Laser printing of organic light-emitting diode pixels by LIFT

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Materials Science & Technology

Optimising the fabrication of OLEDs by laser-induced forward transfer

Functional Thin Films

5TH VACUUM SYMPOSIUM UK
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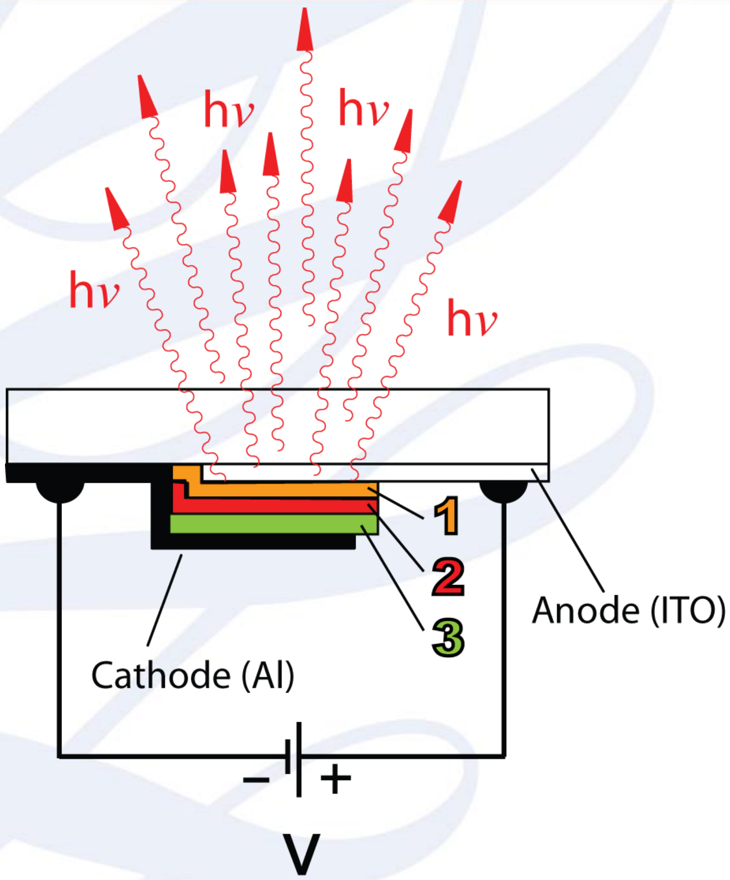
OLED device architecture

