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

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S. Lauzurica, C. Molpeceres

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Outlook

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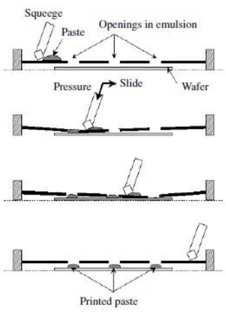
Metallization of Solar Cells

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

- Screen-printing



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

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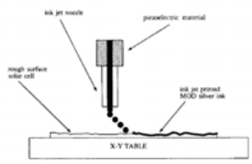
Metallization of Solar Cells

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)

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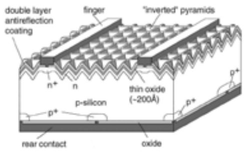
Metallization of Solar Cells

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)

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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)

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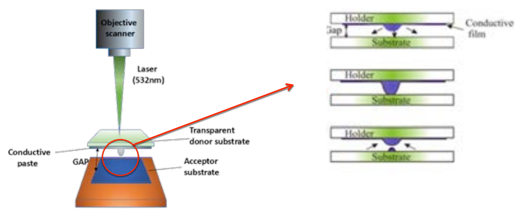
LIFT

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)

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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

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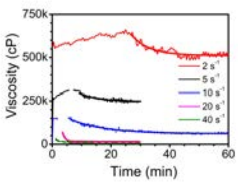
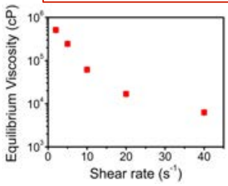
Silver paste

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





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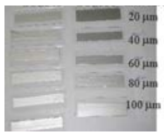
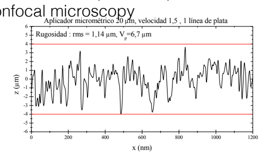
Deposition onto donor substrate

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



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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

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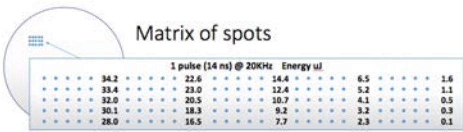
LIFT parameterization

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)



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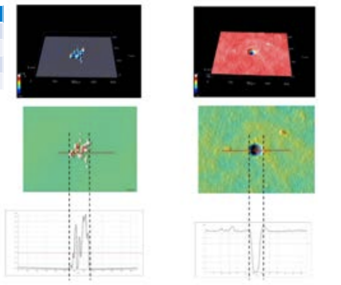
LIFT parameterization

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



W: 117 um
H: 5 um

W: 91 um
H: 33 um

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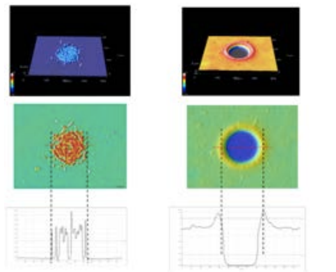
LIFT parameterization

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



W: 205 um
H: 4 um

W: 243 um
H: 32 um

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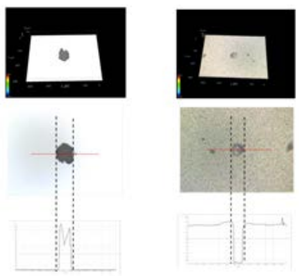
LIFT parameterization

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



W: 88 um
H: 12 um

W: 85 um
H: 55 um

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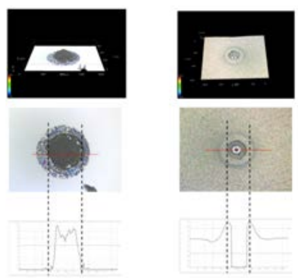
LIFT parameterization

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



W: 236 um
H: 13 um

W: 132 um
H: 57 um

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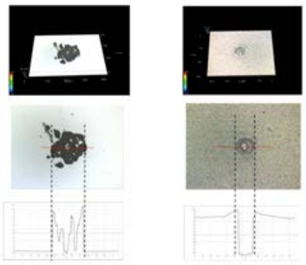
LIFT parameterization

