Presented at the 24th European PV Solar Energy Conference and Exhibition, 21-25 September 2009, Hamburg, Germany

LASER ABLATION OF ETCH RESISTS FOR STRUCTURING AND LIFT- OFF PROCESSES

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ABSTRACT: Structuring of dielectric and metal layers as well as silicon itself are key processes in the production of silicon solar cells. In this paper we suggest selective structuring of etch resist and organic lacquers by laser ablation as a general structuring approach. This approach is a simple and fast way of creating small structures in an etch resist or a precursor for lift- off processes. Two possible applications for laser structured organic lacquers will be presented in this paper. One application includes the structured etch resist technology for the electrical isolation of an aluminum layer acting as a rear side metallization for back contacted cells, the other is based on a lift-off application leading to a process sequence for a front side metallization. Since etch resist absorbs light at wavelengths in the infrared regime (2 - 10 µm) which are not absorbed in silicon the chance of damaging the wafer by choosing an appropriate laser system can be reduced. To this point high efficiency solar cells with Ps-FF of up to 83.1 % and V_{OC} of 661 mV were fabricated.
Keywords: Laser processing, metallization, structuring

1 INTRODUCTION

Structuring of dielectric and metal layers as well as silicon itself are key processes in the production of silicon solar cells. Especially for the complex cell designs of MWT-, EWT- [1], and IBC- solar cells an increased number of structuring process are required. Photo– lithography and screen printing of organic lacquers are well known technologies for structuring surfaces and lift- off processes, but both technologies have significant drawbacks. With photo– lithography it is possible to create small openings in the magnitude of 10 µm and smaller with steep shoulders which enable a following lift– off process, but the process complexity makes it too expensive for industrial applications. Screen printing of etch resist on the other hand is already applicable in industrial production but the width of the printed structures is limited and the shoulders generally are not steep enough to enable lift– off processes.

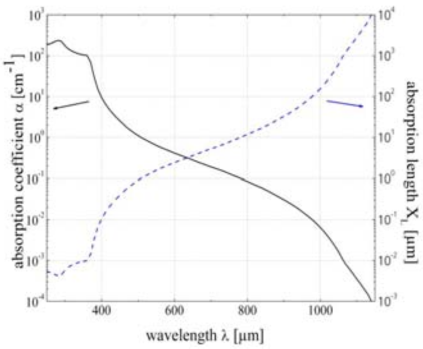


Figure 1: absorption coefficient and absorption length of silicon [2].

In this paper we suggest selective structuring of etch resist and organic lacquers by laser ablation as a general structuring approach. This approach is a simple and fast way of creating small structures which can be used for etch resists as well as a precursor for lift- off processes. Since laser structuring and coating of wafers by spin- on, spray- on or dip coating are contactless processes, this structuring sequence is well suited for thin wafer. The advantage of using organic materials as etch resist consists in their high absorption at comparable long wavelengths (~2 µm) which are not absorbed in silicon (see Figure 1). Due to the selective absorption of the laser light it is possible to structure the etch resist without damaging the silicon beneath. Futhermore, as soon as the specific requirements are defined these organic lacquers probably can be produced cheaper compared to screen printing ones or inkjet pastes due to relaxed specifications.

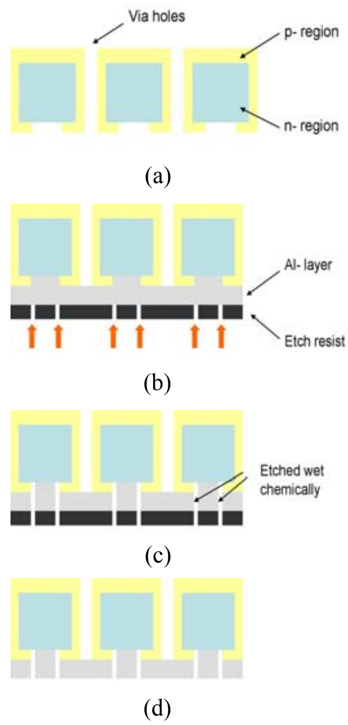


Figure 2: Process sequence for structuring a evaporated metal back contact layer by structuring a screen printed etch resist and subsequent wet chemical etch of the metal in the openings of the etch resist.

