OPTIMIZING THE MECHANICAL ADHESION PROPERTIES OF PLATED CONTACTS OF I-TOPCON SOLAR CELLS

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ABSTRACT: In this study, we have investigated and optimized the laser-induced modification of the silicon surface to improve the mechanical adhesion of Ni/Cu/Ag-plated contacts on the rear side of i-TOPCon Si solar cells. We discuss different approaches to create the laser contact openings (LCO) for the fingers by varying the laser parameters and the geometry of the contact structure, targeting at an enhanced micro surface roughness at the Si/Ni interface. We evaluate the mechanical adhesion via tape tests and the effect on electrical degradation due to increased recombination via photoluminescence measurements. We demonstrate that a well-defined laser parameter set allows for improved adhesion while maintaining no significant loss in implied open-circuit voltage.

Keywords: Plated Contacts, i-TOPCon Solar Cells, Mechanical Adhesion

1 INTRODUCTION

Electrochemical plating is a growing alternative solar cell metallization process that aims to replace screen-printed (SP) silver (Ag) contacts by nickel/copper/silver (Ni/Cu/Ag) plated contacts on silicon solar cells (see Figure 1). This substantially cuts costs through drastically reducing silver consumption, which is projected to be a limiting factor in terms of cost and availability in a multi-TW PV production market [1]. The process involves using an ultra-short pulse laser for LCO (Laser Contact Opening) prior to the deposition of the Ni/Cu/Ag contacts to locally open the passivation layer and create the necessary microstructure for plating. One technical challenge of this technology is the mechanical contact adhesion on non-textured silicon surfaces.

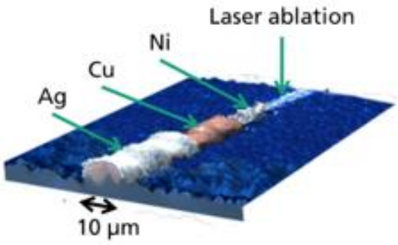


Figure 1: Cross section of electrochemically plated contact of an i-TOPCon solar cell.

Since in industrial TOPCon solar cell (see Figure 2) production the rear side is typically planarized during chemical edge isolation, the back surface contact adhesion can be challenging. We hypothesize that adjusting the laser contact opening parameters and, thereby, modifying the Si surface is a key to improving the mechanical adhesion. However, these parameters cannot be adjusted freely, as excessively laser ablation of the passivation layer to improve the mechanical contact adhesion will result in higher laser-induced damage and by that increased contact recombination. The textured surface of the front side of the cells results in a significantly better contact adhesion due to laser-induced anchor points that act as hooks for the contact fingers [2].

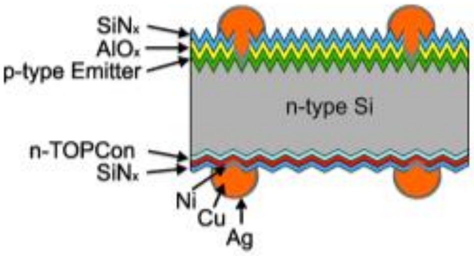


Figure 2: Cross section illustration of plated i-TOPCon solar cell structure.

2 EXPERIMENTAL

Different combinations of laser parameters, targeted at improving the surface roughness within the LCO and, thus, the adhesion of the plated contacts, were applied during the LCO process on the planarized rear sides of industrial i-TOPCon solar cell precursors, which were then characterized, plated and tested for adhesion.

A tape peel test was used to evaluate the adhesion performance of the matrix of contact fingers. The adhesion results of the different laser field structures were then compared against the previously characterized electrical properties obtained through photoluminescence (PL) measurements.

To create the necessary LCO variations for the required tests, the laser pulse energy, overlap density of laser pulses, the number of laser lines per finger, and the laser pulse passes per finger were all varied and adjusted to create the combinations seen in the 8°x°8 field matrix of finger structures described in Table 1 below. These parameters were selected as they are the most relevant for creating variations in the laser induced surface roughness. This matrix was created on M6 size i-TOPCon precursors with fields that are 18 x 18 mm and a finger-to-finger distance of 1.5 mm as seen in Figure 3.

Table 1: Variable LCO parameters used to create the test structures within the 8°x°8 field matrix.