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

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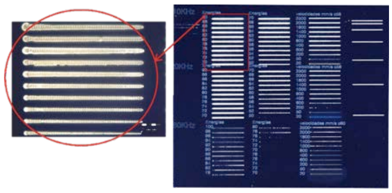
LIFT printing of long lines

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



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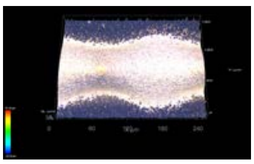
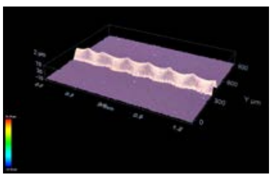
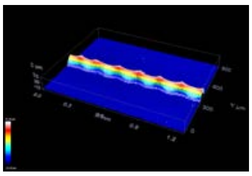
LIFT printing of long lines

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







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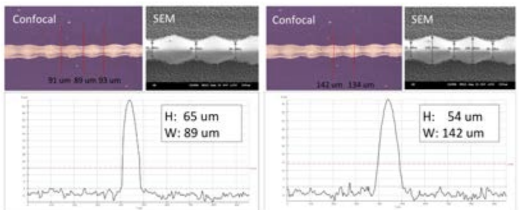
LIFT printing of long lines



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

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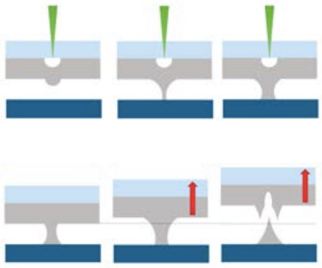
LIFT printing of long lines

- 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



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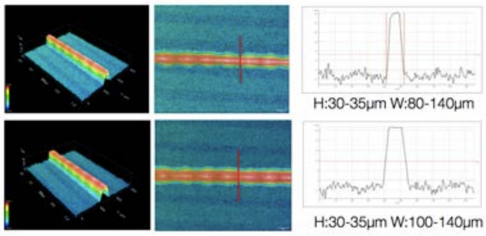
LIFT printing of long lines

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



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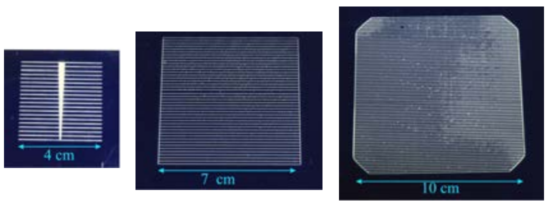
Large area metallization

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.



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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.

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Acknowledgments

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Acknowledgments

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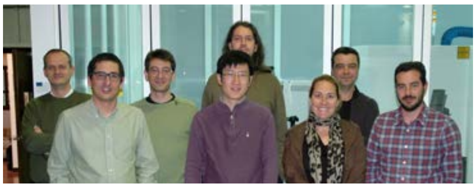

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Laser sintering

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

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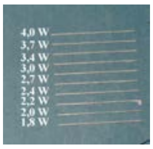
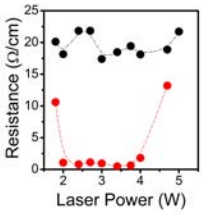
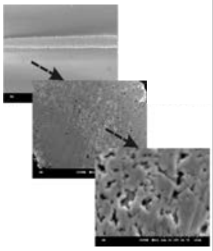
Laser sintering

Lines deposited using screen-printing (Heraeus)







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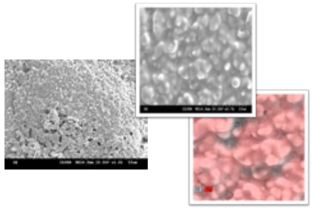
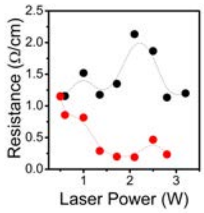
Laser sintering

Lines deposited using LIFT (Heraeus)





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