between the TCO resistivity and transmission, plus an influence on optimum absorber layer bandgap [3,4].

Even with increased thickness or doping of the TCO film, the resistivity is an order of magnitude higher than that of metals such as nickel or aluminum. For this reason, a different approach is proposed in this paper: The use of very thin metal grid lines to assist the TCO in its lateral conductivity. In a thin film module as shown in Fig. 1a, the generated charge carriers have to diffuse in the TCO over relatively long distances. With the help of a dense grid of small metalized traces as shown in Fig. 1b, the average diffusion length can be reduced significantly.



(a) Without front-side metallization



(b) With front-side metallization

Fig. 1: (a) Top views of thin film module with standard cell-to-cell interconnections showing lateral carriers travel path through the TCO, (b) Metalized grid fingers overlaid with TCO for improved lateral carrier conduction.

SIMULATION

Simulation of the impact of a metalized grid in conjunction with a TCO on module performance is presented in **Fig. 2** and **Fig. 3**. In **Fig. 2** it is observed that as the power gain from a metalized groove depends on the grid spacing with the optimum at around a grid line spacing of 0.3 cm. A grid spacing of 0.3 cm produced an optimum power gain of around 8% as shown in Figure 6. Calculations have also shown that a grid width of 50 um produced the best power gain of around 8%, provided a metallization thickness of 200 nm.

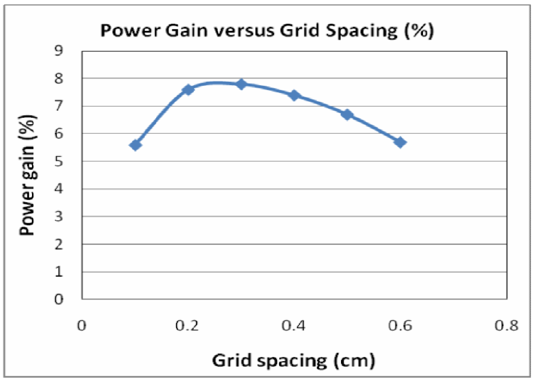


Fig. 2: Power gain as a function of the grid spacing.

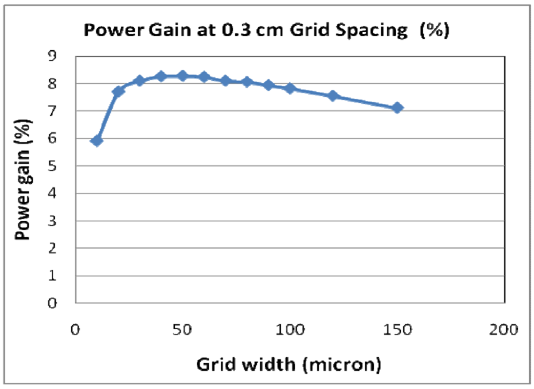


Fig. 3: Power gain as a function of the grid width at the optimum grid spacing of 0.3 cm.

Table 1 shows a summary of the conditions for the calculations on laser grooves for minimizing the power loss in a thin film PV module

As shown in these calculations, a thin TCO of 800 nm combined with metallic grid fingers of 50 μm width and 3 mm spacing is sufficient to transport the current of a single cell low losses of only 1.8 % resulting from high series resistance. TCO transmission loss is not considered in the calculations as it is the same in both scenarios.

Shadowing loss of such a gird finger design is 1.7 %. However, due to the V-shaped form of the grid fingers we estimate that half of the light can be recovered so only only half of the total shading is included in the calculations of the power loss in Fig. 2, 3 and Table 1. These calculations indicate therefore the overall potential of the technology, while a critical assessment of the loss mechanisms needs to be incorporated in subsequent experiments.

Table 1: Percentage power gain for baseline (no grids) and gridded TCO for thin film modules.

Specifications	**Baseline (No metal grids)**	**With metal grids**
TCO thickness	0.8 µm	0.8 µm
TCO resistivity	$1.5x10^{-3}$ Ω-cm	$1.5x10^{-3}$ Ω-cm
Grid finger spacing	N/A	3 mm
Grid finger width	N/A	50 µm
Grid finger length	N/A	10 mm
Material Resistivity	N/A	80 nΩ·m
Total power loss	**10.8%**	**1.8%**

EXPERIMENTAL

In order to achieve ultra fine gridlines with a width of 10 to 50 µm, a new manufacturing scheme has been developed as shown in Figure 2. The substrate (i.e. the front glass sheet in superstrate thin film module manufacturing format) is coated with a masking material. In a second step, a laser is used to cut gaussian-shaped groves through the masking material into the glass. In step 3, the whole surface is metalized. After the mask liftoff in step 4, only the laser groves remain metalized while the metal on the rest of the glass surface is removed together with the masking material. In step 5, the TCO is deposited, forming a conductive interface with the metal grid lines. Subsequently, the standard manufacturing process of substrate thin film technologies can be applied.

