LASER DOPING FROM AL_2O_3 LAYERS

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ABSTRACT: Laser doping is a currently widely investigated field of research for the industrialization of high efficiency silicon solar cell concepts at low manufacturing cost. While most laser doping approaches are applied after surface passivation and/or require some additional/special precursor deposition steps, using a passivation layer that acts as a dopant source at the same time is an obvious choice for further process simplification. In this work we report successful p-type doping from Al_2O_3 layers for both, Eximer (248 nm) and DPSS (532 nm) laser sources. On single Al_2O_3 layers, lower sheet resistances are achieved by single Excimer laser pulses compared to overlapping DPSS laser pulses, with the opposite tendency on stack layers, here Al_2O_3 / TiO_2. Since Excimer beam sizes can be in the order of the solar cell area, featuring masked/shaped single pulse doping, the presented approach has the potential of reduced process complexity and increased throughput compared to the state of the art laser doping techniques. For 20 - 35 nm Al_2O_3 layer thicknesses, sheet resistance in the range of 100 – 200 Ω/□ and contact resistances to evaporated Al below 10^{-4} Ωcm have been achieved within a wide process window. Detailed results on the influence of process parameters on the local doping properties are presented in this paper.
Keywords: laser doping, alumina, Excimer

1 INTRODUCTION

A variety of different laser doping techniques for silicon solar cell applications have been reported so far. This includes selective n-type emitters, either from a PSG remaining after the emitter diffusion [1, 2], from an additionally applied precursor layer [3, 4] or by the LCP technology [5]. Fewer efforts have been made for p-type doping [6, 7] and for Laser Fired Contacts (LFC) [8]. Recently, an approach was presented to use doped amorphous silicon as a dopant source and passivation layer at the same time [9], which simplifies the overall doping process significantly. While it seems obvious to use the surface passivating Al_2O_3 layer in the same way, the first investigations have been reported only very recently on stack layers [10, 11] by using 1064nm laser pulses.

In this work we report for the first time successful laser doping from a single Al_2O_3 layer by 532 nm and 248 nm (Excimer) laser pulses. In particular it is shown that significant doping can be achieved by single Excimer laser pulses only. As Excimer pulse energies are sufficient to process full solar cell areas by a single pulse, the presented process has the potential of very high industrial throughput.

Successful doping is also shown for a frequency doubled (532 nm) pulsed DPSS laser source, the state-of-the-art choice for laser doping.

2 EXPERIMENTAL SETUP

For measuring the sheet resistance of laser doped areas, we used high resistivity (>100 Ω.cm) p-type FZ wafers. Single Al_2O_3 layers are considered as well as a stack layer, both using optimized deposition parameters to achieve well passivating properties.

Single layer: 35 nm Al_2O_3 deposited by APCVD or 20 nm Al_2O_3 deposited by ALD.

Stack layer: 20 nm Al_2O_3 / 40 nm TiO_2 stack deposited by ALD.

Both an Excimer (248 nm wavelength) and frequency doubled DPSS (532 nm wavelength, ca. 25 µm spot size) laser with similar pulse durations (~20 ns) are used for the laser doping process. In the excimer beam path, an aperture and an objective lens is placed to achieve a square focus with approximately uniform intensity distribution (Flat-Top), see Figure 1.

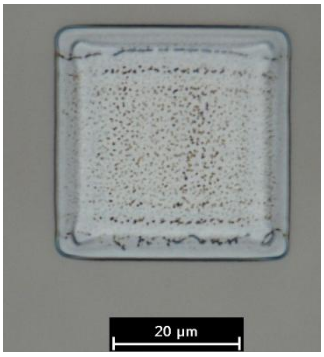

Figure 1: Microscope image of an Excimer laser doped square with a fluence of ~ 1.6 J/cm^2

For measuring the sheet resistance, overlapping pulses are used to create areas suitable for four point probe (4PP) measurements.

Following an HF dip, structuring of evaporated Aluminum is used to create transfer length measurement (TLM) patterns on laser doped areas for analyzing the sheet and contact resistance after a 30 min 400 °C sinter step. Error propagation analysis is performed on the basis of the linear regression errors to derive the 95 % confidence bounds for both sheet and contact resistance.