Laser pulse energy	LCO3 < LCO2 < LCO1 low mid high
Pulse overlap in x and y direction	0%, 20%, 40%, 60%, 80%
Number of laser lines per finger	1, 2, 3, 4
Number of laser pulse passes per line	1, 2, 3, 4, 5, 6, 7, 8

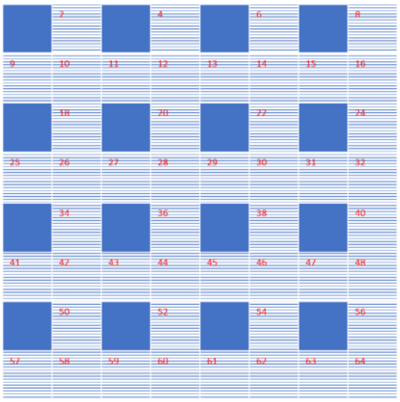
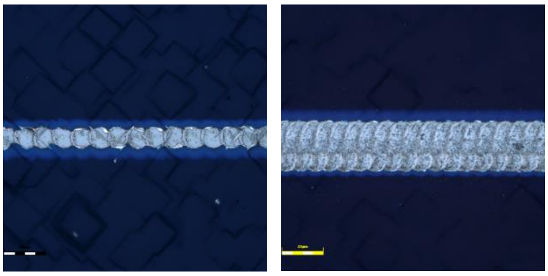


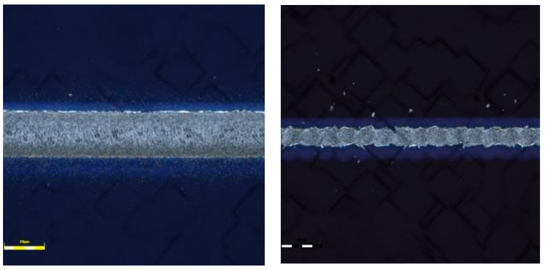
Figure 3: 8x°8 field matrix on the rear side of an M6 i-TOPCon wafer, designed for a large variation of laser parameter. This layout contains 48 fields with LCO finger structures (13 fingers per field with a distance of 1.5 mm), and 16 non-lasered reference fields.

Figure 4 shows representative examples of confocal microscope images of different LCO structures which have been investigated within the field matrix.



Reference: LCO1, 10% overlap, 1 line, 1 pass

LCO1, 20% overlap, 2 lines, 1 pass



LCO1, 80% overlap, 2 lines, 1 pass

LCO3, 20% overlap, 1 line, 6 passes

Figure 4: Confocal microscope images (100x, top view) of different LCO finger structures.

After the i-TOPCon precursors are laser-opened and annealed during a short high-temperature firing step, but before they are plated, microscope images are taken to document the laser contact openings. PL measurements (at 1 sun illumination) to obtain the implied open-circuit voltage V_{oc} (average of each LCO test field) as a measure of the laser-induced damage of the silicon surface are performed.

Contact adhesion was evaluated via a tape peel test. This is done through the following steps:

1. On each of the 8 columns of the field matrix, a strip of tape is placed.
2. A metal mask sheet is placed on top of the cell to ensure even adhesion of the tape and to prevent cell breakage during the peel test.
3. The tape is slowly pulled at a 90 degree angle, then the remaining contact fingers are counted and documented.

Each of the field structures of the matrix shown in Figure 3 has 13 contact fingers, and the remaining contact fingers after the peel test is the documented result, thus a higher number of remaining contacts indicates better adhesion.

RESULTS

For the test field structures, the graphs in Figure 5 and 6 show the results of what was found to be the best performing groups out of all LCO parameter variations tested. As is expected, the trendline of Figure 5 suggests that an increased laser pulse energy (LCO3 < LCO2) or number of laser pulse repetitions (1…8) yield better mechanical contact adhesion, with the downside of a drop in implied V_{oc} as seen in Figure 6. The results imply that roughening of the silicon surface by applying e.g. a lower (LCO3) laser pulse energy in combination with about 6 passes is a promising approach for LCO, as about an average > 90% of the plated contact fingers are retained with a corresponding V_{oc} drop < 5mV. Thus, we hypothesise that a laser-induced modification of the Si surface creates an advantegeous micro roughness, leading to improved mechanical contact adhesion similarly to the under-cut structures reported in [2].