Two possible applications for the laser structured etch resist will be presented in this paper. On the one hand a structuring approach of an aluminum layers for the back contact metallization of back contacted solar cells will be introduced; on the other hand a process sequence for a front side metallization based on laser structured etch resist and subsequent lift- off process will be presented. To simplify the experiments presented in this paper they were all conducted using commercially available screen printed etch resists, for which extensive processing experience is available. A transfer to contactless coating technologies nevertheless should work without problems.

2 EXPERIMENTAL

2.1 Structuring of Back Contacts

One possible application of this process scheme is the separation of n- and p – contact areas on the rear side of an MWT- or EWT- cell. If the metallization is realized by evaporation of a full area aluminum layer on the rear side, the contact regions have to be reliably separated to avoid shunting between n- and p- doped regions. This can be realized by screen printing of etch resist and structuring by laser ablation (see Figure 2). After locally ablating the etch resist the aluminum beneath can be wet chemically etched for separating the contact areas. Subsequently the etch resist has to be removed.

For parameter optimization and to investigate the practicability of this approach test structures were fabricated. Therefore damaged etched Cz- wafers were passivated with a 105 nm thick thermally grown silicon dioxide layer and a 5 µm thick aluminum layer was evaporated. Afterwards the etch resist was printed on the whole surface and structured by laser ablation in a pattern shown in Figure 3. After the structuring step the small test structures were separated by breaking the wafer along the dotted lines indicated in Figure 3. These structures allow investigating a high number of laser parameters and at the same time feature a long borderline.

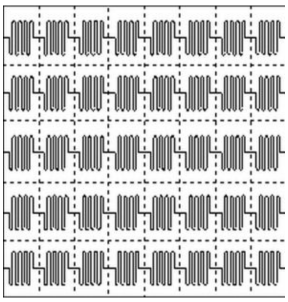


Figure 3: Schematic sketch of a test structure for measuring the resistance between separated metal areas.

The laser system used in this experiment is the Coherent AVIA- 355- X featuring a wavelength of 355 nm, an average output power of 10 W and a pulse width of approx. 30 ns. After structuring the etch resist the samples were etched in HCl to remove the aluminum and the etch resist was removed in acetone. Then the resistance between the separated contact regions was measured with a multimeter.

The resistances between the separated areas for laser parameters featuring a pulse energy as low as approx. E_P=200 µJ and almost non- overlapping pulses were above 1 MΩ and therefore confirmed that the metallic layers were reliably separated. Figure 4 shows a microscopy picture of the structured aluminum layer. The width of the laser groove before etching was approx. 25 µm and 50 µm afterwards.

Since the aluminum underneath the etch resist is absorbing the laser radiation very well it can be even beneficial to remove some of the aluminum during the structuring of the etch resist in order to reduce the etching time. Depending on the aluminum layer thickness, this results in a wide range of applicable laser parameters. Furthermore, this broad process window enables the application of cost-efficient lasers even in the infrared wavelength region. Basically, depending on the aluminum thickness all laser sources emitting pulse energies above a minimum threshold energy can be used.

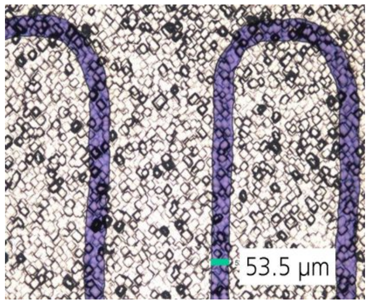


Figure 4: Microscopy picture of a test structure after the wet chemical etching of the metal and removing of the etch resist.

2.2 Lift- off Processes with Structured Etch Resist

Another possible application is the process sequence of a front side metallization (shown in Figure 5) with a similar scheme to a photo- lithography processed front side metallization for high efficiency solar cells. With this scheme it is possible to reduce shadowing losses due to higher aspect ratios and smaller finger widths compared to screen printed contacts and therefore to ,increase the short current density J_{SC}. Additionally a high phosphorous concentration at the surface is not required because of the low contact resistance and therefore emitters with high V_{OC}- potential can be used.