3 RESULTS

3.1 DPSS laser

For the 532 nm DPSS laser the effect of pulse energy and pulse distance on the sheet resistance is evaluated. As lines/dots are the most likely structure to be used in a solar concept, the pulse distance is varied within a line scan only, while the overlap of the lines to create a measurably large doped area is kept constant at 10 µm. Note that the presented values for the sheet resistance therefore are different from, however the trends are representative for a single line doping.

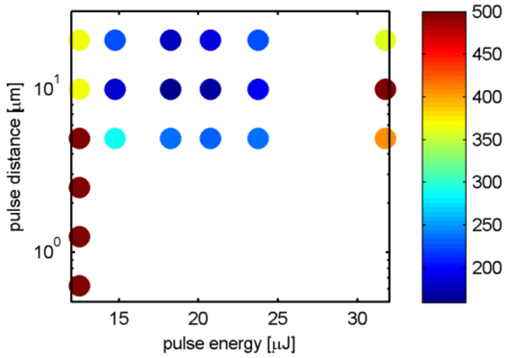

Figure 2: Sheet resistance [Ω/□] of 532 nm DPSS laser doped areas from a single Al_2O_3 layer.

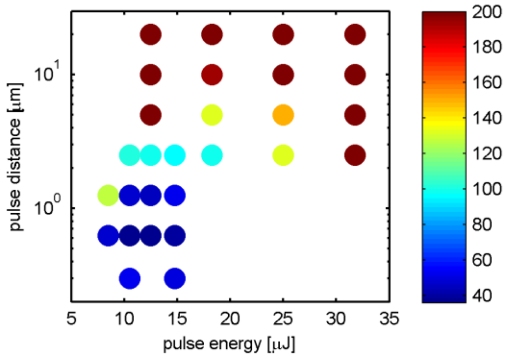

Figure 3: Sheet resistance [Ω/□] of 532 nm DPSS laser doped areas from a Al_2O_3 / TiO_2 stack layer.

On single Al_2O_3 a minimum sheet resistance of around 160 Ω/□ is achieved using a relatively high pulse energy and pulse distance. For the stack layer much lower sheet resistances below 50 Ω/□ can be achieved for lower pulse energy and pulse distances. For these observations the following explanation based on the doping mechanism which involves melting of the silicon and the dissociation and removal of Al_2O_3 is suggested: For a single layer most of the Al_2O_3 seems to be removed after a single pulse impact, thus multiple pulses, i.e. low pulse distances, are not able to achieve increased doping. This also means that a relatively high pulse energy is needed to achieve significant dissociation and melting within a single pulse only. For the stack layer on the other hand, the transparent TiO_2 layer effectively hinders the removal of Al_2O_3 at lower pulse energies, that's why low overlap and low pulse energies significantly increase the doping.

3.2 Excimer laser

With the excimer laser, which is also a known possibility for laser doping [12], doping was achieved for both tested layers. The sheet resistances for different laser fluences measured by 4PP on laser doped boxes with a pulse pitch of 30 µm are shown in Figure 4. The minimum sheet resistance for the single Al_2O_3 layer is around 100 Ω/□ and for the stack around 250 Ω/□. This very different trend compared to the DPSS laser can be explained by the different wavelength. For 248 nm TiO_2 is significantly absorbent, leading to removal of TiO_2 and partly also Al_2O_3 before any doping can take place. However, for the single layer, the sheet resistance achieved by a single eximer pulse only is significantly lower than for the DPSS. A large fluence window for the lowest sheet resistances is observed especially for the single Al_2O_3 layer.

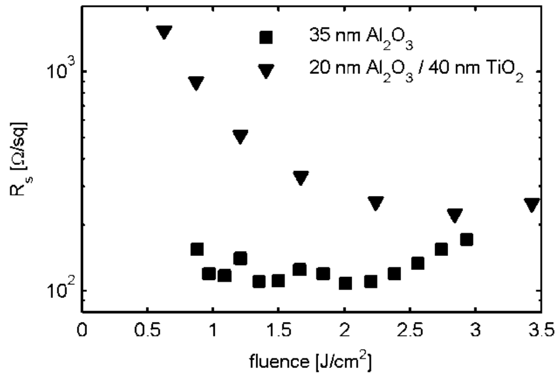

Figure 4: Sheet resistance for (quasi) single excimer laser pulses

For a given fluence of 2.1 J/cm_2, boxes with varying laser pulse pitch were processed. The results in **Figure 5** show a constant sheet resistance up to a pitch similar to the spot size, which corresponds to non-continuous doping due to separated doped regions. Consequently, the presented sheet resistance values (for just overlapping pulses) are very good approximations for the doped region resulting from a single laser pulse. It also indicates that a subsequent pulse doesn't change the sheet resistance significantly, probably due to the fact that most of the Al_2O_3 layer is already removed.