For the development of the manufacturing process for ultra fine gridlines we used 1”x1” glass samples of standard solar front glass. As a masking material, a water based paint containing titanium dioxide (TiO_2) particles has been used. As the masking process has to be applied on large areas of today’s thin film modules, a key feature of any masking technology is the use of inexpensive masking materials and masking and stripping processes. We developed a masking process using a water soluble inexpensive masking material as well as a stripping process using only DI-water in an ultrasonic bath.

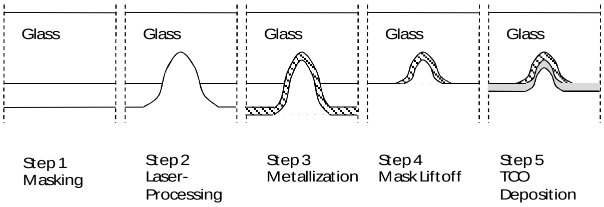


Fig. 4: Illustration of the process chain for metallization of laser ablated grooves and subsequent TCO deposition for selective metallization of the gridlines.

A laser operating at a wavelength of 266 nm was used to structure the masking material, as well as to ablate small grooves into the glass. Both processes were accomplished in one single step. In these experiments a frequency quadrupled Nd:YVO_4 laser operating at 266 nm wavelength was used to create the grooves. The beam was delivered to the work piece through a beam expander to optimize the focal spot diameter and a galvanometric scanner with a telecentric focusing lens. The high intensity pulses of the laser remove material through a process of laser ablation. Using a high pulsing frequency in the order of tens of kilohertz, a continuous groove is ablated through the masking material and into the glass substrate. Following this, the entire surface was covered with a metallic layer in a sputtering process. Then the masking material was removed in de-ionized water. This leaves behind the metalized grooves recessed into the otherwise transparent glass surface. In this very early stage of development of this technology, we did not add further processing in form of a TCO layer. The main objective was to find suitable masking materials, laser structuring processes and metallization steps. A next development step will be the deposition of a TCO layer about 200 nm thick followed by the standard thin film semiconducting emitter and absorber layers in based on typical superstrate for CdTe or amorphous Si manufacturing process.

RESULTS

Several laser groove structures were fabricated on glass substrates for evaluation of electrical and optical performance. The structures include contact pads for resistance measurements as shown in Figures 4 and 5. The metallic layer was applied using a sputter deposition process.

Laser parameter optimization is crucial to remove the masking material and to avoid excessively high thermal impact on the underlying glass.

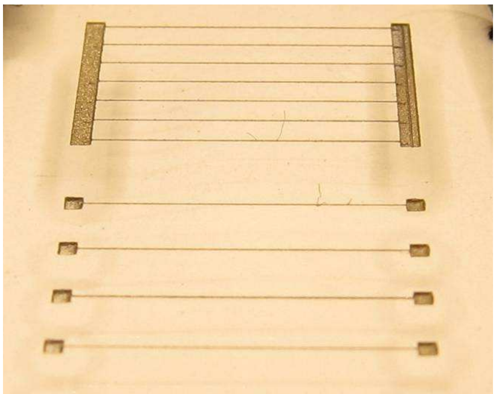


Fig. 5: Test samples for resistivity measurements showing the ultra fine lines and pads.

Fig. 6 shows a high magnification image of one of the smallest grooves we manufactured showing the details of the structure. With improvements in process development, ultra fine gridlines smaller than 10 µm with metal coverage on the sidewalls were achieved, as shown in Figure 3.

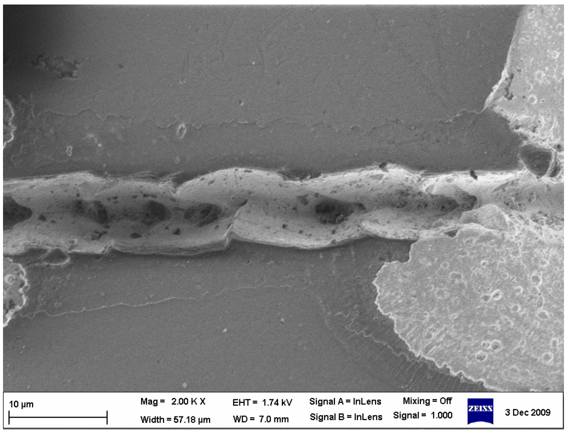


Fig. 6: SEM image of laser groove with a fully metalized finger. The material contrast to the unaltered glass surface indicates the presence of a metal layer in the groove. To the right, the fully metalized contacting area can be seen which was scratched manually into the mask.

