



Laser based metallization processes for PV devices

D. Munoz-Martin, M. Morales, Y. Chen,
M. I. Sanchez-Aniorte, L. Rubio, C. Molpeceres



POLITÉCNICA



CENTRO LÁSER
UNIVERSIDAD POLITÉCNICA DE MADRID



appolo

Hub of Application Laboratories for Equipment Assessment
in Laser Based Manufacturing

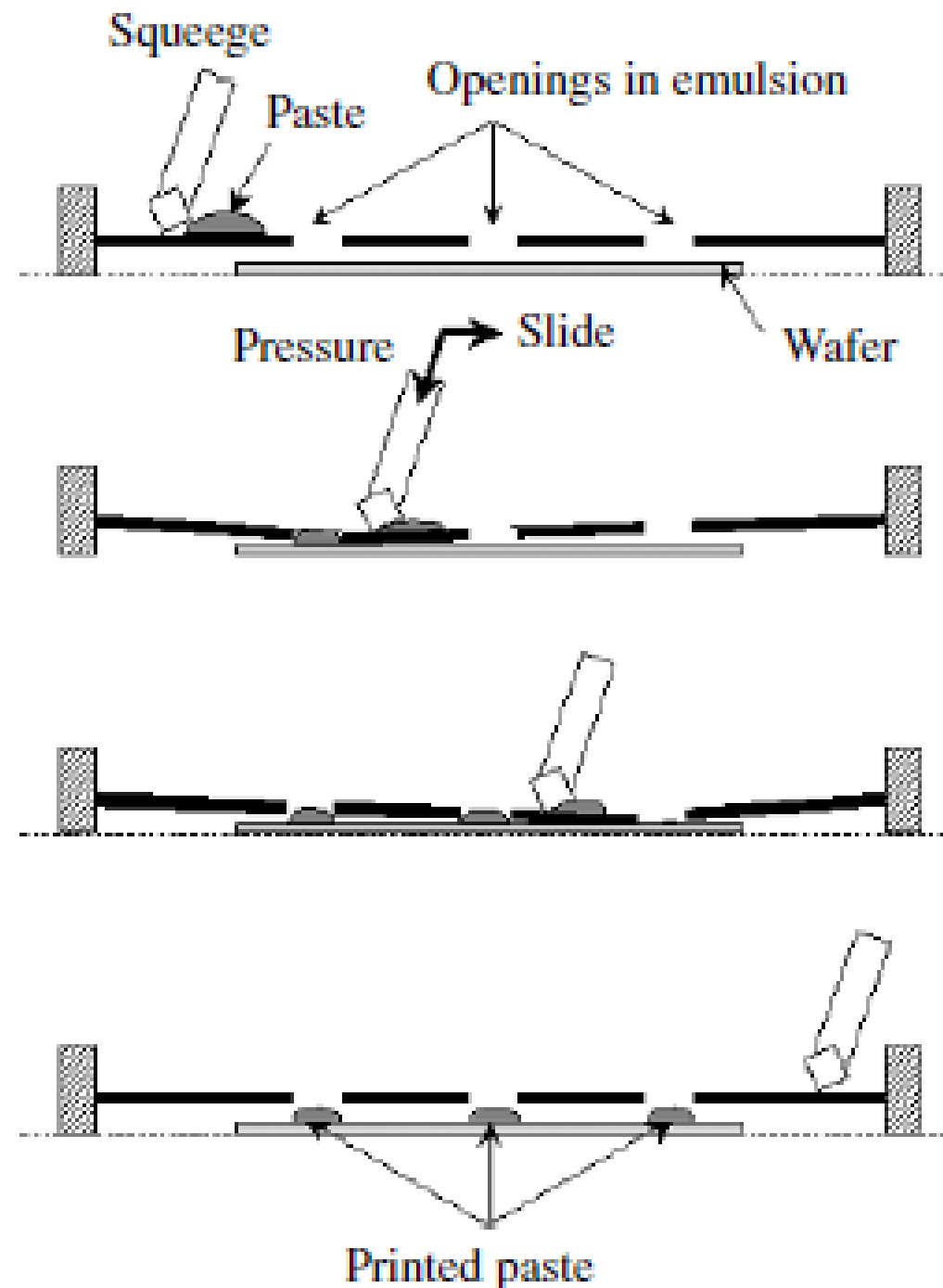


1. Introduction: metallization of solar cells
2. Laser-Induced Forward Transfer (LIFT)
3. Experimental results on metallization using LIFT
4. Numerical model simulation
5. Laser sintering
6. Summary
7. Acknowledgements



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

- Screen-printing

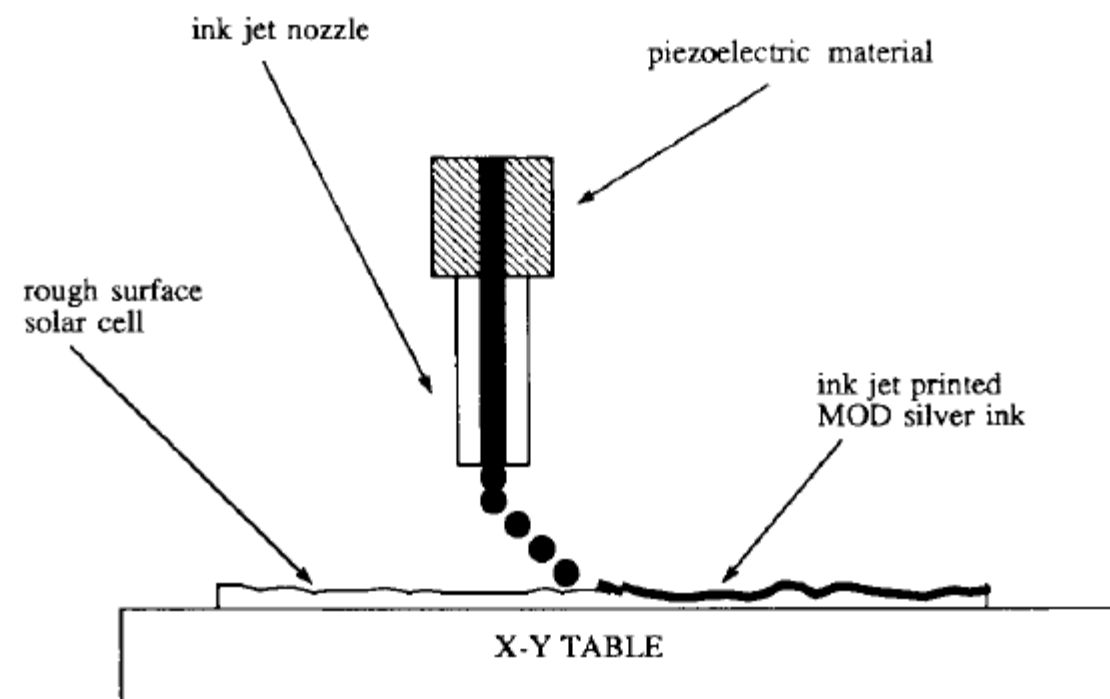


Luque &
Hegedus,
Handbook of
Photovoltaic
Science and
Engineering
(2003)



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

- Screen-printing
- Ink-jet printing

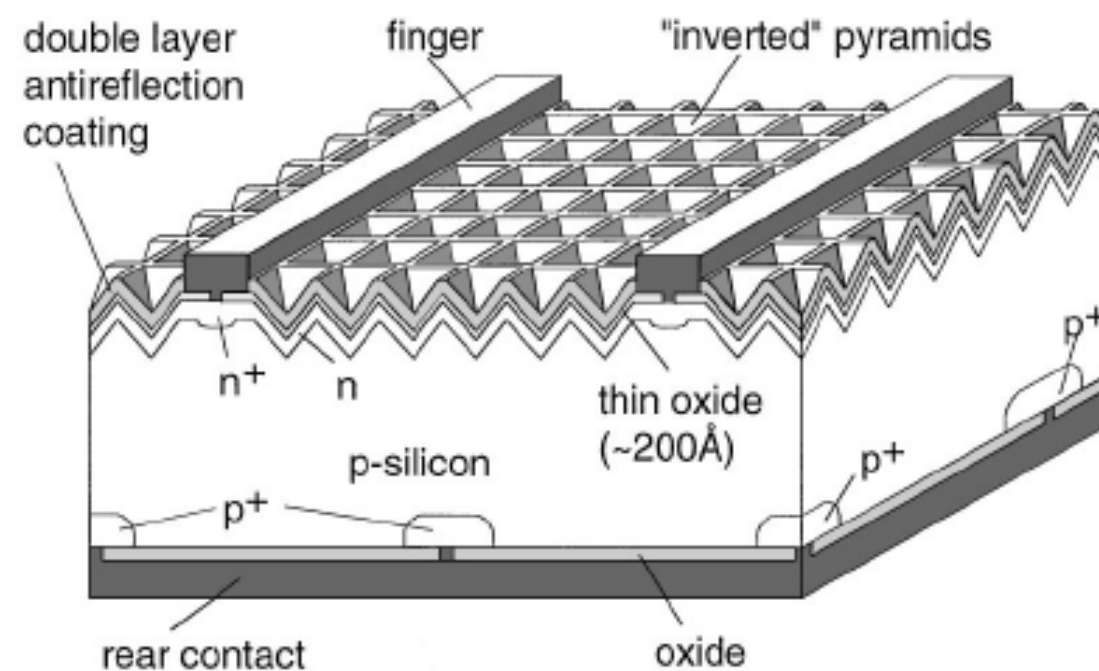


Teng & Vest, IEEE
Trans. Compon.,
Hybrids, Manuf.
Technol (1988)



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

- Screen-printing
- Ink-jet printing
- High-efficiency approaches: photolithography / evaporation / plating

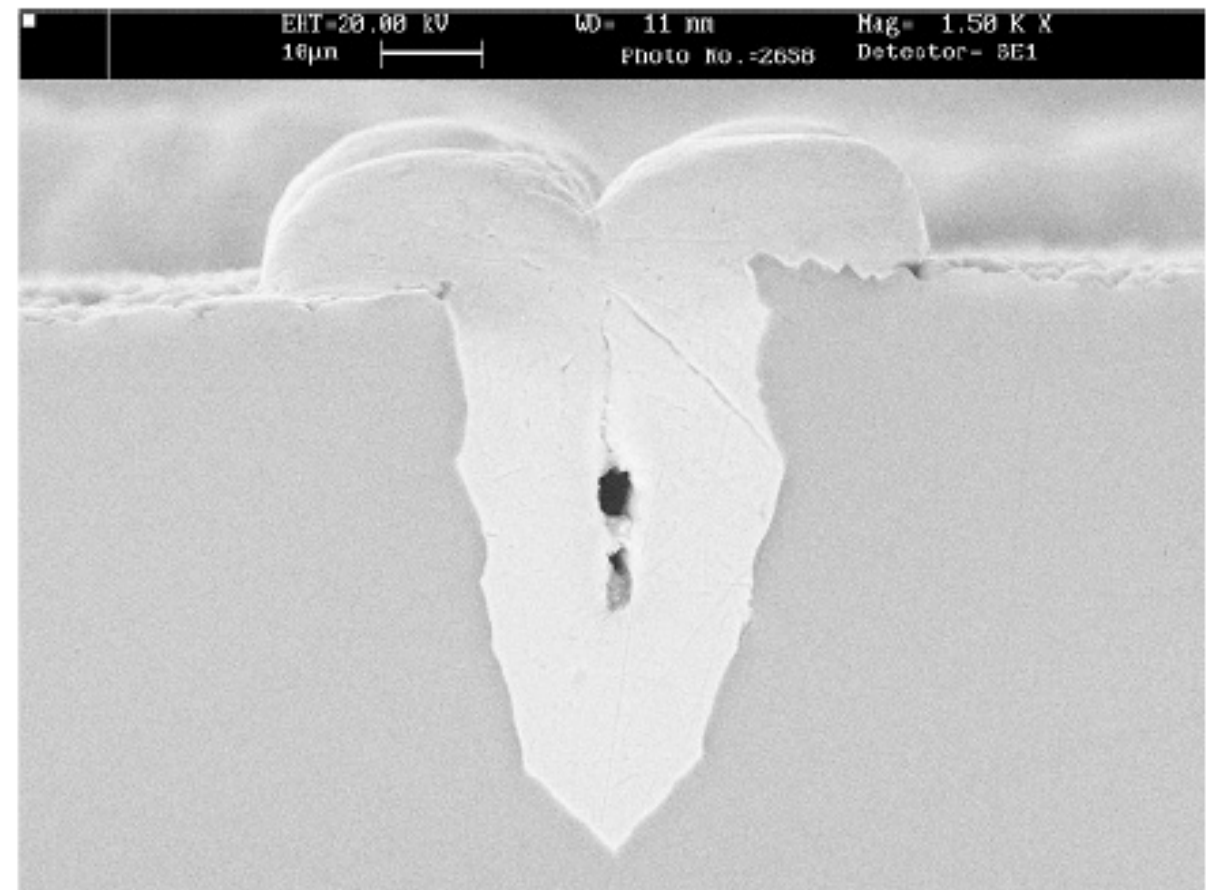


Zhao et al, Sol. Energ. Mat. Energ. C. (2001)



