Free form metallization of solar cells using Laser Induced Forward Transfer

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ABSTRACT:

Front metallization is an expensive, fundamental step in the fabrication of solar cells. Laser additive direct writing techniques, such as Laser Induced Forward Transfer (LIFT), can be used for printing optimized metallization patterns or free form personalized designs with applications in building integrated photovoltaics. In this work, metallic fingers and busbars have been printed onto different rigid and flexible photovoltaic materials using commercial, high viscosity, micron-sized particles, silver-based pastes. Printed lines show very large aspect ratios, low electrical resistivity and good adherence to the substrate. Functional test cells have been metallized from unfinished CIGS flexible solar cells.

Key words: Laser Direct Write; Laser induced forward transfer; Silver paste; 3D printing; Photovoltaic; Metallization.

1.- Introduction

Laser Induced Forward Transfer (LIFT) is an additive direct-write laser technique, suitable for printing materials with a great range of viscosities [1]. Figure 1 shows a scheme of the LIFT process: a transparent donor substrate is coated with the material to be transferred; the laser beam is focused at the donor substrate/film interface, vaporizing a small amount of the material, and pushing and accelerating the non-vaporized part of the donor film towards the acceptor substrate. Several works have been recently published on LIFT of inks or pastes containing nano- and micro- particles of silver for its application as a structured, conductive material in microelectronics [2-6]. One particular electronic application of LIFT with very large industrial interest and possible future industrial implementation is the photovoltaic (PV) field. Front metallization plays a fundamental role in the fabrication of solar cells, since the standard deposition of fingers and buses by screen-printing using silver pastes are one of the most expensive fabrication steps. LIFT can be thus used to print metallic lines, which act as fingers or busbars, in a single step [7], in a similar way than the conductive lines are printed for microelectronics. In this work, free form designs have been printed onto PV substrates and finished flexible solar cells using LIFT of fully commercial silver-based pastes.

2.- Experimental method

Commercial silver pastes (DuPont Solamet PV17F and PVF19) were used as donor materials for LIFT. The main difference of using this paste when compare to other LIFT experiments using silver inks are the larger size of the silver particles (in the order of several microns) and the very high viscosity (in the order of hundreds of Pa·s). As the silver pastes exhibit non-Newtonian pseudoplastic thixotropic fluid behavior, they were gently stirred for 5 minutes to attain the equilibrium viscosity before using it. Silver pastes were then deposited onto microscope glass slides, which act as donor substrates. Donor film is placed at a known gap distance respect to the acceptor substrate using Kapton tape.

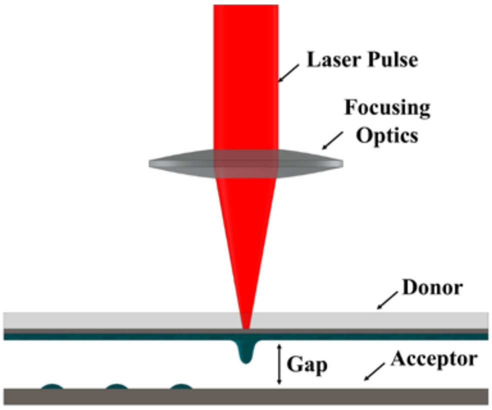

Fig. 1: Schematic of the standard LIFT set-up.

Two laser sources with different pulses duration were used: a compact ns-laser (Spectra Physics Explorer) and a high-power industrial ps-laser (EKSPLA Atlantic), both emitting at 532 nm. Different PV materials were used as acceptor substrates: standard polished c-Si wafers, commercial textured c-Si wafers, and copper indium gallium diselenide (CIGS) thin film solar cells deposited onto metallic flexible substrates. In every case, it is possible to transfer material, but the properties of the printed lines strongly depend on the nature of the acceptor substrate [8].

Samples morphology were characterized using confocal microscopy (Leica DCM 3D). JV curves of solar cells were measured at 1000 W/m^2 using the four probe method and a solar simulator (Newport 67005) with a xenon arc lamp.

3.- Results and discussion

The morphology of the transferred dot of paste (voxel) using LIFT is strongly dependent on the experimental process parameters, namely the laser fluence, the thickness of the donor film, and the gap distance between donor film and acceptor substrate, similar to the case of LIFT of Newtonian fluids. Once the thickness and the gap distance have been fixed, only a narrow interval of fluence values allows printing well defined paste voxels [9]. Continuos lines can be thus printed by scanning the focused beam and overlapping single dots. Since the objective of the present work is to applied LIFT technology for the metallization of solar cells, the aspect ratio, calculated as the height divide by the width of the lines, was selected as figure-of-merit. Large aspect ratios reduce shadowing effects and allow producing optimized metallization patterns with a less number of fingers to extract the current from the device. Figure 2 shows the morphology of a line deposited using the ns-laser and the PVF19 paste. The maximum height of the printed line is 60 µm, while the minimum width is 100 µm, which leads to aspect ratios between 0.35 and 0.5. Printed lines show also low electrical resistivity and good adherence to flexible substrates [10].