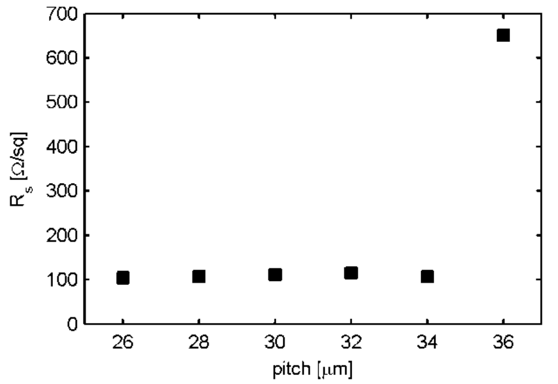

Figure 5: Sheet resistance of 2.1 J/cm^2 excimer laser doped boxes from single Al_2O_3 layer with varying pulse pitch

With the aim of lowering the sheet resistance, two consecutive and fully overlapping pulses with different fluence were used. With this approach, a minimum sheet resistance of 80 Ω/□ and 210 Ω/□ was achieved for the single Al_2O_3 layer and the stack layer respectively.

TLM measurements were performed for Excimer doping from single Al_2O_3 layer. Contact resistances as low as 10^{-4} Ωcm^2 are achieved on evaporated Aluminium for fluences around 1 J/cm^2. Remarkably, the sheet resistance is significantly higher compared to the 4PP measurements on the doped boxes, which is believed to be related to a conductive silicon-aluminum phase which is removed by the HF dip used for the TLM samples.

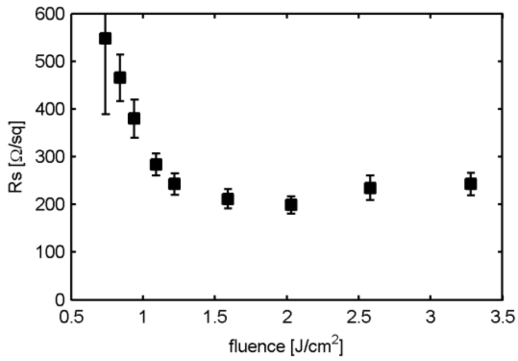

Figure 6: Sheet resistance derived from TLM measurements of Excimer doped areas.

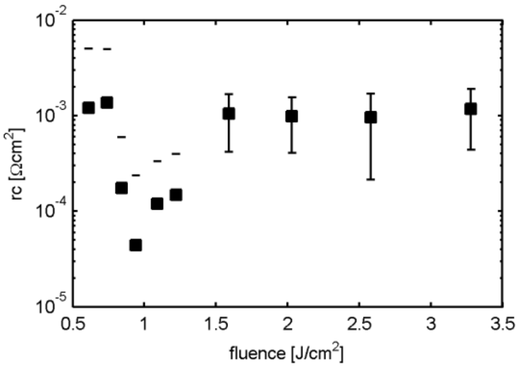

Figure 7: Contact resistance derived from TLM measurements of Excimer doped areas.

4 CONCLUSIONS

Successful p-type doping is shown from single Al_2O_3 layers for the first time as well as from a stack layer for two different laser sources. With the industry standard frequency doubled (532nm) pulsed DPSS laser, minimum sheet resistances of 50 Ω/□ and 160 Ω/□ are achieved on standard thickness and well passivating single Al_2O_3 layer and a stack layer respectively by using overlapping pulses. Using the Excimer laser source (248 nm) with similar pulse duration, significant doping can be achieved by a single pulse doping only, i.e. 100 Ω/□ and 250 Ω/□ for a single layer and stack respectively. Low contact resistances to evaporated Aluminium have been shown by TLM measurements for both laser sources. As the Excimer laser is capable of pulse energies providing sufficient fluence on a full solar cell wafer, this process is believed to have a great potential in industrial process simplification and speed.

ACKNOWLEDGEMENTS

This project has been supported by the Australian Government through the Australian Solar Institute (ASI), part of the Clean Energy Initiative. The authors would like to acknowledge the support of the project commercial partners, Transform Solar.

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