METALLIZATION OF SILICON SOLAR CELLS USING PS- AND NS-PULSED LASERS

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ABSTRACT: Metallization plays a fundamental role in the fabrication of solar cells and it is then a key process for enhancing the efficiency of silicon solar cells in a cost effective way. In this work, Laser Induced Forward Transfer (LIFT) technique has been used to direct write the metallic contacts (fingers and busbars) onto c-Si cells. Commercial silver pastes, used in conventional screen-printing process, are deposited onto a glass substrate, placed over the cell, and transferred be means of focusing a laser pulse in the interface between the paste and the glass substrate.
Standard ns-pulsed diode pumped solid state lasers and new generation ps-pulsed industrial lasers have been used as laser sources for LIFT. Fine parameterization of the process is needed. Single dots of paste have been transfer in a wide parametric window. Once the optima experimental conditions are determined, it is possible using both pulse time durations to transfer large material volumes per pulse (~10^2 pL) and define metallic lines with large aspect ratios.
Keywords: Metallization, Laser Processing, Laser induced forward transfer

1 INTRODUCTION

The aim of solar cell researchers and manufacturers is to find technologies leading to an increase in the efficiencies of solar cells and, at the same time, keep low costs. Procedures capable of making better contacts by improving the aspect ratio, decreasing contact loss, and keeping low costs, is one of the goals to reach [1]. The main objective of this work is to adapt the Laser Induced Forward Transfer (LIFT) technique to define metallic contacts (fingers and busbars) using a silver paste of high viscosity onto c-Si cells that can fulfil these requirements.

LIFT uses laser pulses to push thin disks of a ribbon material from a transparent substrate and deposit them onto an acceptor substrate [2]. The laser beam is focused in the donor substrate/ribbon interface. During the pulse duration, the laser energy is deposited within the laser spot size into the interface, evaporating a little amount of the material and generating the expansion of the remaining material, accelerating the non-evaporated part of the metal film towards the acceptor substrate (see Figure 1).

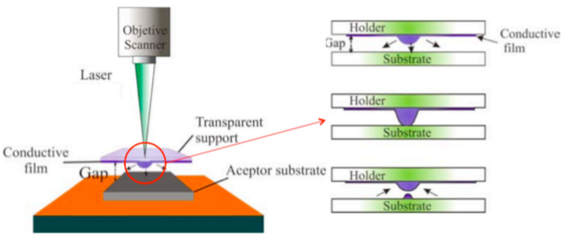

Figure 1: Principle of LIFT process for metallization of thin-film solar cells.

High definition user-defined patterns can be produced depositing droplets, translating the donor and acceptor substrates or moving the pulse location with a rotating mirror between pulses. Therefore, LIFT can be considered a direct-write technique capable of printing precise patterns of a variety of materials, what allows a large flexibility in the choice of inks. The Experimental setup is quite easy and can be then industrially implemented. LIFT made with ns pulses is a well-known technology to generate structured metallization in microelectronics [3,4] but have not been applied up to the moment to define in a single step the fingers of front contact in a photovoltaic device, although two steps approaches has been developed in the last years [5]. In the present work, cm-long silver paste lines have been printed using LIFT and two laser sources with different pulse duration (ns- and ps-pulses). The effect of the pulse length and experimental process parameters on the morphology of the transferred paste is studied using confocal microscopy.

2 EXPERIMENTAL METHOD

The paste used in these experiments is the Solamet PV17F (DuPont), originally designed for low temperature screen printing. It is a highly conductive silver paste that provides excellent efficiency, reliable soldered adhesion, low lay down, rapid dry, and very fast firing. Although it is designed for screen printing, its excellent electrical and sintering properties makes it a good candidate for LIFT metallization. The main challenge when using this paste for LIFT is its high viscosity (30-50 kcPs), much higher than the typical Newtonian fluids used normally for LIFT like inks. The paste was deposited onto microscope slides (donor substrate) using a commercial coater (Control Coater model 101, RK PrintCoat Instruments Ltd). The ribbon thickness on the donor substrate was selected in the range from 20 to 100 µm. c-Si wafers and solar cells were used as acceptor substrates. The donor substrate was set at a gap distance over the acceptor substrate using Kapton tape, stuck on the microscope slide. The gap is controlled using tape of different thickness or using several layers of tape. The basic LIFT configuration, without any intermediate absorbing layer or assisting liquid matrix was used [2].

Two different diode-pumped solid state laser sources have been used in the present work: a ns-pulsed laser (Spectra Physiscs Explorer) and a high-power industrial ps-laser (EKSPLA Atlantic). Table I summarizes the main parameters of both lasers.

The beam is focused onto the interface between glass and silver paste with an optical scanner (Scanlab hurrySCAN II) in the case of ns-laser and with a fixed lens (Ronnar) in the case of ps-laser. Thus the beam diameter in the focus is 25 and 10 µm respectively. Lines are printed be overlapping several laser pulses either by scanning the beam over the sample (ns-laser) or by moving the sample with an X-Y motorized stage while keeping fixed the beam position (ps-laser). The morphology of the transferred paste is measured using confocal microscopy (Leica DCM3D).

Table I: Description of laser sources.

