

Laser-doped Silicon Solar Cells by Laser Chemical Processing (LCP) exceeding 20% Efficiency

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ABSTRACT

The introduction of selective emitters underneath the front contacts of conventional solar cells with contacts on both sides can considerably increase the cell efficiency. Thus, easy fabrication methods for this process step are sought. Laser Chemical Processing (LCP), the chemical liquid jet-guided laser, based on the waterjet-guided laser (LaserMicroJet®) developed and commercialized by Synova S.A., is able to perform local diffusions at high speed and accuracy without the need of masking or any high-temperature step of the entire wafer.

We present experimental investigations on simple device structures to choose the right laser parameters for selective emitter formation. These parameters are used to fabricate high-efficiency oxide-passivated LFC solar cells that exceed 20% efficiency.

INTRODUCTION

The efficiency of conventional screen-printed solar cells can be increased significantly via the introduction of a passivated rear side with local point contacts [1]. Another important increase in efficiency is expected by using local strong diffusions underneath the front contacts. Thus the illuminated emitter can be optimized for blue sensitivity and optimum passivation without the need of providing a low contact resistance. This concept is already manufactured in a high volume production at BP Solar [2] under licence of the laser-grooved buried contact solar cell of UNSW [3]. However, a strong simplification of the process chain is expected when the local high doping is performed by LCP [4]. In this paper, we present experimental investigations on the choice of the right laser parameters as well as the manufacture of high-efficiency solar cells with LCP selective emitter.

BENEFITS AND CHALLENGES OF HIGH SHEET-RESISTANCE EMITTERS

The use of illuminated emitters with higher sheet resistance is known for the potential to increase the open-circuit voltage as well as the internal quantum efficiency in the short wavelength region. Mette has shown this impressively in his PhD [5]. Using homogeneous emitters between 40 and 90 Ω/sq with hot-melt screen-printed and electroplated front contacts, combined with oxide-

passivated LFC rear sides, an efficiency increase of 0.5 %_{abs} has been observed. However, the cells with 90 Ω/sq emitters showed the best values of V_{oc} and j_{sc} , but the series resistance increased considerably from 0.60 to 1.19 Ωcm^2 . Thus, a further increase in sheet resistance leads to even higher contact resistance so that the full efficiency potential cannot be exploited.

Mette calculated also the optimum contact width of plated contacts depending on the contact resistance. From this, the benefits of high local doping underneath the contacts can be derived: When the contact resistance is decreased (via heavy doping at the metal-semiconductor interface e.g.), the optimum contact width is decreased as well. This means also more and smaller fingers that need to transport less current to the busbar, thus requiring smaller heights than can be manufactured faster in the electroplating process.

FABRICATION METHODS FOR SELECTIVE EMITTERS

Commercial LGBC cells make use of dry lasers to open the front SiN_x layer. A subsequent damage etch and second diffusion with PSG etch are needed before the plated metallization can be applied. For lab-scale cells, photolithography can be used to locally open the AR layer without the need of damage etching.

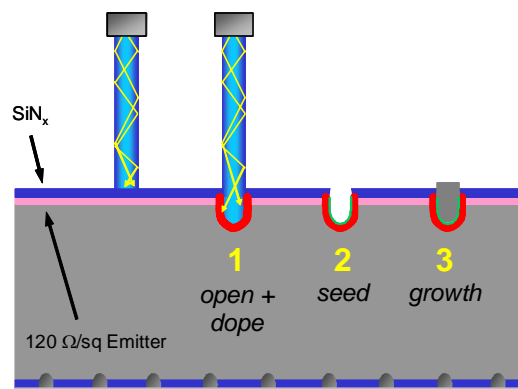


Figure 1: Principle of LCP selective emitter fabrication. The opening of the SiN_x layer and local high doping is performed in

the first step. The deposition of a seed layer and subsequent plating then follow to complete the metallization.

LCP provides a more elegant way to perform this process step, cf. fig. 1. The opening of the AR layer and the groove doping is done in one step without the need to remove any damage wet chemically after the laser process. Thus metal seed layer deposition and contact thickening via electroplating can follow right after LCP. In this way, two wet etching steps (damage etch and PSG etch) and one high temperature step (second diffusion) are saved.

EXPERIMENTAL RESULTS

Since the numerical simulation of the entire LCP process is not yet available, a parameter study has been performed on a simple device structure. The used material was 8 Ω cm FZ(B) from which planar solar cells have been fabricated, featuring a 50 Ω /sq spray emitter and PECVD SiN_x AR coating. The rear side was fully contacted via screen-printing. We performed LCP with H₃PO₄ as carrier liquid and two different laser systems: A frequency-doubled Nd:YVO₄ laser from Edgewave® with ~10 ns pulse duration and an infrared Nd:YAG laser with ~1 μ s pulse duration. After the LCP process, a variation in the application of the seeding layer has been performed by using electroless Ni plating or TiPdAg evaporation. Both variants underwent Ag light-induced plating (LIP) as contact thickening step.