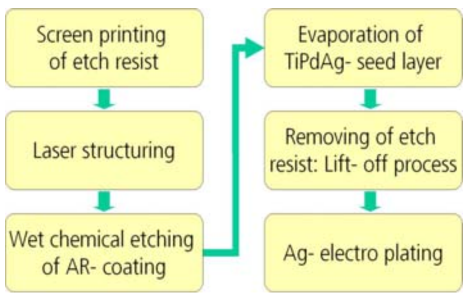
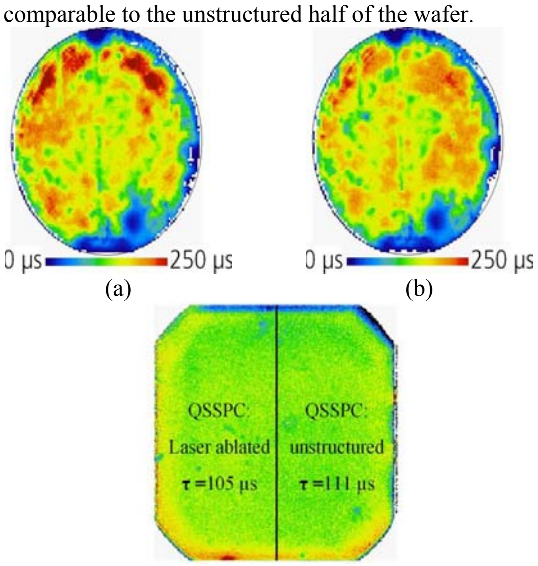


Figure 5: Process sequence for a front side metallization scheme similar to a high efficiency front side based on laser structuring of etch resist and subsequent lift- off process.

In this process scheme the etch resist is screen printed on the front side of the cell and opened in a grid shape with small finger widths. The etch resist was chosen for this approach due to its high absorption at a 2 µm wavelength. Afterwards a wet chemical etching step (20 % HF) removes the antireflection coating in the laser ablated openings of the etch resist. Then a metallic seed layer of TiPdAg is evaporated over the whole surface and structured by a wet chemical lift- off process. After an annealing step the seed layer is thickened by electroplating in silver solution.

For this application it is important not to damage the emitter beneath the antireflection coating during laser ablation of the etch resist. Due to the organic nature the etch resist already absorbs laser light at comparably long wavelengths which are not absorbed in silicon, it is possible to lessen the chance of damaging the wafer by choosing an appropriate laser system. For the experiments presented in this paper a continuous wave fiber laser (IPG LASER TLR- 50) featuring a wavelength of 2 µm, an average output power of up to 50 W and a galvanometer scanning device was tested.

To verify that radiation with a wavelength of 2 µm is not creating damage in a silicon wafer, first a SiN passivated float zone wafer was irradiated over the whole surface with the same laser parameter also used for ablating the etch resist. The lifetime of the wafer was measured by microwave photo- conductance decay (µ-PCD) before and after the laser treatment. As can be seen in Figure 6, the radiation has no visible influence on the minority carrier life time of the sample. To evaluate a possible damage in the silicon due to the high temperatures during the ablation of the etch resist, etch resist was printed on the front and back side of a SiO_2 passivated float zone wafer. The etch resist was structured on one half of the wafer with laser grooves featuring a 500 µm pitch and removed in acetone afterwards. Figure 6c shows the µ-PCD lifetime scan of the wafer after removing of the etch resist. As can be seen, the wafer shows no signs of the laser structuring and the lifetime measured by QSSPC [3] is comparable to the unstructured half of the wafer.

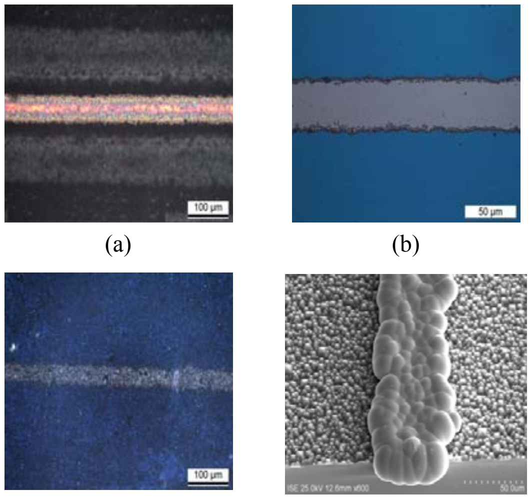


(a) (b)

(c)

Figure 6: µ-PCD scans of the minority carrier life time of a SiN- passivated float zone wafer before (a) and after (b) processing with a 2 µm wavelength IPG laser system. The laser parameters were the same for structuring the etch resist. 6(c) shows the lifetime scan of a wafer after structuring and removing the etch resist.

First experiments regarding the application on the front side were conducted on planar and textured surfaces with screen printed etch resist on silicon wafers coated with a PECVD- SiN antireflection coating. Different laser parameters for the ablation were tested. After structuring the etch resist with the laser the antireflection coating was etched in HF and the etch resist was stripped in acetone. As can be seen in Figure 7 we successfully structured planar and textured surfaces with finger width between 30 µm and 70 µm. This line width is influenced by the optical setup which was available for the experiments and can be easily decreased further.



