Centro Láser
UPM

High volume transfer of high viscosity silver pastes using Laser Direct-Write Processing for metallization of c-Si cells

M. Morales, Y. Chen, D. Munoz-Martin,
S. Lauzurica, C. Molpeceres

POLITÉCNICA CENTRO LÁSER UNIVERSIDAD POLITÉCNICA DE MADRID appolo

---

Centro Láser
UPM

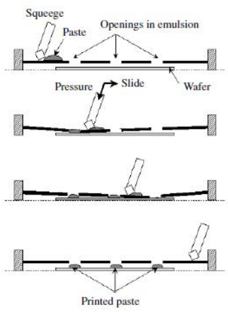
Outlook

Centro Láser
UPM

Metallization of Solar Cells

Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing



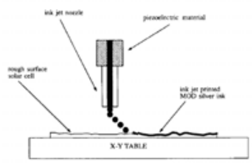
Luque & Hegedus, Handbook of Photovoltaic Science and Engeeniering (2003)

Centro Láser
UPM

Metallization of Solar Cells

Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing
- Ink–jet printing



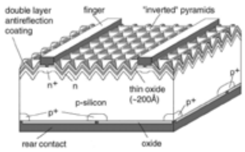
Teng & Vest, IEEE Trans. Compon., Hybrids, Manuf. Technol (1988)

Centro Láser UPM

Metallization of Solar Cells

Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing
- Ink–jet printing
- High-effiency approaches: photolitography / evaporation / plating



Zhao et al, Sol. Energ. Mat. Energ. C. (2001)

Centro Láser UPM

Metallization of Solar Cells

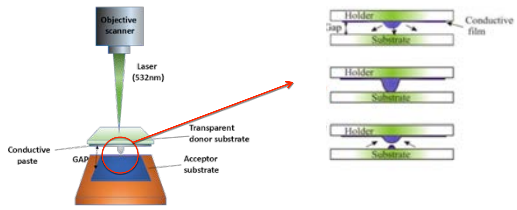
Front-side Metallization: key process for enhancing efficiency in a cost effective way

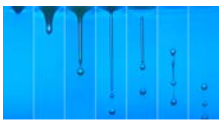
- Screen-printing
- Ink–jet printing
- High-effiency approaches: photolitography / evaporation / plating
- Laser Printing based on Laser-Induced Forward Transfer (LIFT)

Centro Láser UPM

LIFT

LIFT: Laser-Induced Forward Transfer





Some materials deposited using LIFT:

- Metals, Oxides, Nanopowders
- Organic polymers, Biomaterials & living cells
- Conductive inks, Ag nanoparticles pastes

Brown et al, Microfluid Nanofluid (2011)

Centro Láser UPM

Experimental setup

- Low temperature screen-printing Ag pastes.
- Deposition onto donor substrate using a commercial paint coater.
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix).
- Diode Pumped Solid State Laser (Spectra Physics Explorer)
  - Nd:YVO4 emiting 532 nm
  - Pulse duration 14 ns
- Optical Scanner (ScanLab HurryScan)
  - F-Theta Lens, focal 250 mm
  - Focused beam diameter 22-25 µm

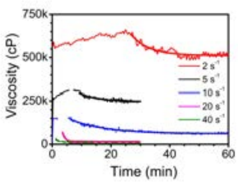
Centro Láser UPM

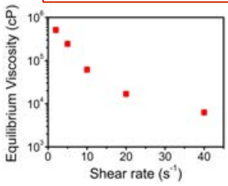
Silver paste

Dupont PV17F

Viscosity (Brookfield HBT, 10 rpm SC4-14/6R utility cap and spindle, 25°C)	280 - 400 Pa·s
Solid Content at 750 °C	89.5 - 91.0 %
Resistivity	< 5 mΩ/sq/µm
Silver grain	1-5 µm
Organic carrier	N,N'-Ethane-1,2-diylbis(decanamide) 12-Hydroxy-N-[2-[(1-oxydecyl)amino]ethyl]octadecanamide N,N'-Ethane-1,2- diylbis(12-hydroxyoctadecanamide)
Thinner	9450