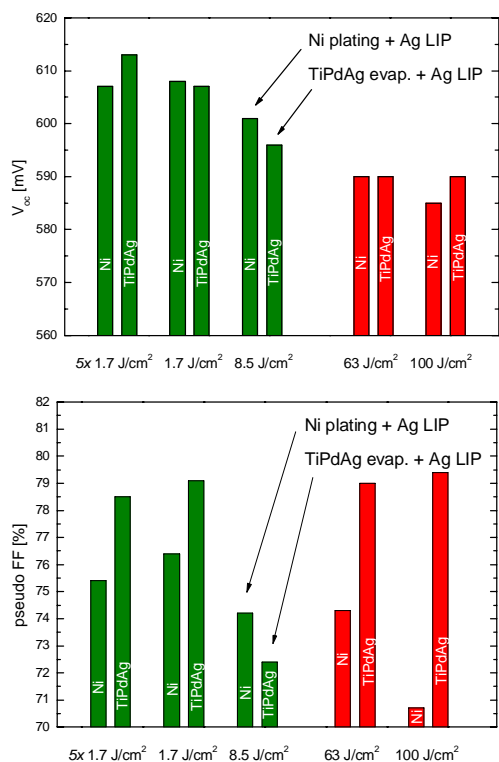


Figure 2: Suns- V_{oc} measurements on simple planar cells with screen-printed Al-BSF and LCP selective emitter and Ni or TiPdAg seed layer. Green bars: LCP performed with 10 ns green

laser, red bars: LCP performed with 1000 ns infrared laser. X-axis: laser energy density. For more details see text.

In fig. 2, the results of Suns- V_{oc} measurements are shown. From the measured V_{oc} values we derive that the green laser performs much better than the infrared laser. Also, lower energy densities seem to be beneficial for high V_{oc} . No large difference between the two seeding technologies in terms of V_{oc} can be observed. This is not true for the pseudo FF which reflects a strong degradation due to the Ni plating, especially for the infrared laser cells. The increased recombination of these samples occurs mostly at low voltages so that it degrades the fill factor but implies only a minor effect on V_{oc} .

We measured FF, R_s and the contact resistance ρ_c on the finished cells. Maximum FF above 76% could be demonstrated using the green laser and low energy densities. The R_s values of the cells made with the green laser range between 0.4 and 0.7 Ω cm² showing a sufficiently low level. Contact resistances below 1 m Ω cm² could be measured via TLM which were further reduced to 0.1 – 0.6 m Ω cm² via multiple LCP passes.

From these preliminary experiments we derived suitable laser parameters for fabricating high efficiency solar cells with oxide passivation and LFC local point contacts. For these cells, we performed the LCP step right after the 120 Ω /sq emitter diffusion before the oxide passivation. So the oxide was opened via photolithography and the TiPdAg contact seed layer was evaporated before Ag LIP was used to thicken the front contacts.

The best cell parameters measured on 250 μ m thick 0.5 and 1 Ω cm FZ(B) are shown in tab. 1. Open-circuit voltages up to 665 mV, short-circuit currents close to 39 mA/cm² and fill factors up to 79% lead to efficiency in excess of 20%. To our knowledge this is the highest efficiency reported for laser-doped silicon solar cells.

| Base resistivity | V_{oc} [mV] | J_{sc} [mA/cm ²] | FF | η [%] |
|------------------|---------------|--------------------------------|-------|-------------|
| 1 Ω cm | 652.3 | 38.4 | 0.780 | 19.5 |
| 0.5 Ω cm | 664.9 | 38.7 | 0.792 | 20.4 |

Table 1: Best cell results for high-efficiency solar cells with oxide passivation, LFC rear side and LCP selective emitter.

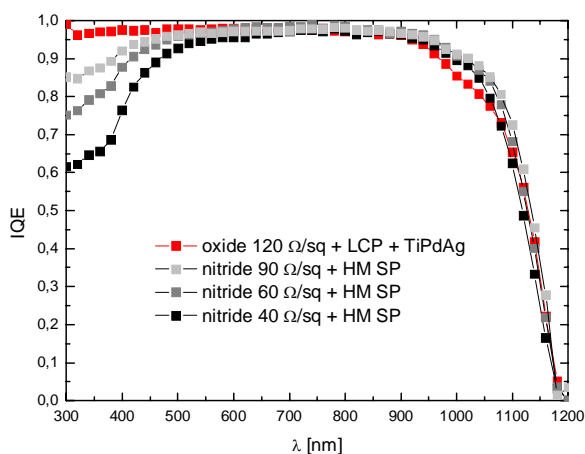


Figure 3: IQE of oxide passivated LFC solar cells with different emitter diffusion and contact methods (HM SP: hot-melt screen-print). All cells contacts are thickened by Ag LIP.