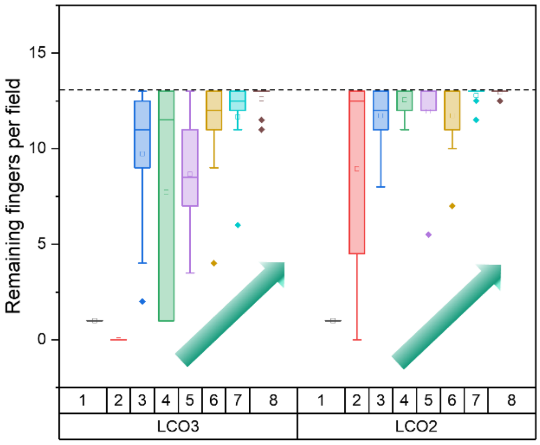


Figure 5: Number of remaining contact fingers per field (out of 13) after tape peel test for different laser pulse energies (LCO3 < LCO2) and per number of laser pulse passes at one laser line and 20% pulse overlap.

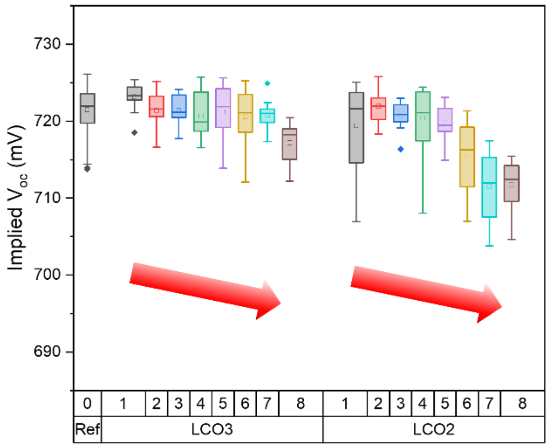


Figure 6: Implied open circuit voltage V_{oc} for different laser pulse energies (LCO3 < LCO2) and number of laser pulse passes at one laser line and 20% pulse overlap. Reference (0) without LCO.

Additionally, we found that increasing the number of laser pulse lines leads to a large drop in i-V_{oc}. This results from the combination of the enhanced laser-opened area and the increased laser-induced damage due to the additionally overlapped laser pulses. The effect of different overlap densities on the implied V_{oc} is displayed in Figure 7.

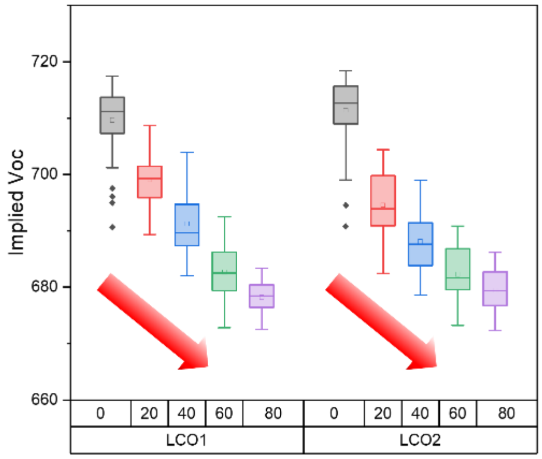


Figure 7: Implied open circuit voltage V_{oc} for different laser pulse energies (LCO1 > LCO2) and laser pulse overlap densities.

CONCLUSIONS

Generally, we have demonstrated that increasing the number of lines, laser energy, or overlap density improves the mechanical adhesion strength of the plated Ni/Cu/Ag contact fingers, but at different costs of damage to the silicon surface. It is observed that an optimal result is achieved using a lower laser pulse energy, in combination with 6 or 7 passes of repetition, as relatively good adhesion is achieved with only a small drop in implied V_{oc} of under 5 mV at a level of around 720 mV, thus showing minimal electrical degradation.

The results strongly imply that roughening of the silicon surface using a low-medium laser energy with many repetitions is a low-damage approach for LCO. Applications of such LCO parameters on full size M6 solar cells will be made in further work to confirm a successful translation of these optimal adhesion results.

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