In Figure 3 the single laser pulses can be distinguished very well. Due to the limited positioning accuracy and vibration isolation of the ablation equipment used in the experiments, a slight dislocation of about 1 µm between the single laser pulses is noticeable.

The laser processing step is sufficiently flexible to enable a degree of control over the profile of the groove. A variety of groove cross-sections have been produced including square, Gaussian and V-shaped profiles.

Incident light that falls on flat or square shaped grid lines and is not adsorbed can be expected to be reflected back out of the module. However, V-shaped grooves are of particular interest since they can be expected to partially reflect incident light onto the active part of the cells, further minimizing optical losses.

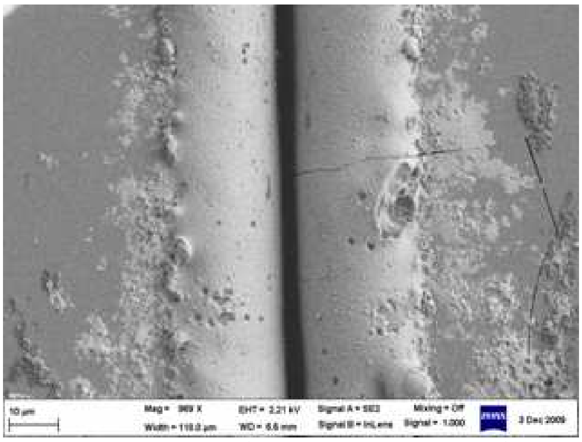


Fig. 7: SEM image of Gaussian shaped profile with partially re-melted glass. The re-melting caused significant tension in the material leading to micro-cracks as seen in the right part of the grove.

The sputtered metal layers consisted of an adhesion layer and a main metallization layer. As adhesion metals Chromium and Titanium were used, as main metallization materials Nickel and Molybdenum, The adhesion of the sputtered metals to the unprocessed glass was found to be excellent. However, adhesion to the processed surface was much weaker. One reason for this behavior is the higher roughness of the surface structure, leading to local peaks in the tension within the deposited metals. The roughness also led to poor coverage of the grooves. However, at least the latter problem is resolvable by increasing the thickness of the metal films from 200 nm to a few microns by electronic plating.

Metalized micron-scale size gridlines with good electrical conductivity could be manufactured by this method. The best conductivity achieved was 6 k-Ohm for a structure of 8 parallel grid lines with a length of 10 mm, using a metallization with nominal thicknesses of 50 nm Chromium and 200 nm Nickel. Groove width was around 10 µm.. It is expected that further improvements in the grooves and metallization conditions should produce better grooves, and metallic gridlines and ultimately an increase in the electrical conductivity of the TCO aided by the metallic grids.

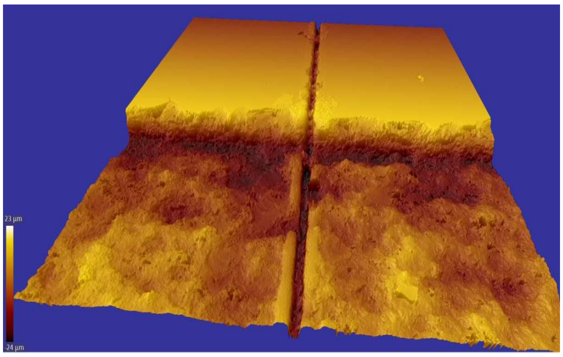


Fig. 8: High magnification white light interferometry image of a typical improved laser groove micron size line.

CONCLUSION

In conclusion, very ultra fine grid lines have the potential for significant improvement in thin film module efficiency. A new manufacturing methodology has been developed which features a four-step process (masking, laser ablation, metalization and mask removal). A key feature of this technology is the use of cheap masking materials and water based mask stripping processes. Preliminary tests have indicated that the grid lines are electrically conductive with widths as low as 10 µm can be achieved, which is an order of magnitude less than what can be achieved with screen printing. Power gain using this technology has been estimated at 4 - 9%.

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