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

- Screen-printing
- Ink-jet printing
- High-efficiency approaches: photolithography
- Laser-Grooved Buried-Grid cells



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

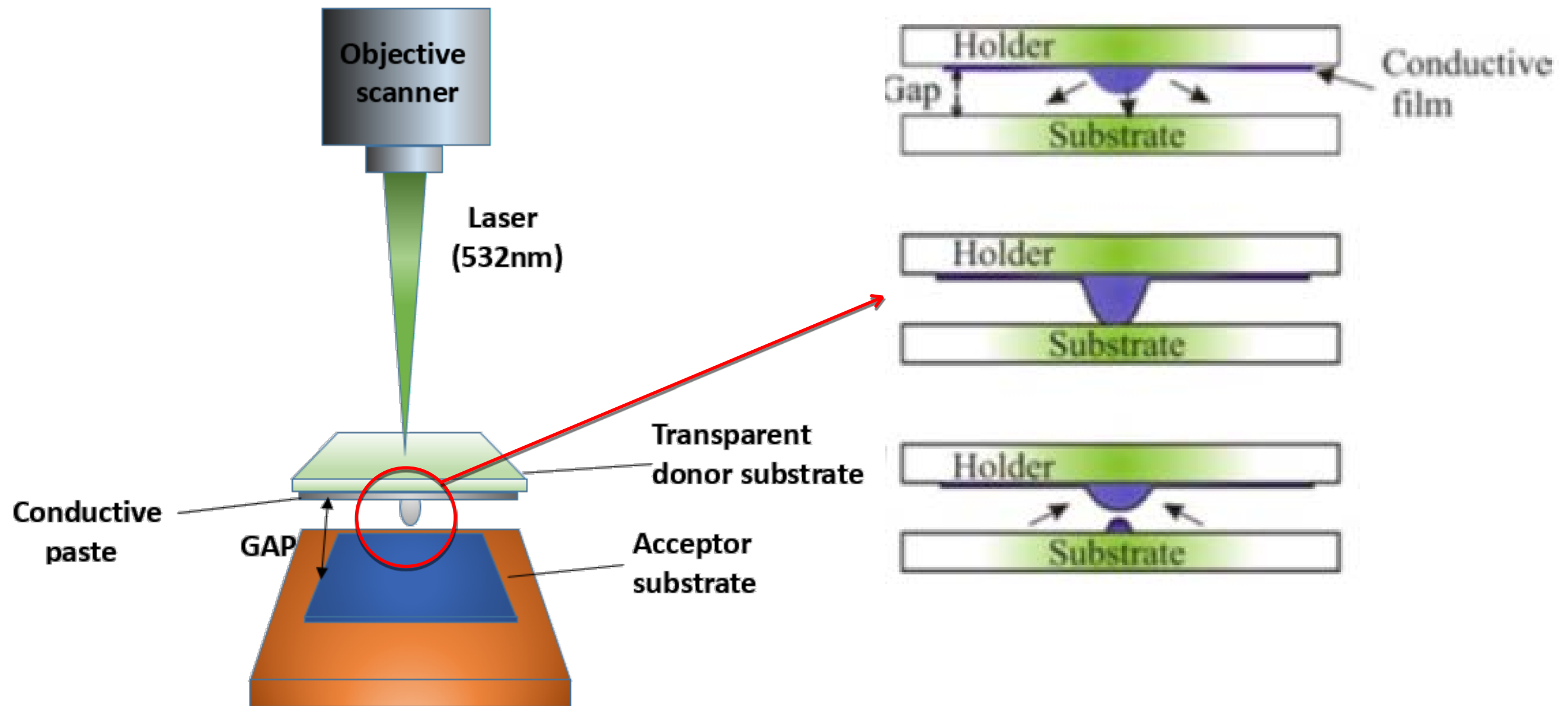


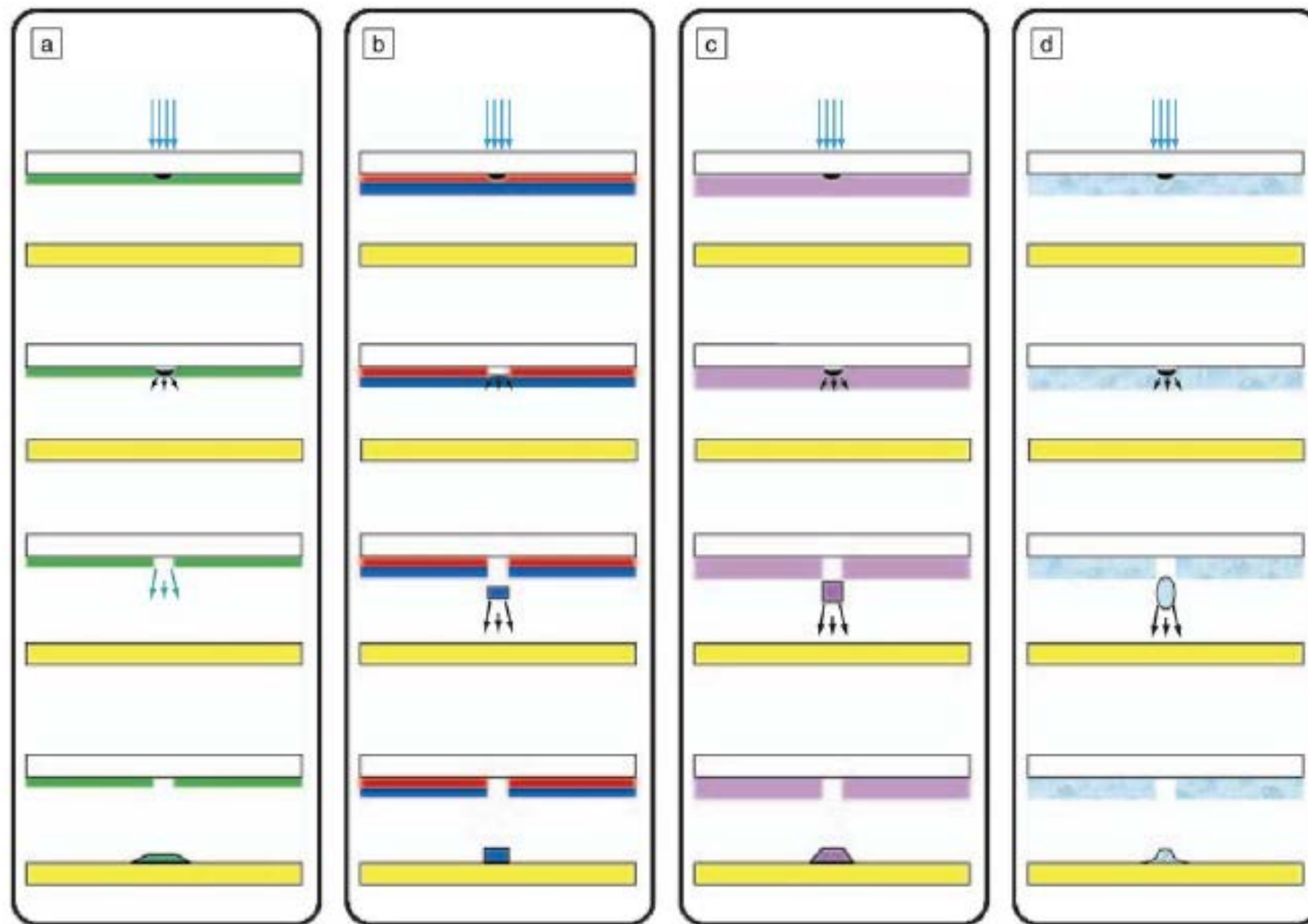
Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing
- Ink-jet printing
- High-efficiency approaches: photolithography / evaporation / plating
- Laser-Grooved Buried-Grid cells
- Laser Printing based on Laser-Induced Forward Transfer (LIFT)

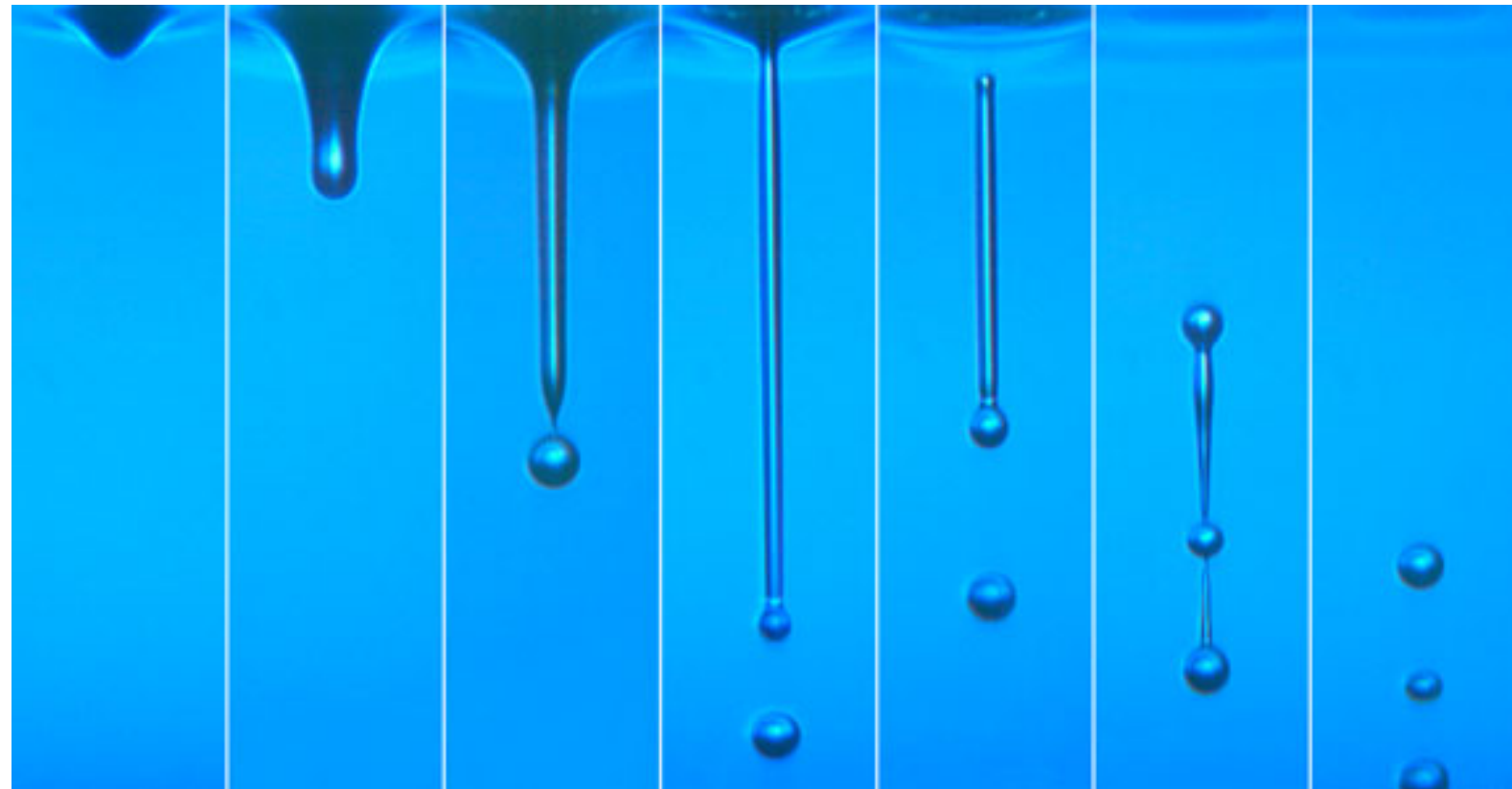


LIFT: *Laser-Induced Forward Transfer*





Arnold et al, MRS Bull. (2007)



