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LIFT front-contact metallization of silicon solar cells

D. Canteli [a,*], C. Munoz-Garcia [a], P. Ortega [b], E. Ros [b], M. Morales [a], S. Lauzurica [a], C. Voz [b], C. Molpeceres [a]

[a] Centro Láser, Universidad Politécnica de Madrid, Alan Turing 1, Madrid 28031, Spain
[b] Departament d'Enginyeria Electrònica, Universitat Politècnica de Catalunya, C/ Jordi Girona 1-3, Mòdul C4, 08034 Barcelona, Spain

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ABSTRACT

Laser-Induced Forward Transfer (LIFT) is a very versatile technique, allowing the selective transfer of a wide range of materials with no contact and high accuracy. This work includes the analysis of heterojunction silicon solar cells with the frontal grid deposited by LIFT, and the electric characterization of the deposited lines.

Introduction

Laser-Induced Forward Transfer (LIFT) is a promising printing and metallization method for the PV industry, where screen printing, being the standard method, is the most expensive of the fabrication steps. In this work, a commercial high viscosity silver paste is used to deposit lines by LIFT. The study focusses on the electrical properties of the cured lines, and the characterization of metallized silicon heterojunction solar cells, quite sensible to processing steps with temperatures over 200 °C.

Experimental procedure

We used a commercial micro-sized silver paste (DuPont PV19B) with the viscosity adjusted to 11.8 Pa·s by adding thinner (DuPont 9450). The thickness of the donor paste film was 70 μm, with a gap distance between the donor and the acceptor around 40 μm. The laser source used was a ns-pulsed, solid-state Nd:YVO_4 DPSS laser emitting at 532 nm. Lines were printed using a pulse energy of about 25 μJ, and a pitch between adjacent pulses about 100 μm. Details on the LIFT experimental set-up can be found elsewhere [1].

The morphology and dimensions of the transferred lines were measured by confocal microscopy. To study the effect of the curing temperature on the electric resistivity, lines deposited on crystalline silicon with an alumina layer on top and cured at different temperatures were analyzed. The contact resistance, the sheet resistance, and the transfer length were determined by the TLM method, using lines deposited on a crystalline silicon substrate with an indium-tin-oxide (ITO) film as a top layer [2].The temperature used for this characterization was 300 °C, the same as used for the curing of the cells' frontal grid.

To check the viability of the LIFT metallization process, we deposited the front-contact grid on 1 cm^2 heterojunction silicon solar cells. The grid used had six fingers and a bus of decreasing width from 450 μm to 250 μm. To cure the silver paste without thermal deterioration of the cells, a non-contact thermal process was used, maintaining the cell at less than 1 mm from a surface of controlled temperature. The temperature and time of the curing process were adjusted to 300 °C and 9 min, respectively. The JV and pseudo-JV curves of the cells were measured and analyzed. The different cells included in this work have been made with the same process parameters.

Results and discussion

The deposited lines present a homogeneous and smooth line profile, with around 140 μm width and 40 μm high, for a cross-section of about 2800 μm^2. Left image in Fig. 1 shows the drop on the resistivity of the deposited lines with the curing temperature from almost non-conductive as-deposited paste to only some tens of μΩ·cm. The analysis of lines cured at 300 °C lead to a resistivity value of about 40 ± 5 μΩ·cm (See the center image in Fig. 1). This value is about one order of magnitude higher than the resistivity values obtained by thermal evaporation of pure silver. However, the much higher line section ensures a low series resistance for a metalized solar cell.

The analysis by the TLM method of the paste lines over Si/ITO samples (Right image in Fig. 1), led to a contact resistance value of 1.15 Ω, a transfer length of 113 μm, a sheet resistance for the substrate layer of 81 Ω/□, and a for the specific contact resistance of $7.4 \cdot 10^{-3}$ Ω·cm^2. [3], probably because the curing temperature is not enough to

* Corresponding author.
E-mail address: david.canteli@upm.es (D. Canteli).