(a) (b)

(c) (d)

Figure 7: Microscopy pictures of structured etch resist on a planar surface (a), a structured SiN- antireflection coating on a planar (b) and textured (c) surface. SEM picture of a finger after lift- off and Ag- electro plating (d).

For a complete removable of the etch resist and therefore a successful structuring of the antireflection coating a distinctive threshold energy was needed. Figure 8 shows the necessary repetitions in dependence of the propagation velocity of the laser beam for different pump diode powers. The number of required repetitions rises in a linear slope with increasing velocity. The slope of the curves decreases with increasing diode power which indicates that the number of repetitions could be reduced further by using a more powerful laser system.

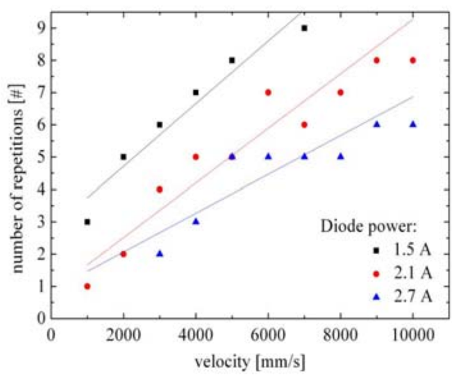


Figure 8: Repetitions required for a complete removal of the etch resist in dependence of the propagation velocity of the laser beam for different pump diode powers.

After this successful evaluation of the process parameters the experiment was repeated, applying the evaporation of a TiPdAg- seed layer after the wet chemical structuring of the antireflection coating. By stripping the etch resist

the metal layer is removed from the front side, while only in the ablated region the contact metallization remains as can be seen in Figure 7d.
In the next step this metallization scheme was transferred to the solar cell process. 20x20 mm^2 high efficiency PERC- cells with a 120 Ω/sq. emitter, a LFC rear contact [4] were used featuring a 105 nm thick thermally grown SiO_2 passivated front and back side based on 1 Ω cm FZ-silicon. The front side contact was formed according to the above described scheme. Solar cells featuring a cell size of 50x50 mm^2 based on Cz- silicon featuring a textured front side coated by a PECVD- SiN antireflection coating, a screen printed aluminum back surface field and a 75 Ω/sq. emitter were processed as well.
The samples showed disrupted fingers due to small inhomogenities during the laser ablation process. Therefore the solar cells could only be characterized by SunsVoc- measurements. The results show pseudo- fill factors of up to 83,1 % and open circuit voltages of up to 661 mV for the high efficiency cells, which leads to the conclusion that the emitter is indeed not damaged by the laser ablation (see Table I). On the 50x50 mm^2 Cz cells pseudo fill factors of up to 80,5 % and open current voltages of up to 604 mV were realized.

Table I: Pseudo-fill factors and open current voltage of the best 20x20 mm² FZ high efficiency cell and the best 50x50 mm^2 CZ cell.

	PS-FF [%]	V_{OC} [mV]
High efficiency cell (120Ohm/sq.):	83,1	661
CZ- (50x50 mm^2)- cell (75 Ohm/sq.):	80,5	604

3 CONCLUSION

In this paper a structuring approach based on laser ablation of etch resist was presented.
We successfully demonstrated a process scheme to separate the p- and n- contact regions of a back contacted solar cells by structuring a screen printed etch resist and subsequent wet chemical etching of the metal. Experiments on test structures showed a wide range of laser parameters.
Another possible application for laser structured etch resist is a metallization scheme on the front side which features a lift- off process. It is possible to structure the etch resist selectively by choosing a wavelength of 2 µm for the ablation which is not absorbed in the silicon.
We were able to develop a structuring process for the front side antireflection coating and realize a metallization of the ablated region with a lift- off process. The process needs further improvement regarding the width of the ablated structures. Smaller structures could be realized by using a gantry system or a scanner head with smaller focal length.
First test on high efficiency solar cells showed promising pseudo- fill factors of up to 83,1 % and open current voltages V_{OC} of up to 661 mV.

4 ACKNOWLEDGEMENT

The authors would like to thank A. Leimenstoll, M. Retzlaff, S. Seitz and E. Schäffer for process technology and measurements as well as T. Westphäling at IPG Laser for providing the laser system and Peters for providing etch resists.

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