Brown et al, Microfluid Nanofluid (2011)

Some materials deposited
using LIFT:

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



1. Introduction: metallization of solar cells
2. Laser-Induced Forward Transfer (LIFT)
3. Experimental results on metallization using LIFT
4. Numerical model simulation
5. Laser sintering
6. Summary
7. Acknowledgements



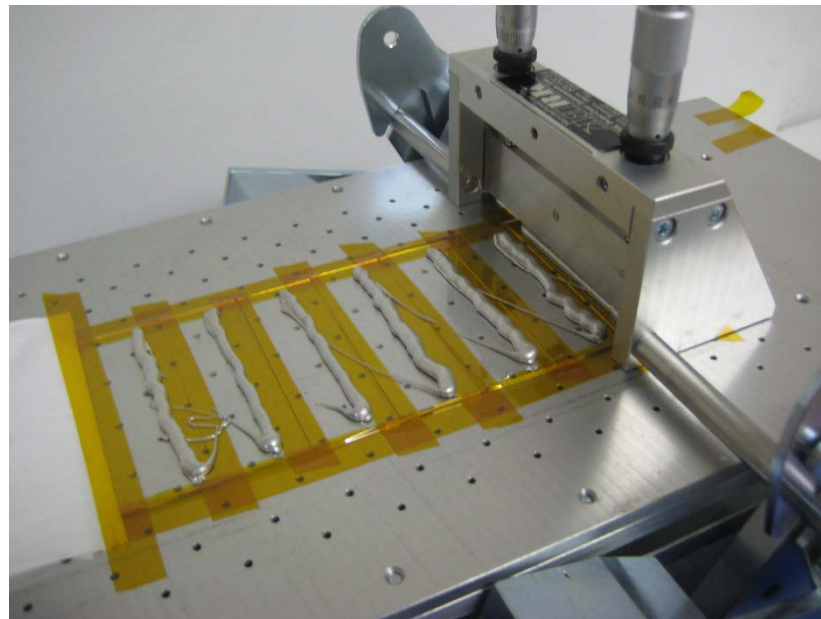
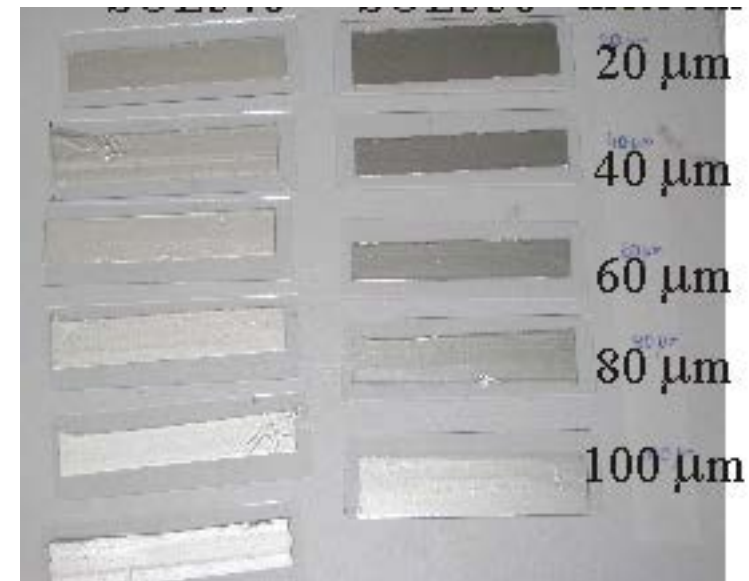
Experimental setup

- Low temperature screen-printing Ag pastes (Heraeus, DuPont).



Experimental setup

- Low temperature screen-printing Ag pastes (Heraeus, DuPont).
- Deposition onto donor substrate using a commercial paint coater (RK PrintCoat Instruments).





Experimental setup

- Low temperature screen-printing Ag pastes.
- Deposition onto donor substrate using a commercial paint coater (RK PrintCoat Instruments).
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix).



Experimental setup

- Low temperature screen-printing Ag pastes.
- Deposition onto donor substrate using a commercial paint coater (RK PrintCoat Instruments).
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix).
- Diode Pumped Solid State Laser (Spectra Physics Explorer)
 - Nd:YVO4 emitting 532 nm
 - Pulse duration 15 ns



Experimental setup

- Low temperature screen-printing Ag pastes.
- Deposition onto donor substrate using a commercial paint coater (RK PrintCoat Instruments).
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix).
- Diode Pumped Solid State Laser (Spectra Physics Explorer)
- Optical Scanner (ScanLab HurryScan)
 - F-Theta Lens, focal 250 mm
 - Focused beam diameter 22 μm



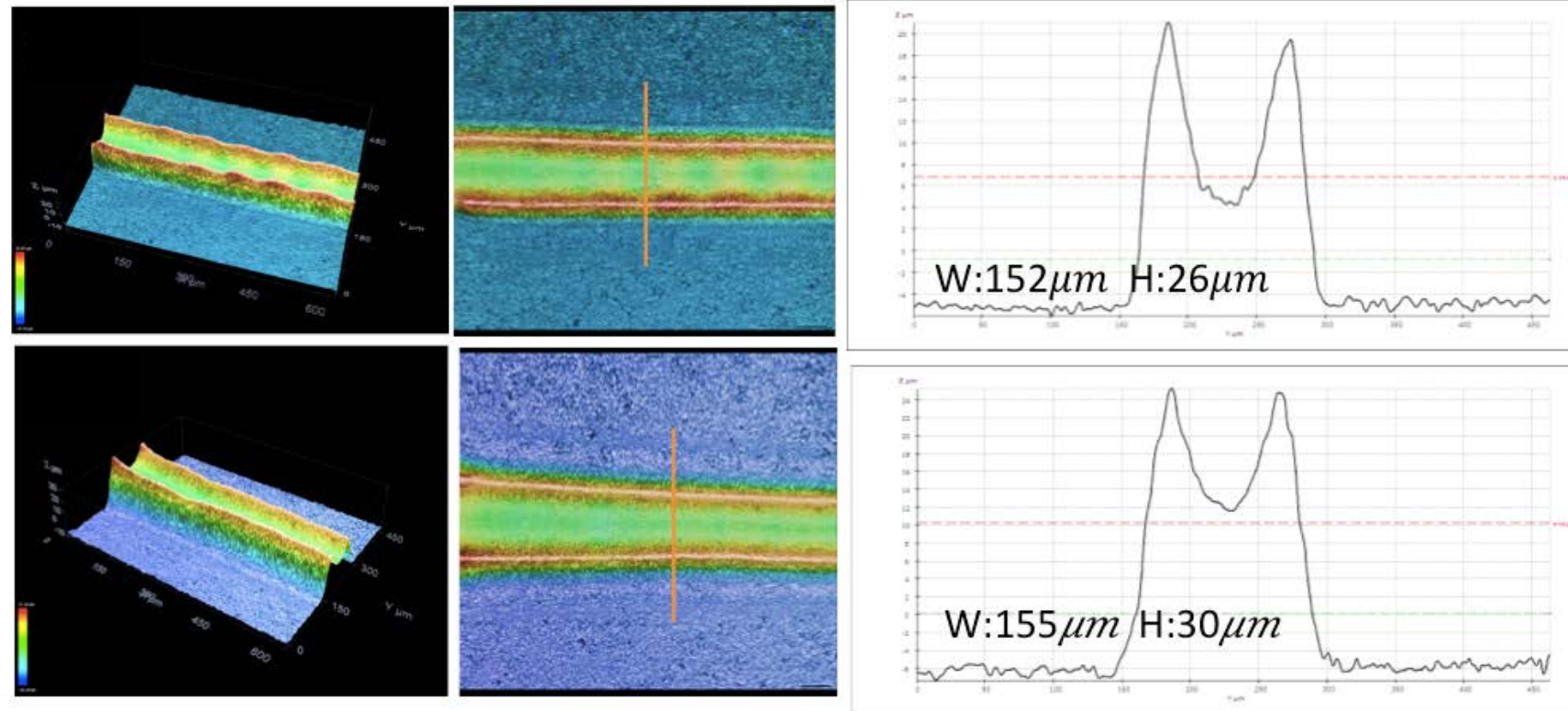
Process parameterization:

- Laser:
 - pulse energy
~10 μJ
 - repetition rate
~50 kHz
 - scanning speed
>1m/s
- Set-up:
 - Layer thickness
20 – 100 μm
 - Gap
~50 μm
- Ag Paste



Process parameterization:

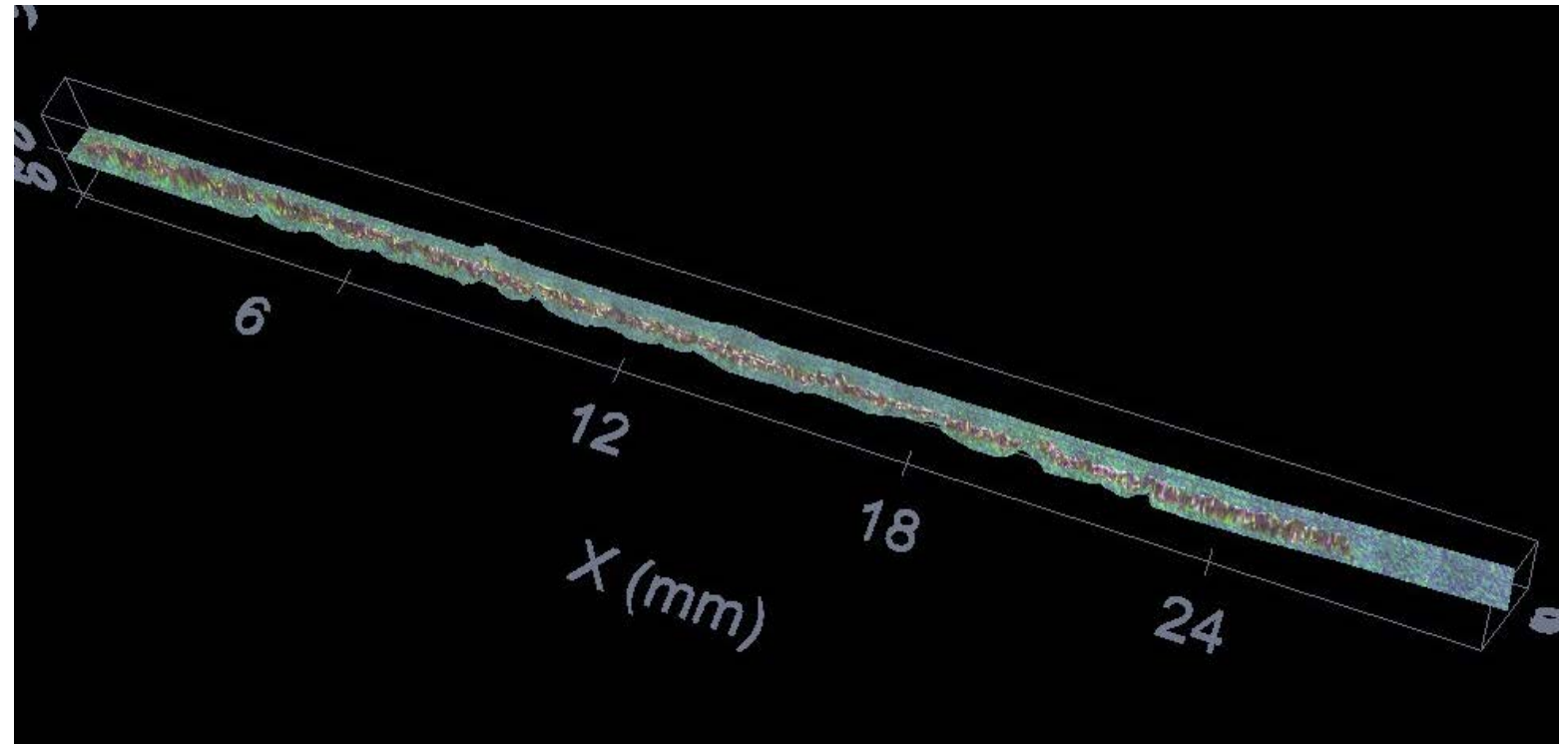
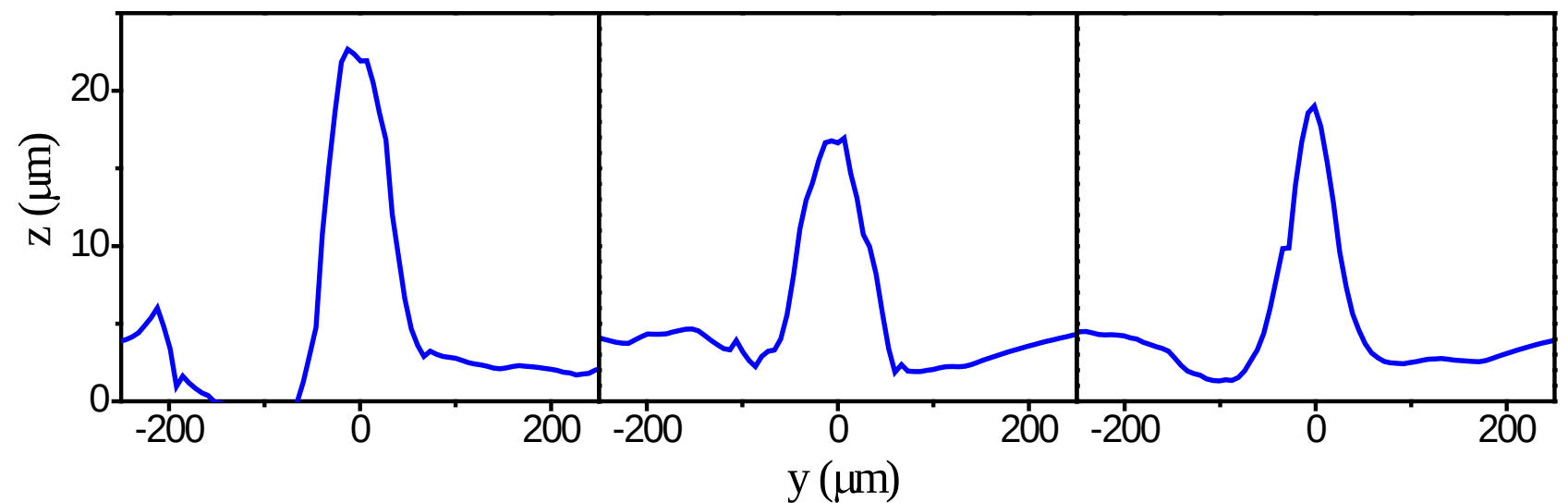
- Laser:
 - pulse energy
~10 μJ
 - repetition rate
~50 kHz
 - scanning speed
>1m/s
- Set-up:
 - Layer thickness
20 – 100 μm
 - Gap
~50 μm
- Ag Paste: Heraeus





Process parameterization:

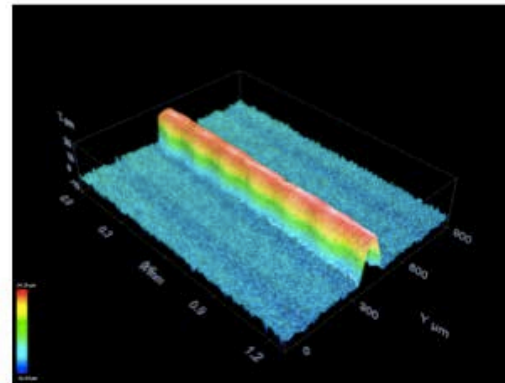
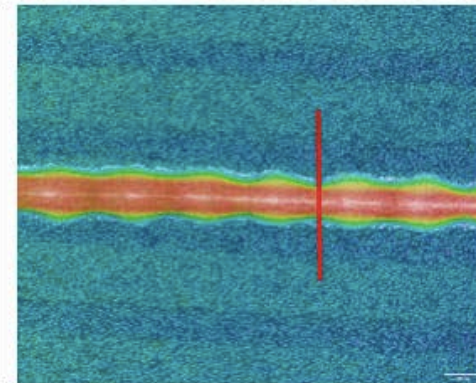
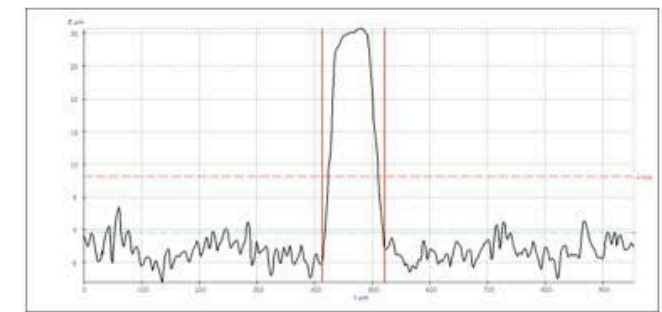
- Laser:
 - pulse energy
~10 μJ
 - repetition rate
~50 kHz
 - scanning speed
>1m/s
- Set-up:
 - Layer thickness
20 – 100 μm
 - Gap
~50 μm
- Ag Paste: Heraeus



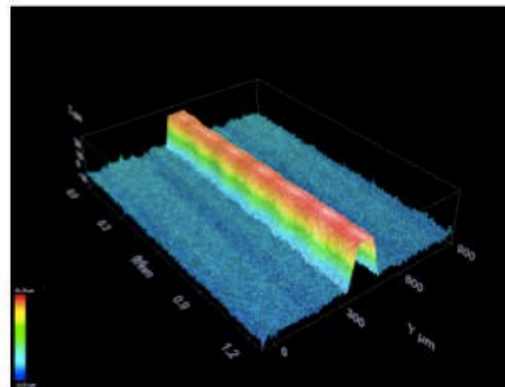
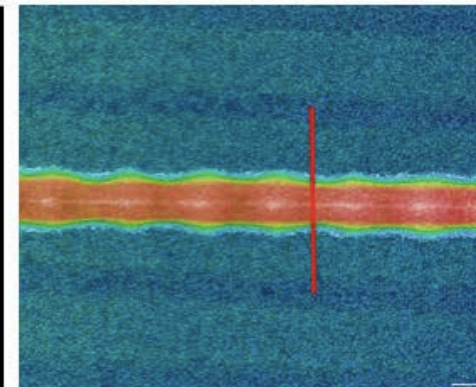
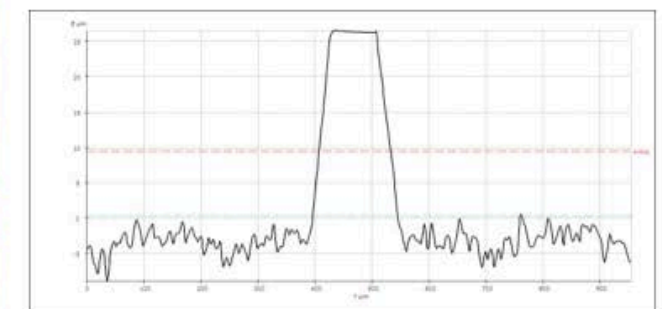


Process parameterization:

- Laser:
 - pulse energy
~10 μJ
 - repetition rate
~50 kHz
 - scanning speed
>1m/s
- Set-up:
 - Layer thickness
20 – 100 μm
 - Gap
~50 μm
- Ag Paste: DuPont



H:30-35 μm W:80-140 μm



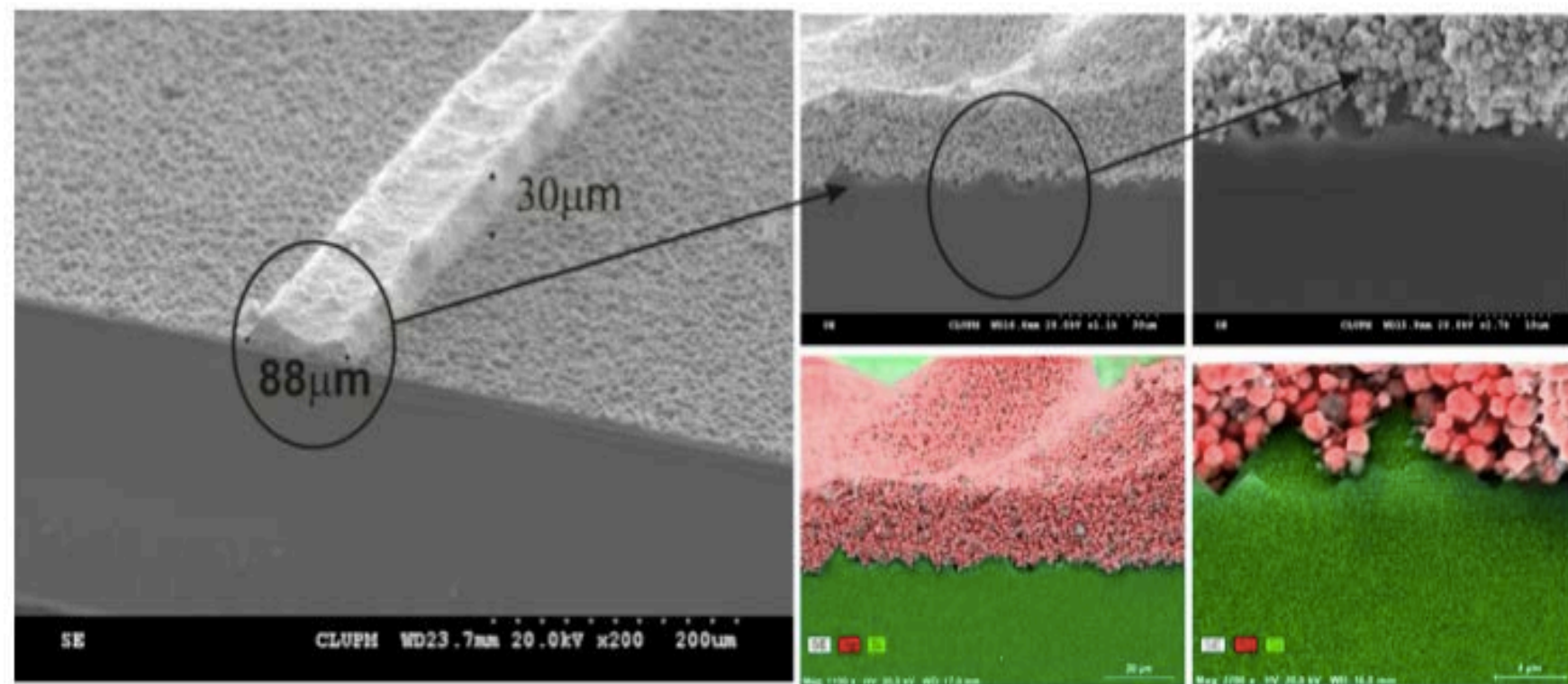
H:30-35 μm W:100-140 μm

Aspect Ratio $\approx 0.25 - 0.40$
Voxel $\approx 300 \text{ pL}$



Process parameterization:

- Laser:
 - pulse energy $\sim 10 \mu\text{J}$
 - repetition rate $\sim 50 \text{ kHz}$
 - scanning speed $> 1 \text{ m/s}$
- Set-up:
 - Layer thickness $20 - 100 \mu\text{m}$
 - Gap $\sim 50 \mu\text{m}$
- Ag Paste: DuPont

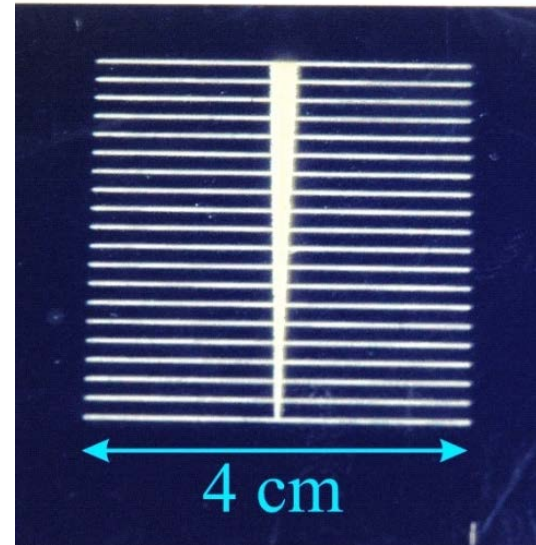
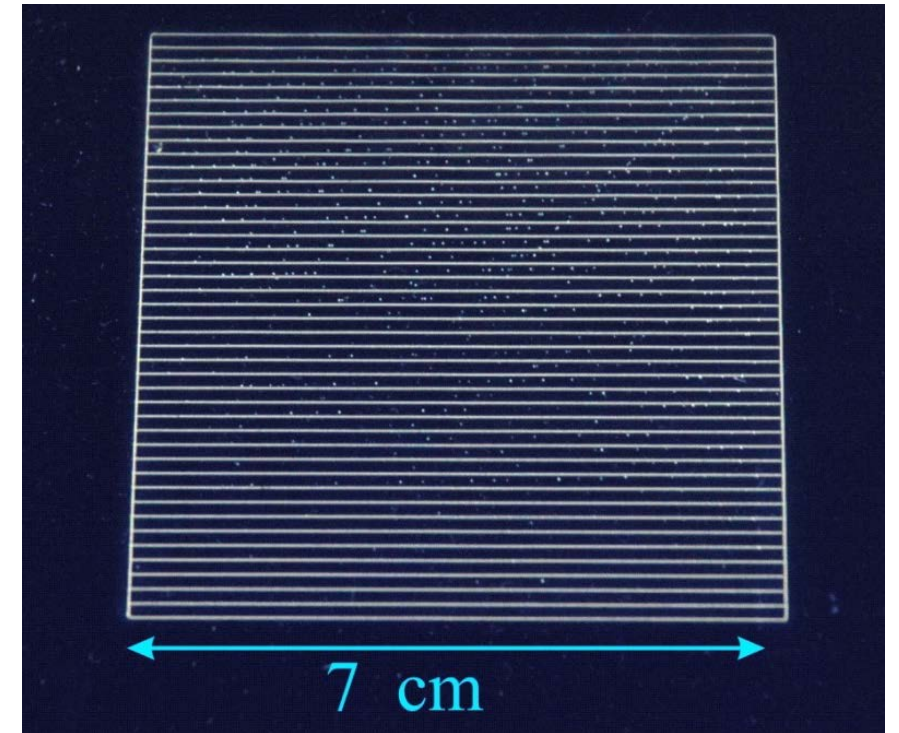
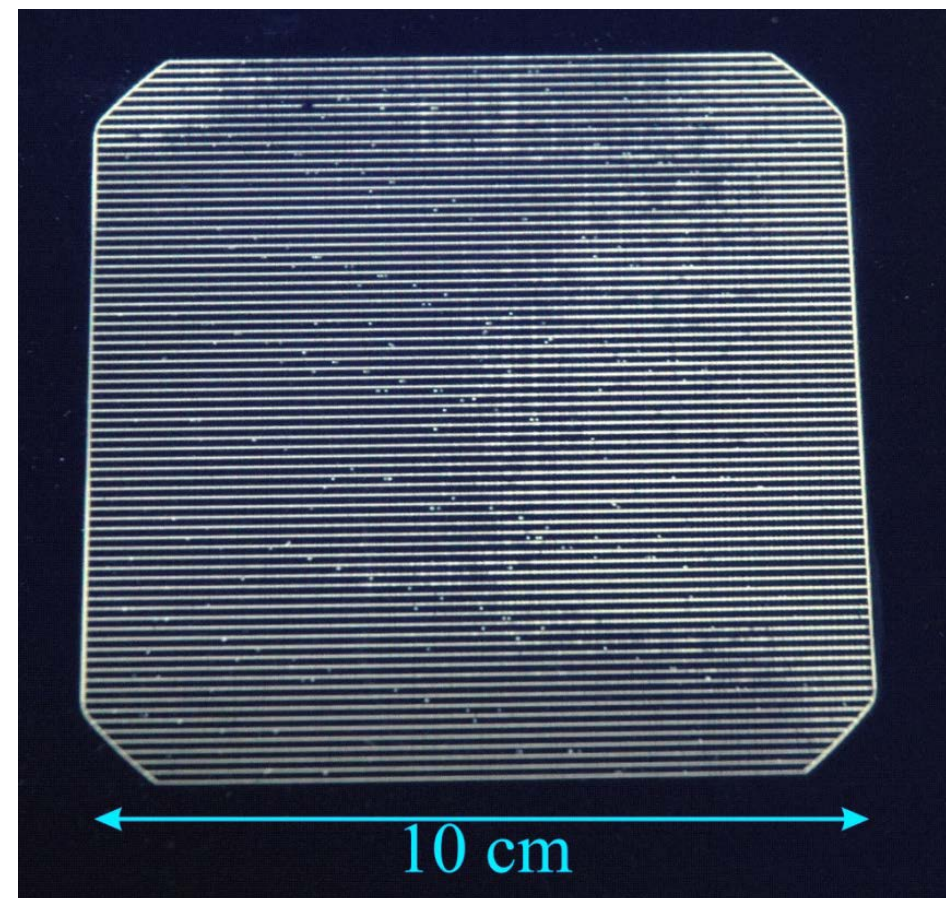


Aspect Ratio $\approx 0.25 - 0.40$
Voxel $\approx 300 \text{ pL}$



Process parameterization:

- Laser:
 - pulse energy
~10 μJ
 - repetition rate
~50 kHz
 - scanning speed
>1m/s
- Set-up:
 - Layer thickness
20 – 100 μm
 - Gap
~50 μm
- Ag Paste: DuPont

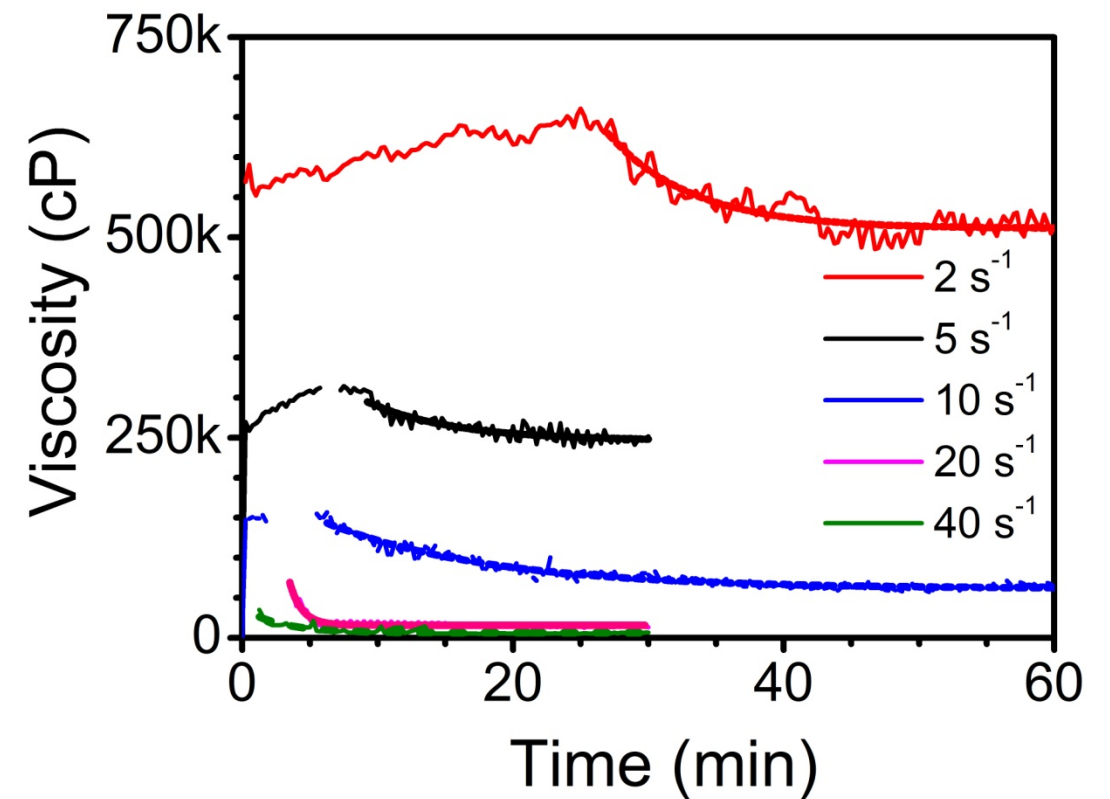
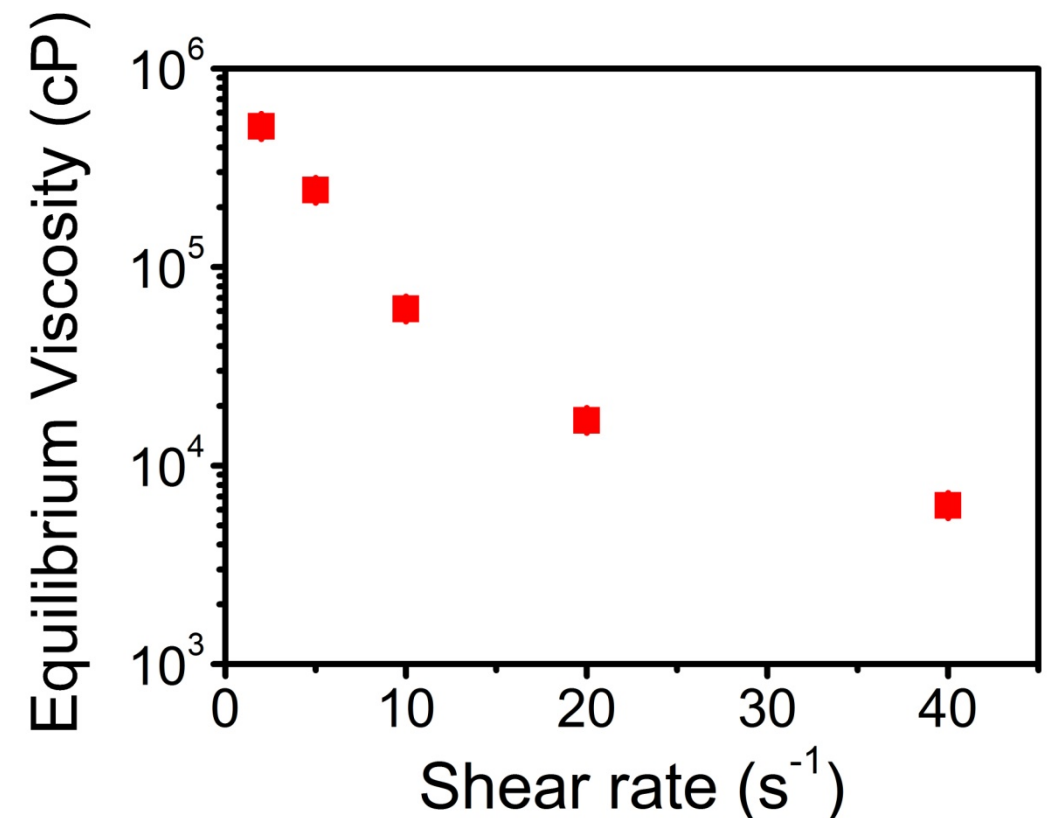