When the IQE of these high-efficiency cells is compared to the cells with hot-melt screen-printed front contacts on 40-90 Ω/sq emitters of Mette, the improvement in the short wavelength region is obvious, cf. fig. 3. In this curve, also one of the technological problems of the cell batch is visible: The LFC process did not run properly so that a dip in the IQE around 1000 nm is generated. Combined with the non-optimum random pyramids texture, a loss in efficiency of about 1%_{abs} is generated.

To determine the contact resistance of the LCP and reference cells, we performed TLM measurements. From these we found that the contact resistance on the 120 Ω/sq emitter could be reduced by a factor of 4 via the LCP selective emitter (from 4.0 $\text{m}\Omega\text{cm}^2$ to 0.9 $\text{m}\Omega\text{cm}^2$). In figure 4, this data is put in the graph of the calculated total loss of a solar cell with 120 Ω/sq emitter from Mette [5]. It can be derived that the optimum contact width is decreased from 22 μm (evaporated TiPdAg on emitter) to 12 μm (evaporated TiPdAg on selective LCP emitter) and the total loss is decreased by about 1%_{rel.}

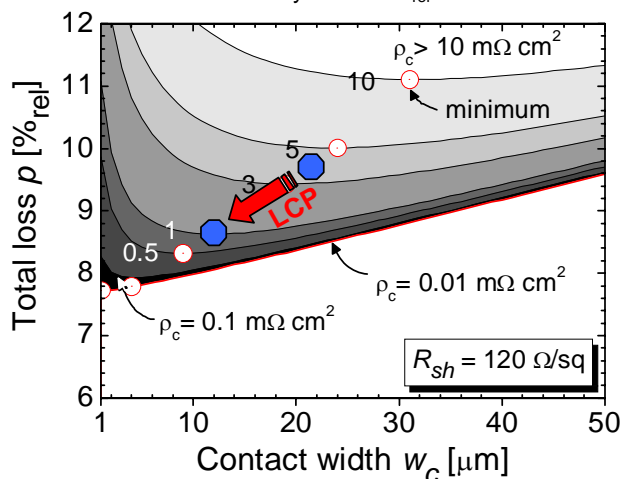


Figure 4: Calculated total loss of solar cells with plated contacts and 120 Ω/sq emitter and varying contact width and contact resistance (from [5]). The use of LCP selective emitters allow for smaller contact widths and lower total losses.

This fact raises the question if such fine lines can be manufactured. While 30 μm nozzles are readily available, allowing for ~ 27 μm street width in chip dicing with LaserMicroJet®, we performed LCP tests with larger nozzle. In fig. 5, a microscope picture of a damage-etched Cz silicon surface coated with PECVD SiN_x is shown. We used a 150 μm nozzle (resulting in ~ 125 μm jet diameter) to scribe the surface with LCP and H_3PO_4 as carrier liquid. With the right choice of laser parameters, the inhomogeneous energy deposition on the surface orthogonal to the scan direction can be exploited to further concentrate the microstructuring. Thus we were able to generate an opening of ~ 25 μm with this 150 μm nozzle. Therefore we expect that the reduction in contact width

can progress so that the efficiency potential of solar cells the LCP selective emitters can be realized at full extent.

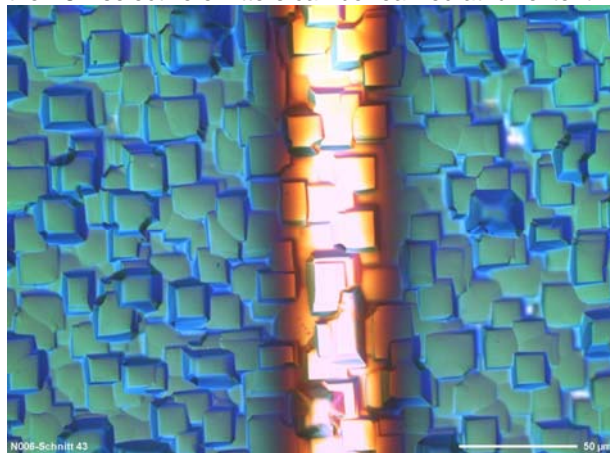


Figure 5: Light microscope picture of SiN_x opening of ~ 25 μm width machined via LCP (H_3PO_4) with 150 μm diameter nozzle.

SUMMARY

In this work, we presented Laser Chemical Processing (LCP) as an elegant method to realizing selective emitters for high-efficiency solar lasers. From preliminary experiments, short pulse green lasers have been chosen as laser sources for fabricating high-efficiency oxide-passivated solar cells. These cells exhibit efficiencies above 20% and allow for even higher performance when smaller contact widths are used.

ACKNOWLEDGEMENTS

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