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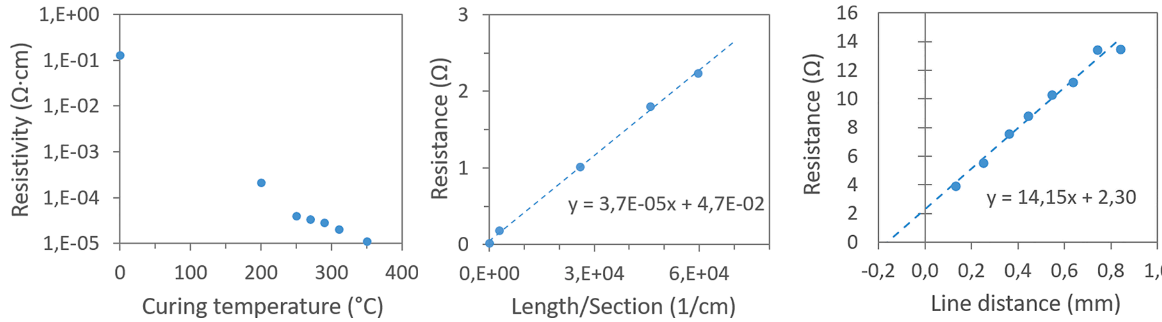

Fig. 1. Left: Resistivity of silver paste lines deposited by LIFT cured at different temperatures. Centre: Resistance vs line length/section for different series of lines. The resistivity of the silver paste is the slope of the curve. Right: TLM measurement for 8 mm long Ag paste lines deposited on ITO films.

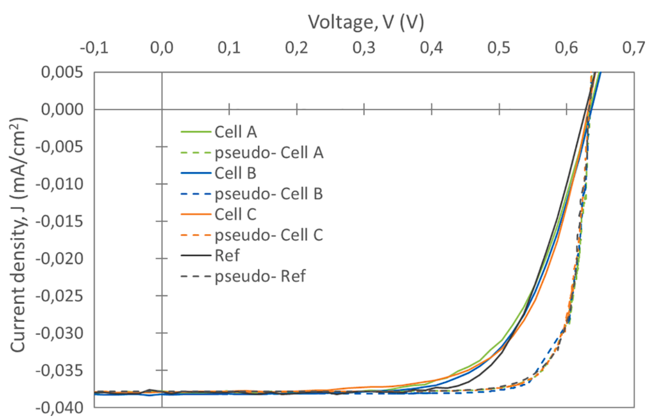

Fig. 2. JV curves (solid lines) and pseudo-JV curves (dotted lines) of heterojunction solar cells with the front grid deposited by LIFT and reference cell.

Table 1
Main parameters of the different cells presented in Fig. 2.

Cell	Jsc (mA cm^{-2})	Voc (V)	FF (%)	Eff (%)
A	37.9	0.635	66.0	15.9
B	38.2	0.635	66.9	16.2
C	37.9	0.635	67.4	16.2
Ref.	37.8	0.635	69.9	16.8

completely melt the silver particles. Although during the non-contact curing process the solar cells surely did not reach 300 °C, the length resistance and contact resistance values at 300 °C may be considered as the better values we could have, being the real ones probably higher.

Fig. 2 includes the JV curves (solid lines) and pseudo-JV curves (dotted lines) of three solar cells with the frontal grid deposited by LIFT, and a reference solar cell metallized by thermal evaporation. Table 1 show the main parameters of the cells. As it can be seen the LIFT metallization process almost does not affect the cell behavior: The Voc and Jsc values are the same in all the solar cells. Furthermore, the series resistance of solar cells metallized by LIFT is similar to that in the reference solar cell, around 2.5 Ω·cm^2. There is a slightly drop in the fill factor, about 2–3%, due to some shunt of around 1 mA/cm^2 near the cell's point of maximum power. A possible explanation for this drop in the FF could be some Ag paste passing through the ITO and a-Si layers (just 80 nm + 15 nm thick).

Conclusion

Lines deposited by LIFT and cured by a thermal step present higher line resistance and contact resistance values than lines deposited by evaporation, but the much higher section of the lines allow a good electrical behavior of the cells, proving that LIFT is a valid metallization process. The solar cells do not suffer from the curing process, although a slight drop of 2–3% in the FF points out that more work should be done to optimize the metallization process. LIFT metallization can significantly reduce the cost for electrode fabrication, since the expensive silver pastes are more efficiently used in this technique.

CRediT authorship contribution statement

D. Canteli: Methodology, Investigation, Writing - original draft, Writing - review & editing. **C. Muñoz-Garcia:** Methodology, Investigation, Writing - review & editing. **P. Ortega:** Resources, Writing - review & editing. **E. Ros:** Resources, Investigation. **M. Morales:** Supervision. **S. Lauzurica:** Writing - review & editing, Funding acquisition. **C. Voz:** Writing - review & editing, Funding acquisition. **C. Molpeceres:** Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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