As a proof of concept of the technology, we studied the metallization of flexible solar devices, namely CIGS solar cells on a steel flexible substrate. 2 cm^2 lab test cells were metallized using the PV17F paste. After printing the fingers and contact pads, the metallized lines were thermally cured at 200 ºC for 2 hours. Figure 3 shows JV curve of several cells, showing good functionally.

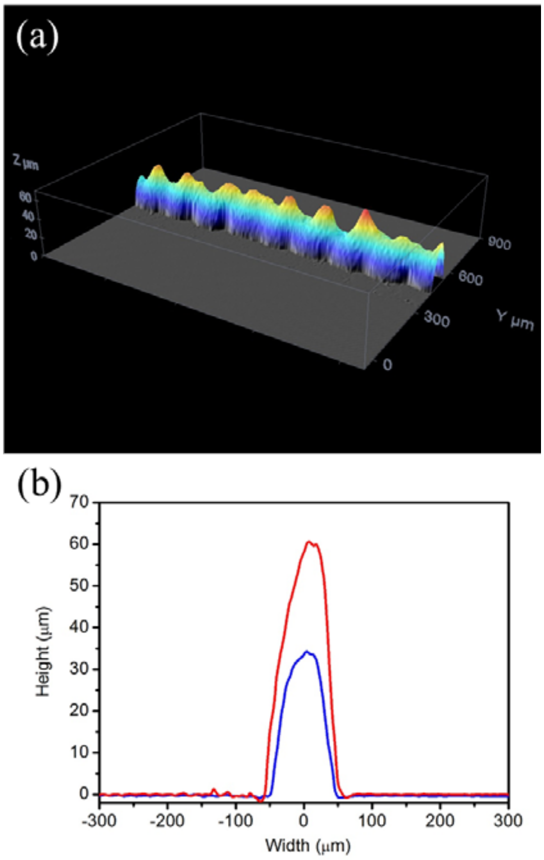

Fig. 2: A line deposited onto a c-Si wafer using LIFT: (a) 3D false color confocal image and (b) transversal height profiles.

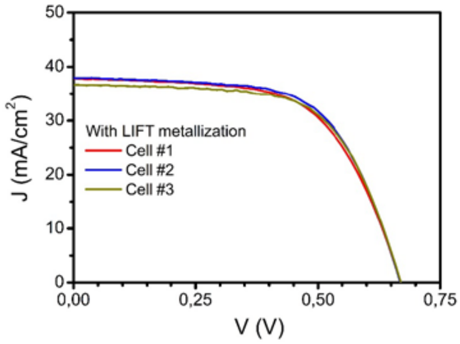

Fig. 3: JV curve of CIGS solar cells metallized using LIFT.

Besides the good morphology of the transferred lines. the main advantage of LIFT for the metallization of solar cell over the standard techniques is its flexibility and feasibility of printing free-form, personalized designs, for building integrated PV, as shown in Figure 4.

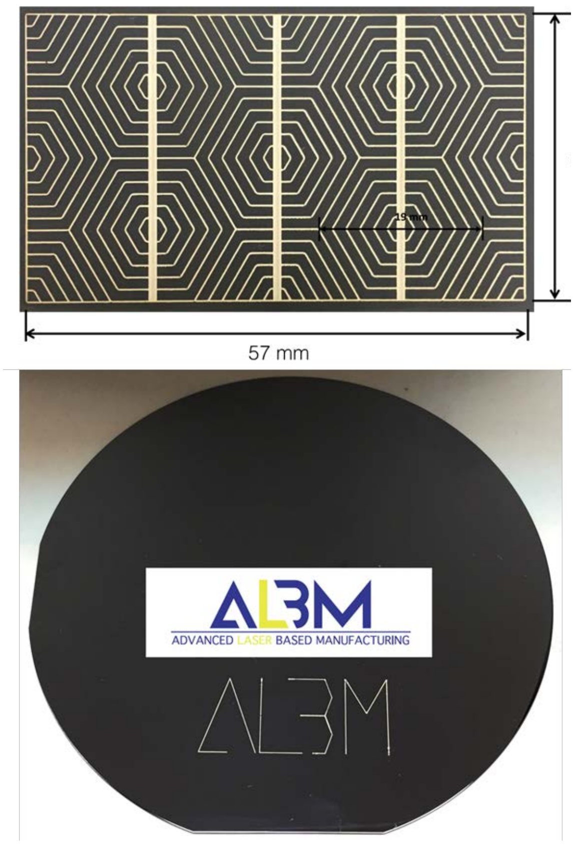

Fig. 4: Free-form metallization designs (upper figure adapted from ref [10])

4.- Conclusion

LIFT technique can be used for printing lines from high viscosity silver pastes, using both ns- and ps-lasers. Lines have been printed by means of overlapping single voxels, using a high scanning speed optical scanner or a low speed motorized stage, onto different PV materials, such as CIGS flexible solar cells. The good functionality of those devices has been proved.

The large flexibility in designs of direct-write laser techniques and the possibility of printing high aspect ratio lines, makes LIFT a promising technique for its application in the metallization of solar cells.

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