Non-newtonian, pseudoplastic, thixotropic fluids

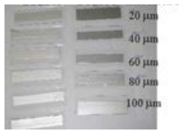




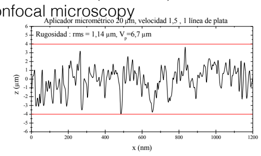
Centro Láser UPM

Deposition onto donor substrate

Commercial paint coater (RK PrintCoat Instruments).
Incorporates spreading blade adjustable using micrometers



Thickness, roughness (~ 2 um) and waviness (~ 5-8 um) are meassured for every experiment by means of confocal microscopy



Centro Láser UPM

LIFT configuration

Laser system

Spectra Physics Explorer	
DPSS Nd:YVO4	532 nm
Pulse duration FWHM	14 ns
Frequency	20 -150 kHz
Power	2 W @ 50 kHz
Energy attenuator	
Scanner	
Processing area	120 mm x 120 mm

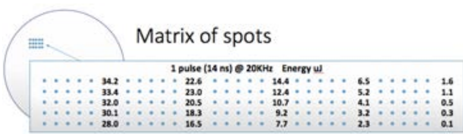
Experimental scheme

Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Laser frequency	20 kHz
Pulse duration	14 ns
Pulse energy	0.1 – 35 uJ
Paste thickness	30 um, 50 um, 80 um
GAP	50 um
Receiving substrate	Monocrystalline Silicon wafer (520 um)

Matrix of spots



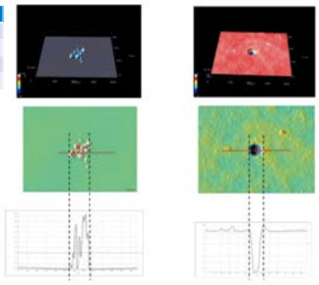
Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	30 um
GAP	50 um
Pulse energy	1.6 uJ

- Transfer threshold
- Explosive transfer
- All paste is removed from the donor substrate
- Transferred paste height is similar to silver powder size

Acceptor substrate | Donor substrate



Acceptor: W: 117 um, H: 5 um

Donor: W: 91 um, H: 33 um

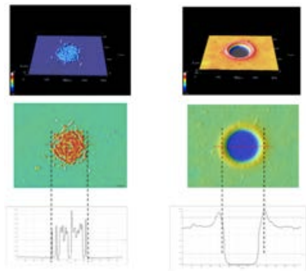
Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	30 um
GAP	50 um
Pulse energy	14.4 uJ

- Explosive transfer
- All paste is removed from the donor substrate
- Transferred paste height is similar to silver powder size

Acceptor substrate | Donor substrate



Acceptor: W: 205 um, H: 4 um

Donor: W: 243 um, H: 32 um

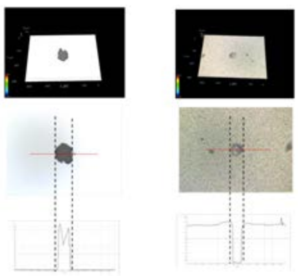
Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	50 um
GAP	50 um
Pulse energy	3.2 uJ

- Transfer threshold
- Compact transfer is obtained
- All the paste is removed from the donor substrate

Acceptor substrate | Donor substrate



Acceptor: W: 88 um, H: 12 um

Donor: W: 85 um, H: 55 um

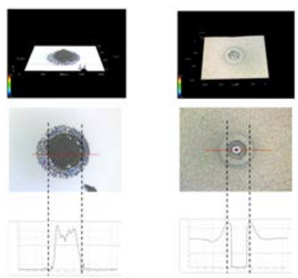
Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	50 um
GAP	50 um
Pulse energy	14.4 uJ

- Compact transfer is obtained
- Spray with silver particle and thinner is present.
- All the paste is removed from the donor substrate