Process parameterization:

- Laser:
 - pulse energy
 - repetition rate
 - scanning speed
- Set-up:
 - Layer thickness
 - Gap
- Ag Paste: Viscosity

Ag Pastes are non-newtonian,
pseudoplastic, thixotropic
fluids



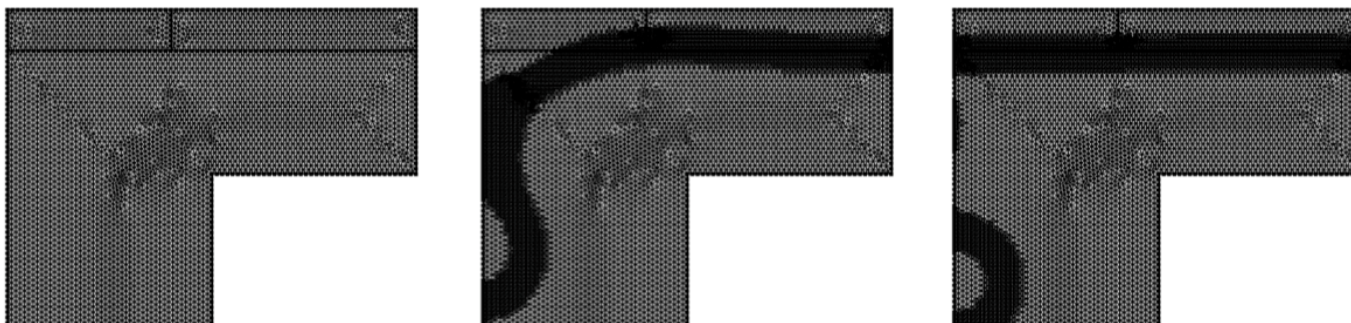


1. Introduction: metallization of solar cells
2. Laser-Induced Forward Transfer (LIFT)
3. Experimental results on metallization using LIFT
4. Numerical model simulation
5. Laser sintering
6. Summary
7. Acknowledgements



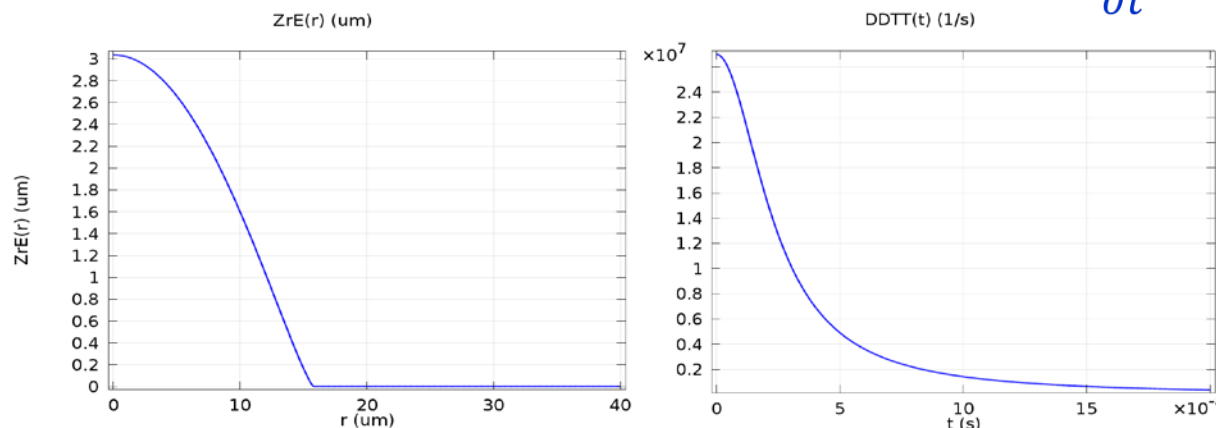
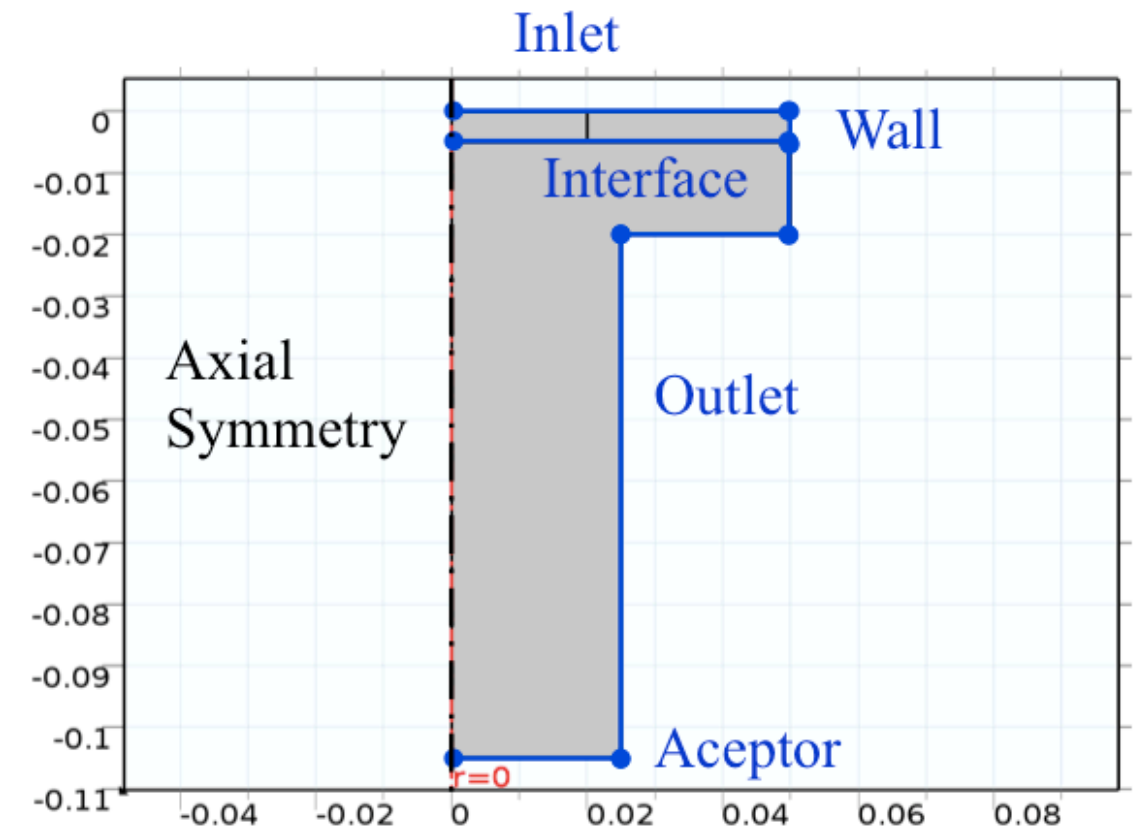
Simulation using COMSOL

- CFD Module
 - o Laminar Two-Phase Flow
 - o Gravity
 - o Boundary conditions
- Physics-Controlled Meshing



- Laser interaction

- o Ink velocity $input\ velocity = Z(r, E) \cdot \frac{\partial T(t)}{\partial t}$

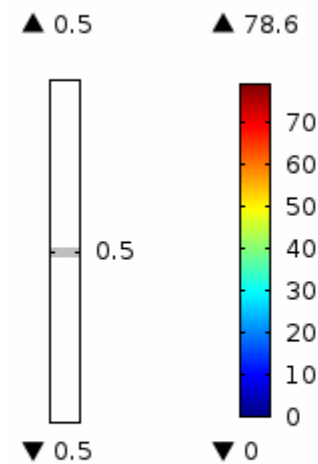
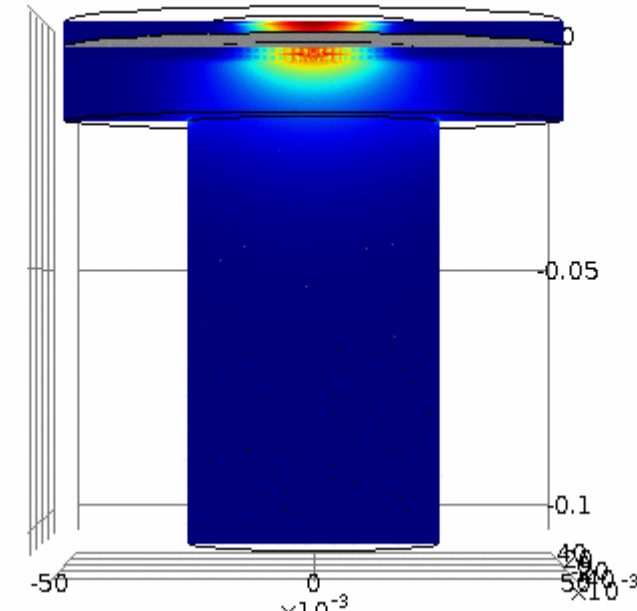


- Ink parameters
 - o Newtonian fluid
 - o Density: 1030 kg/m³
 - o Dynamic viscosity: 1.7 mPa·s
 - o Surface tension: 40.73 mN/m
- Air parameters
 - o Newtonian fluid
 - o Density: 1.1614 kg/m³
 - o Dynamic viscosity: 18.46 μPa·s

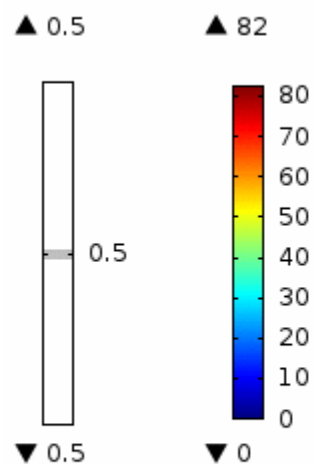
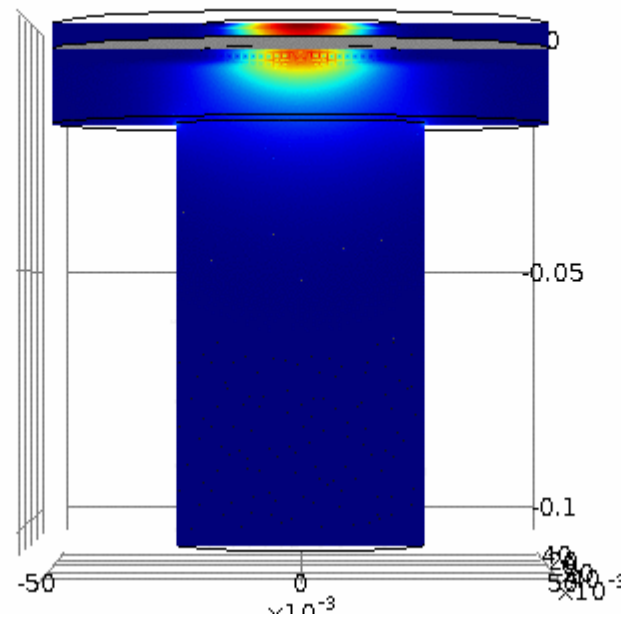