Laser Source	Spectra Physics Explorer	EKSPLA Atlantic
λ (nm)	532	532
Pulse duration	<15 ns	<13 ps
Power (W)	>2	>35
Repetition rate (kHz)	20 – 150	400 – 1000
Max. pulse energy (μJ)	70	85
Pulse energy stability	<3	<2.2%
M^2	<1.3	<1.3

3 RESULTS AND DISCUSSION

As a first step, the transfer or single dots or voxels of paste has been studied in a broad parametric window, including varying the silver paste thickness, the gap between the donor and the acceptor substrates and those parameters directly related to the laser source, such as spot size, pulse energy and number of pulses. The effect of pulse energy, paste thickness and gap distance is strongly correlated and they are the key parameters which determine the transfer mechanisms: too high energy or too large gap lead to an explosive transfer, with heights of the order of silver particles, while energies just above the transfer threshold or shorter gap distances allows compact transfer and larger aspect ratios. To explain these results a two steps transfer process is proposed (Figure 2). LIFT generates a column of paste that connects both donor and acceptor substrates. When the donor substrate is removed the paste is stretched until the final shape is obtained. This two-step process allows the printing of high volume voxels (in the order of 100 pL).

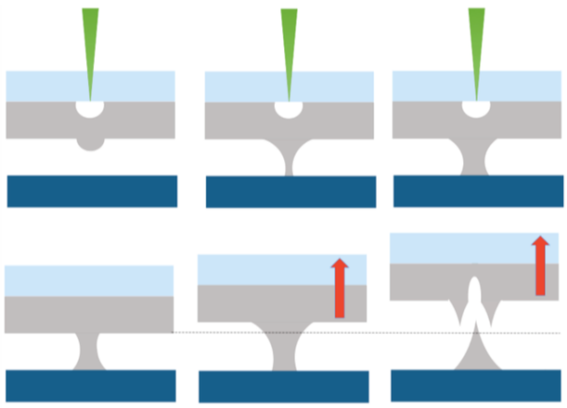

Figure 2: Scheme of the LIFT process for high viscosity pastes, showing the formation of paste column between donor and acceptor substrate, the donor removal and the final shape definition.

Once the optimum parameters are determined, lines are deposited by means of 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 imply large electrical conductivity while keeping small the shadow effect. Figure 3 shows false-color confocal images and profiles of LIFT lines printed with the optimum experimental parameters and the ns-laser (Fig. 3a) and the ps-laser (Fig. 3b). Figure 3c shows the transversal profiles of both lines. Table II summarizes the main experimental parameters used and the resulting morphological characterization.

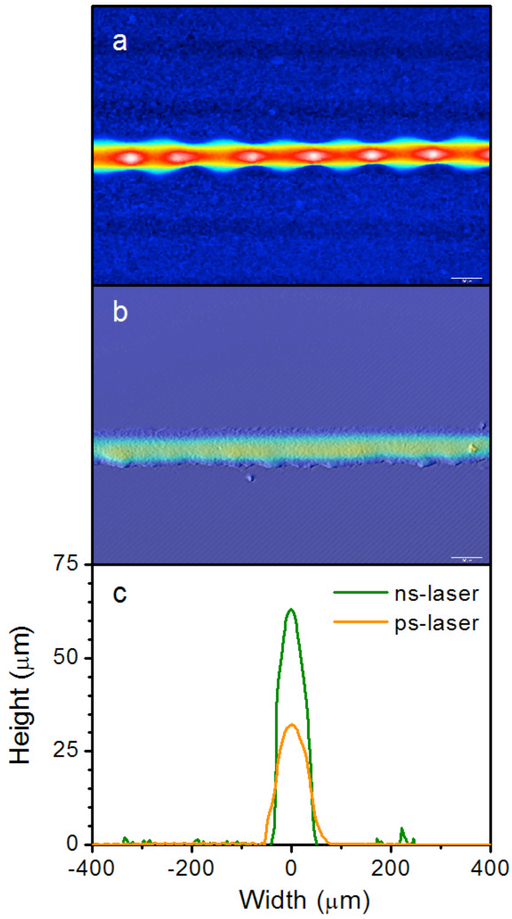

Figure 3: False-color confocal images of silver lines printed using (a) the ns- and (b) the ps-laser. (c) Transversal profiles of the lines shown above.

Typical height of an optimum voxel is around 10 μm while the height of lines is several times larger, while the width only slightly increases. This effect is related to an accumulative effect in the amount of the transferred paste when overlapping. Lines printed using the ns-laser is higher and narrower than those printed with ps-laser. The aspect ratios obtained using LIFT of this silver paste are better than those obtain with the same paste and standard screen-printing techniques.

4 CONCLUSSIONS

From this study it has been shown that both ns- and ps-lasers are suitable for printing lines of high viscosity silver paste.

The transfer process has been parameterized by means of printing single paste voxels. It has been observed that the minimum energy required to transfer the paste increases with the thickness of the paste. The paste thickness and the gap are identified as key variables in the transfer of high viscosity pastes. Gaps with lengths similar or smaller that the paste thickness are required for forming a paste column between donor and acceptor substrate and leading to concrete transfer.

Table II: Experimental parameters for LIFT metallization of lines.

Laser Source	Spectra Physics Explorer	EKSPLA Atlantic
Focusing optics	Optical scanner	Fixed lens
Pulse energy (µJ)	14.4	10.6
Fluence (J/cm^2)	9.2	12.0
Paste thickness (µm)	80	40
Gap distance (µm)	50	50
Scanning speed (m/s)	2	0.06
Line height (µm)	55	35
Line width (µm)	90-150	130
Aspect ratio	0.36-0.61	0.25
Voxel transferred per laser pulse (pL)	495-825	430

Using the optimum experimental parameters, it is possible to print lines with large aspect ratios and with high volume transferred per pulse (voxel) (> 400 pL). The best results have been obtained with ns pulses.

LIFT of commercial screen-printing pastes with optical scanners allows fast processing and flexible design to print large areas becoming a promising technique for the metallization of PV devices.

5 ACKNOWLEDGEMENTS

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