Acceptor substrate | Donor substrate



Acceptor: W: 236 um, H: 13 um

Donor: W: 132 um, H: 57 um

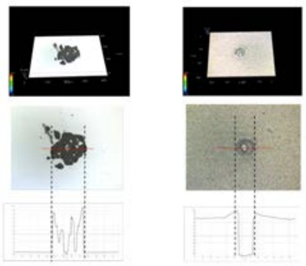
Centro Láser UPM

LIFT parameterization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	50 um
GAP	50 um
Pulse energy	34.7 uJ

- Explosive transfer but with heights higer that particle size
- All the paste is removed from the donor substrate

Acceptor substrate | Donor substrate



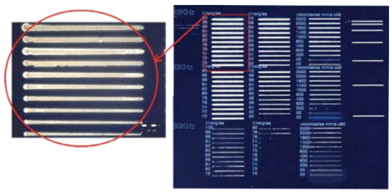
W: 211 um
H: 9 um

W: 136 um
H: 56 um

Centro Láser UPM

LIFT printing of long lines

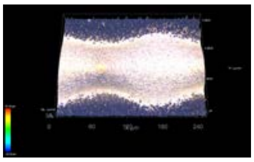
Laser	Explorer@532nm
Laser frequency	20 kHz, 50 kHz
Pulse duration	14 ns
Pulse energy	0.1 – 35 uJ
Paste thickness	80 um
GAP	50 um
Receiving substrate	Monocrystalline Silicon wafer (520 um)
Process speed	20 – 2000 mm/s

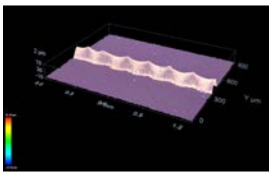


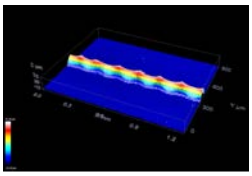
Centro Láser UPM

LIFT printing of long lines

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	80 um
GAP	50 um
Pulse energy	14.5 uJ
Process speed	2 m/s
Laser frequency	20 kHz

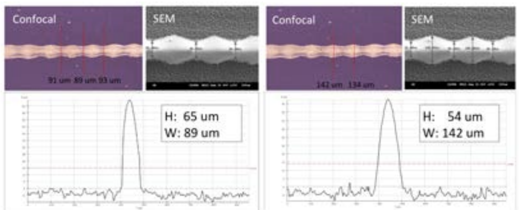






Centro Láser UPM

LIFT printing of long lines

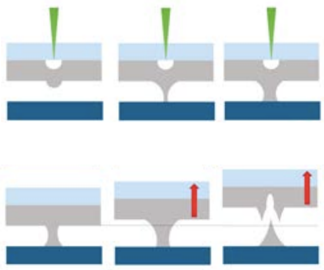


Heigth: 55 µm
Width: 90 µm – 150 µm
Aspect Ratio: 0.36 – 0.61

Centro Láser UPM

LIFT printing of long lines

- The LIFT process generates a column of paste that connects both substrates.
- When the glass substrate is removed the paste is streched until the final shape is obtained.
- This could explain the high aspect ratio and high transferred volume.
- The paste thickness and the gap are key variables in the transfer of high viscosity pastes

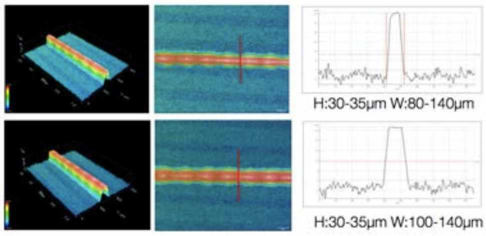


Centro Láser UPM

LIFT printing of long lines

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	80 um
GAP	50 um
Pulse energy	14.5 uJ
Laser frequency	20 kHz
Process speed	2 m/s
Line length	3 cm

Aspect Ratio ≈ 0.25 - 0.40
Voxel ≈ 300 pL

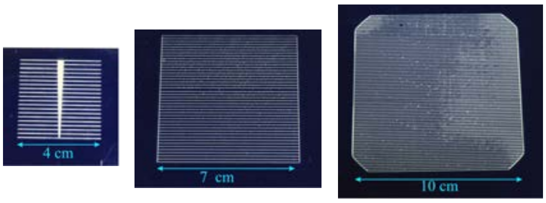


Centro Láser UPM

Large area metallization

Laser	Explorer@532nm
Spot diameter	25 um
Paste thickness	80 um
GAP	50 um
Pulse energy	14.5 uJ
Process speed	2 m/s
Line length	3 cm

- Optical scanners allows fast processing and flexible design to print large areas.
- Good predeposit conditions are needed.