Energy = 4.82 μJ

Time=0 s Isosurface: Volume fraction of fluid 1 (1) Slice: Velocity magnitude (m/s)

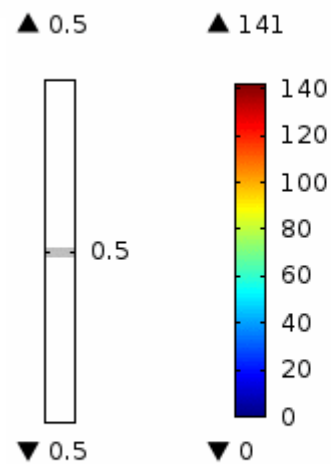
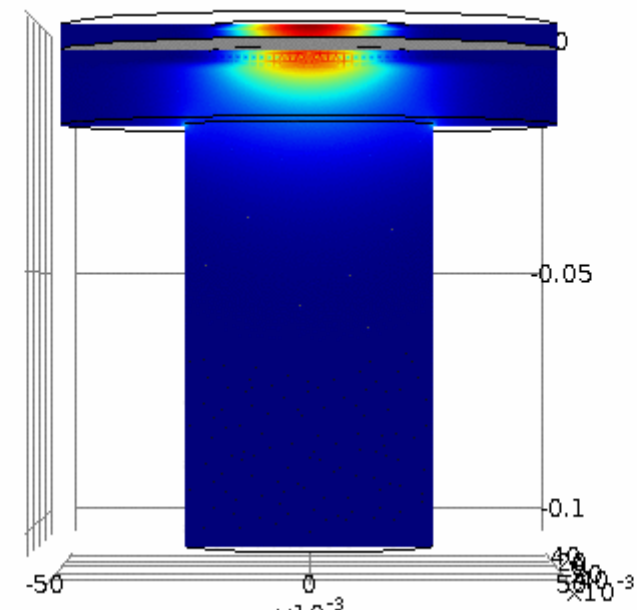


Time=0 s Isosurface: Volume fraction of fluid 1 (1) Slice: Velocity magnitude (m/s)



Energy = 4.87 μJ

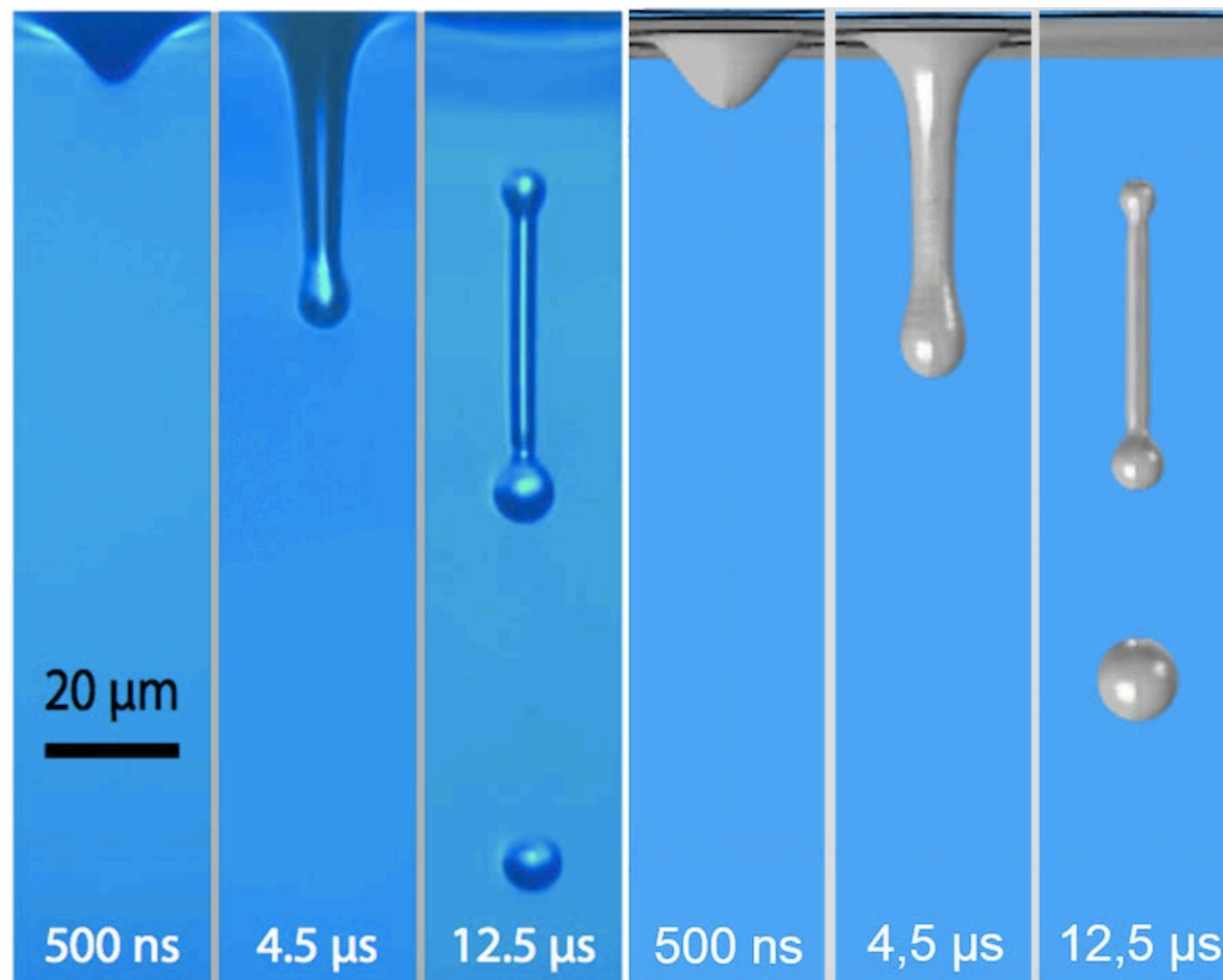
Time=0 s Isosurface: Volume fraction of fluid 1 (1) Slice: Velocity magnitude (m/s)



Energy = 5.70 μJ



Simulation



Brown et al, Microfluid
Nanofluid (2011)



1. Introduction: metallization of solar cells
2. Laser-Induced Forward Transfer (LIFT)
3. Experimental results on metallization using LIFT
4. Numerical model simulation
5. Laser sintering
6. Summary
7. Acknowledgements



Metallization comprise different steps:

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

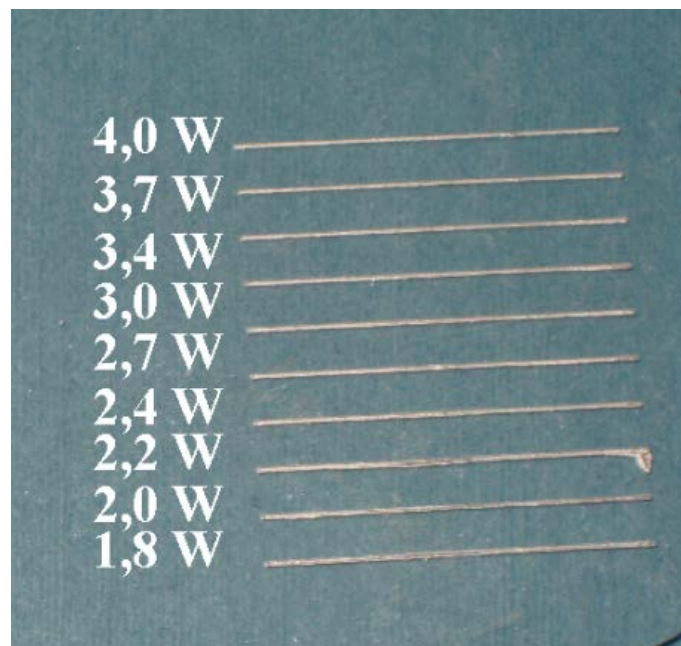
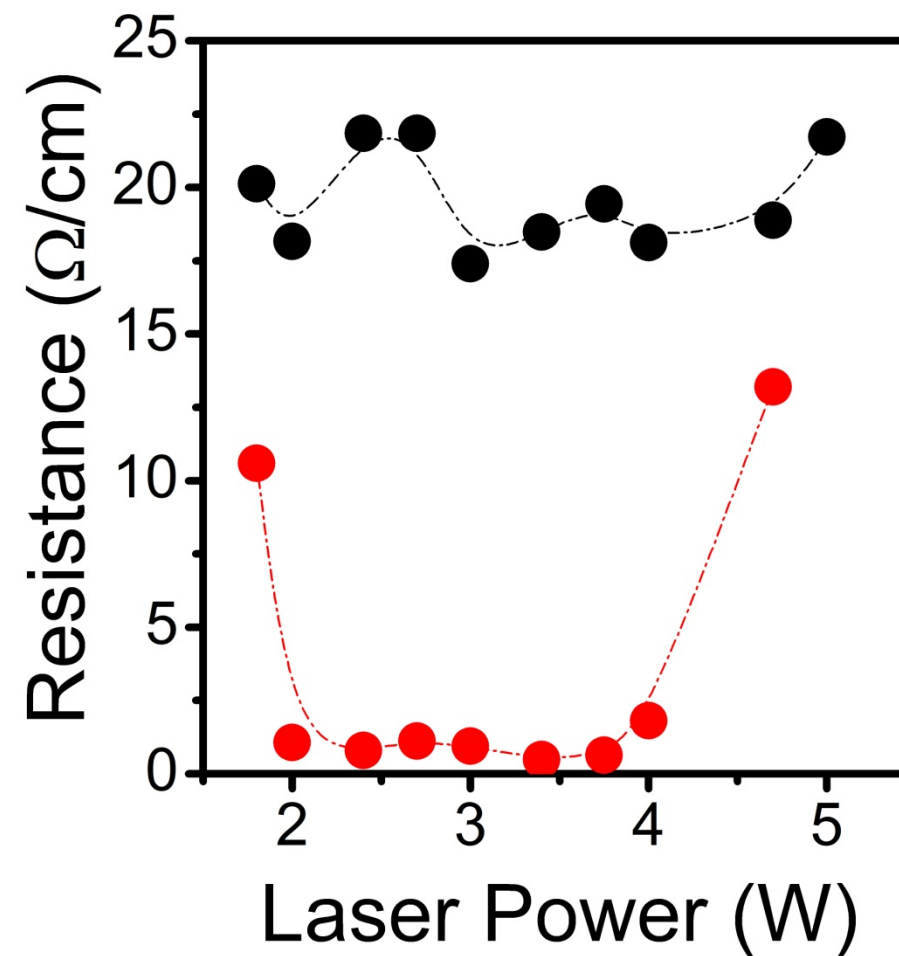
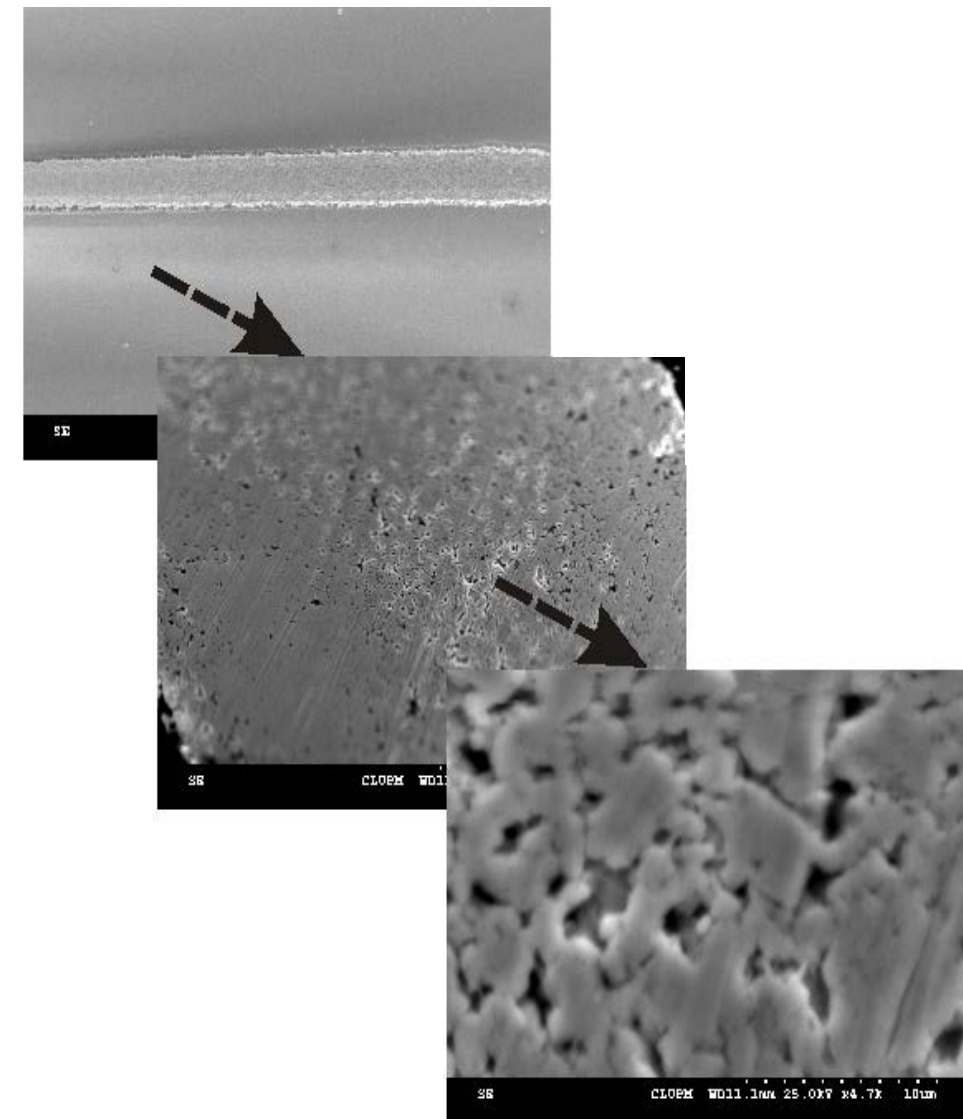
All-laser based process:
Laser heating using a CW source.