Centro Láser UPM

Summary

1) The minimum energy required to transfer the paste increases with the thickness of the paste.
2) Viscosity of the paste plays a fundamental role. Thinner additives are needed for controlling the paste viscosity.
3) The paste thickness and the gap are identified as key variables in the transfer of high viscosity pastes.
4) Lines with higher height than the gap suggest that the paste forms a union with the acceptor substrate and the final shape is reached once the donor substrate is removed.
5) Lines deposited using best parameters have good shape and large aspect ratios (~ 0.3). The volume transferred per pulse (voxel) is quite large (~ 300 pL).
6) Optical scanners allows fast processing and flexible design to print large areas.
7) LIFT is a promising technique for the metallization of PV devices using commercial screen-printing pastes.

Centro Láser UPM

Acknowledgments

appolo

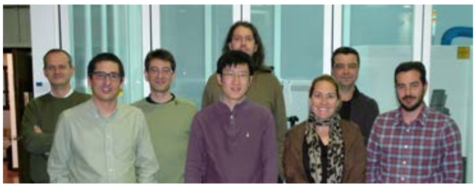
Hub of Application Laboratories for Equipment Assessment in Laser Based Manufacturing

I4MS

Centro Láser UPM

Acknowledgments

This work has been supported by the Spanish MINECO projects SIMLASPV (ENE2011-23359), HELLO (ENE2013-48629-C4-3-R) and EUROPEAN COMISSION APPOLO FP7-2013-NMP-ICT-FOF. 609355



Prof. M. Morales D. Canteli J.M. López Prof. C. Molpeceres
PhD. D. Muñoz C. Yu PhD. S. Lauzurica J.J. García-Ballesteros

Centro Láser UPM

Laser sintering

Metallization comprise different steps:

1. Pre-metallization processes
2. Metallization
3. Curing, sintering and firing

All-laser based process:
Laser heating using a CW source.

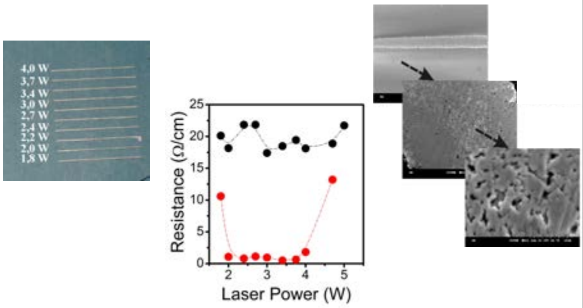
Experimental setup:

- DPSS Laser (Spectra Physics Millenia)
  - Nd:YVO4 emiting 532 nm
  - CW, power up to 20W
- Optical Scanner (ScanLab HurryScan)
  - F-Theta Lens, focal 250 mm
  - Focused beam diameter 20 µm

Centro Láser
UPM

Laser sintering

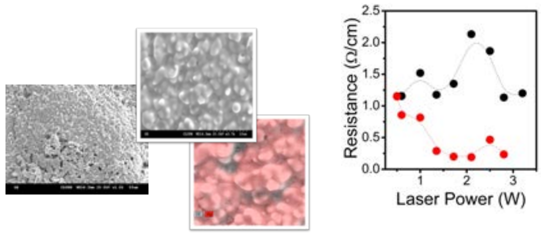
Lines deposited using screen-printing (Heraeus)



Centro Láser
UPM

Laser sintering

Lines deposited using LIFT (Heraeus)



Centro Láser
UPM