Experimental setup:

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

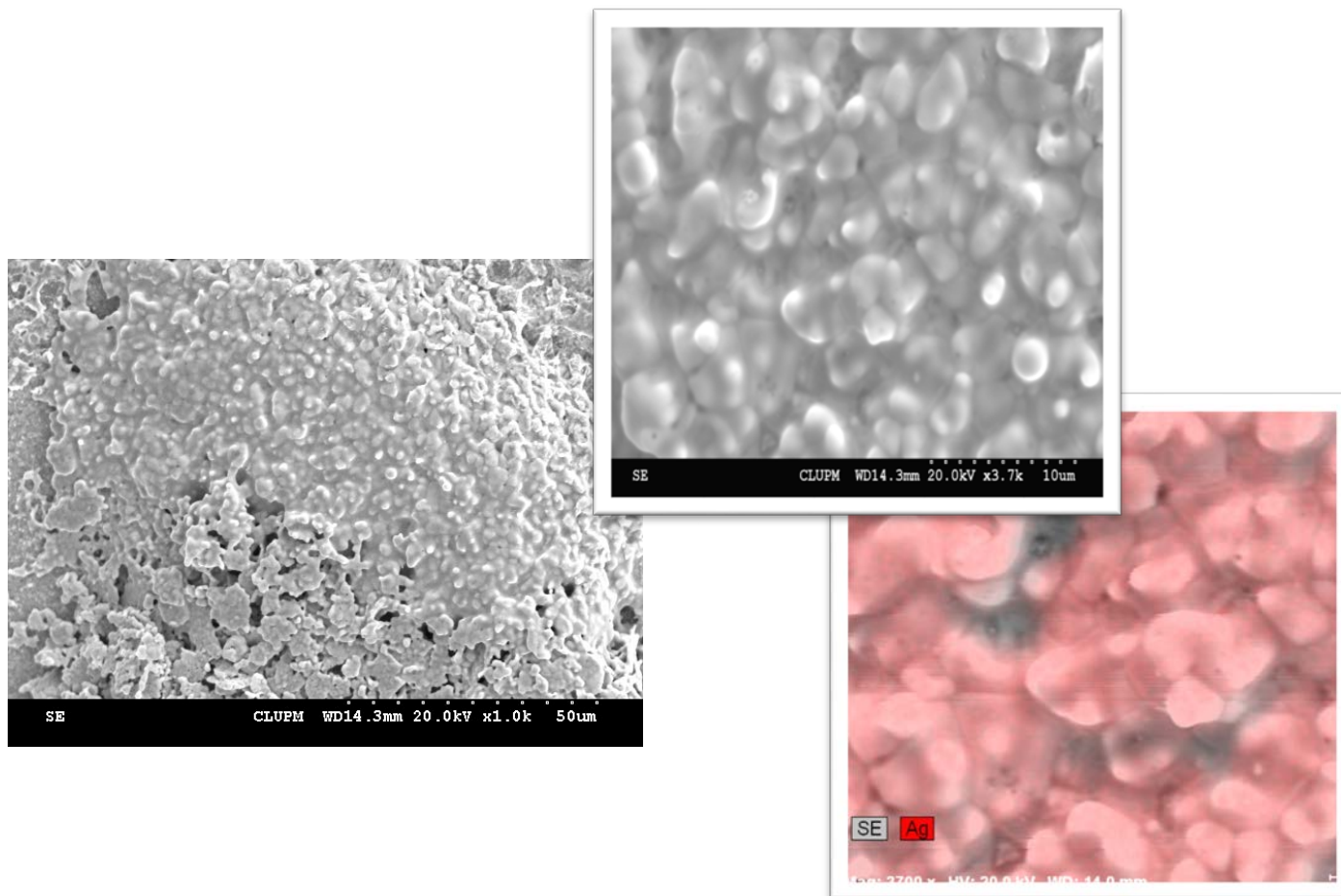
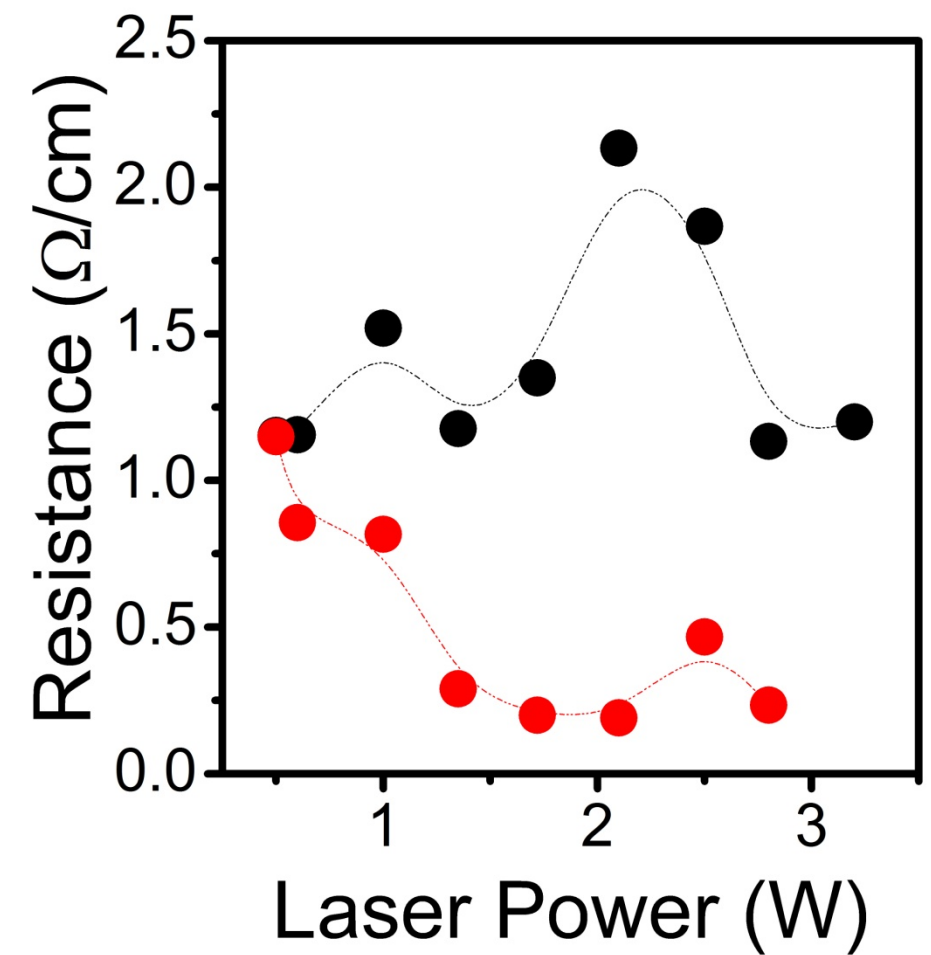


Lines deposited using screen-printing (Heraeus)





Lines deposited using LIFT (Heraeus)





1. Introduction: metallization of solar cells
2. Laser-Induced Forward Transfer (LIFT)
3. Experimental results on metallization using LIFT
4. Numerical model simulation
5. Laser sintering
6. Summary
7. Acknowledgements



- 1) LIFT is a promising technique for the metallization of PV devices using commercial screen-printing pastes.
- 2) Lines deposited using optimal parameters have good shape and large aspect ratios (≈ 0.3). The volume transferred per pulse (voxel) is quite large (≈ 300 pL).
- 3) Optical scanners allow fast processing and flexible design.
- 4) Viscosity of the paste plays a fundamental role. Thinner additives are needed for controlling the paste viscosity.
- 5) Numerical COMSOL simulation allows a deeper understanding of the physics of the deposition process and predicting the better experimental conditions.
- 6) Laser sintering of LIFT deposited lines using a CW laser has been achieved: low temperature process (localized heating) without needing of furnace steps.
- 7) All-laser based metallization processes are possible.



Hub of Application Laboratories for Equipment
Assessment in Laser Based Manufacturing





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



GOBIERNO
DE ESPAÑA

MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD



Hub of Application Laboratories for Equipment
Assessment in Laser Based Manufacturing



תודה
Dankie Gracias
Спасибо شكري
Merci Takk
Köszönjük Terima kasih
Grazie Dziękujemy Děkojame
Ďakujeme Vielen Dank Paldies
Kiitos Täname teid 谢谢
Thank You Tak
感謝您 Obrigado Teşekkür Ederiz
Σας ευχαριστούμε 감사합니다
ขอบคุณ
Bedankt Děkuje vám
ありがとうございます
Tack