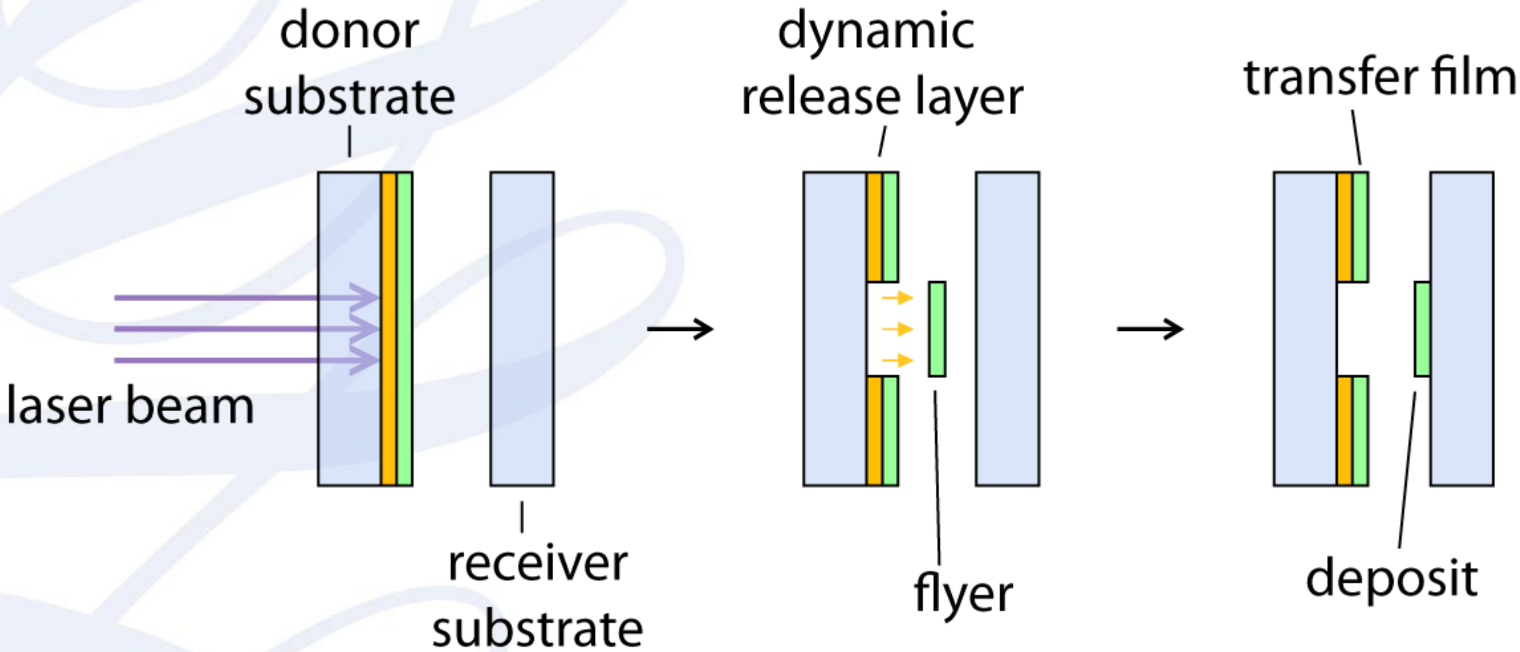


- The layered arrangement for a standard OLED is shown:
  - A transparent anode (usually ITO) and a cathode sandwich the following possible functional layers:

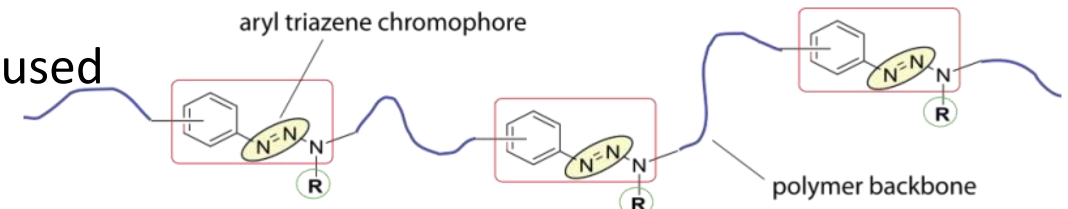
1. Electron-blocking and/or hole-transporting layers
2. Light emitting layer (or interface)
3. Hole-blocking and/or electron-transporting layer

LIFT with a sacrificial dynamic release layer (DRL)

– A photosensitive layer which is sacrificially ablated by the laser beam, in order that the transfer material may be propelled forward as a **flyer**:

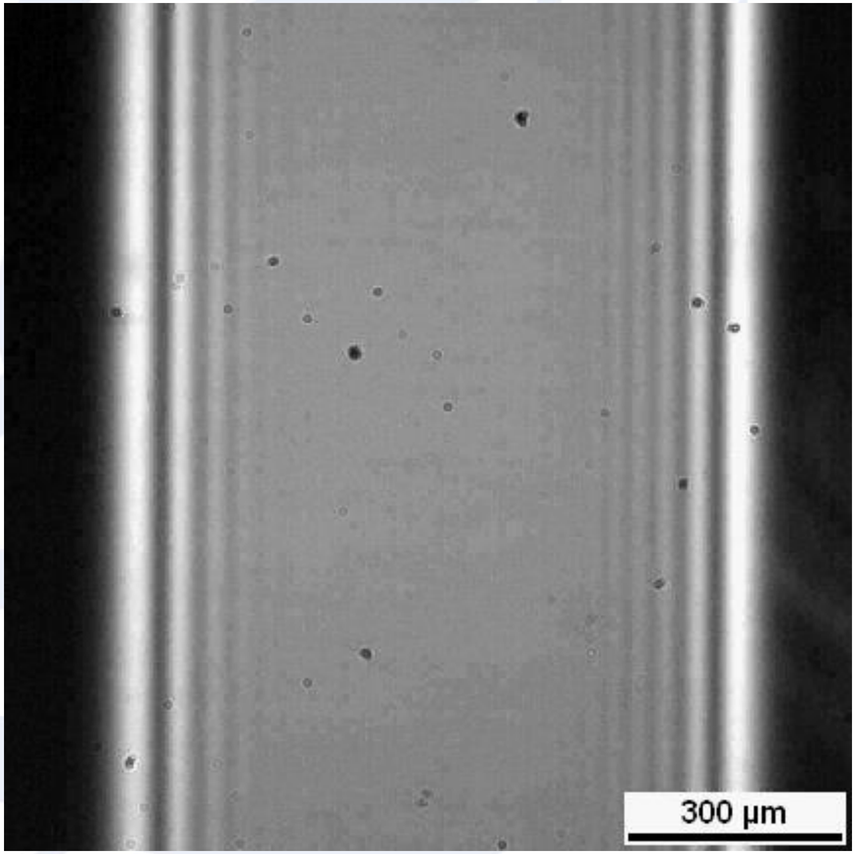


– A type of triazene polymer is used for these experiments:

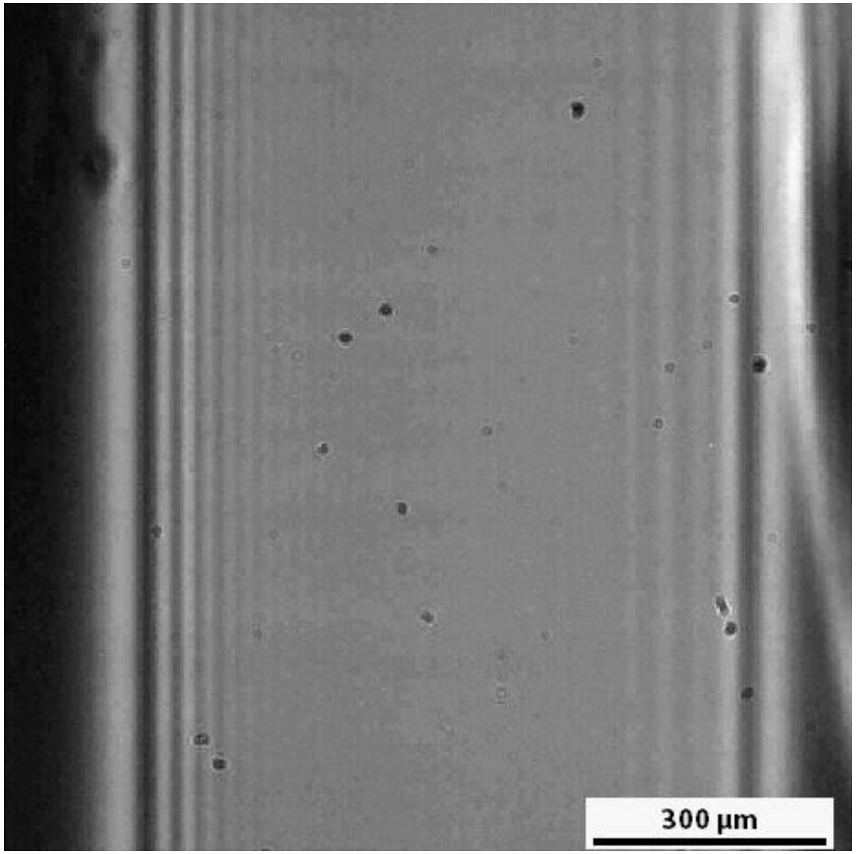


Early shadowgraphy experiments

At atmosphere



At low pressure



Φ = 270 mJ/cm^2

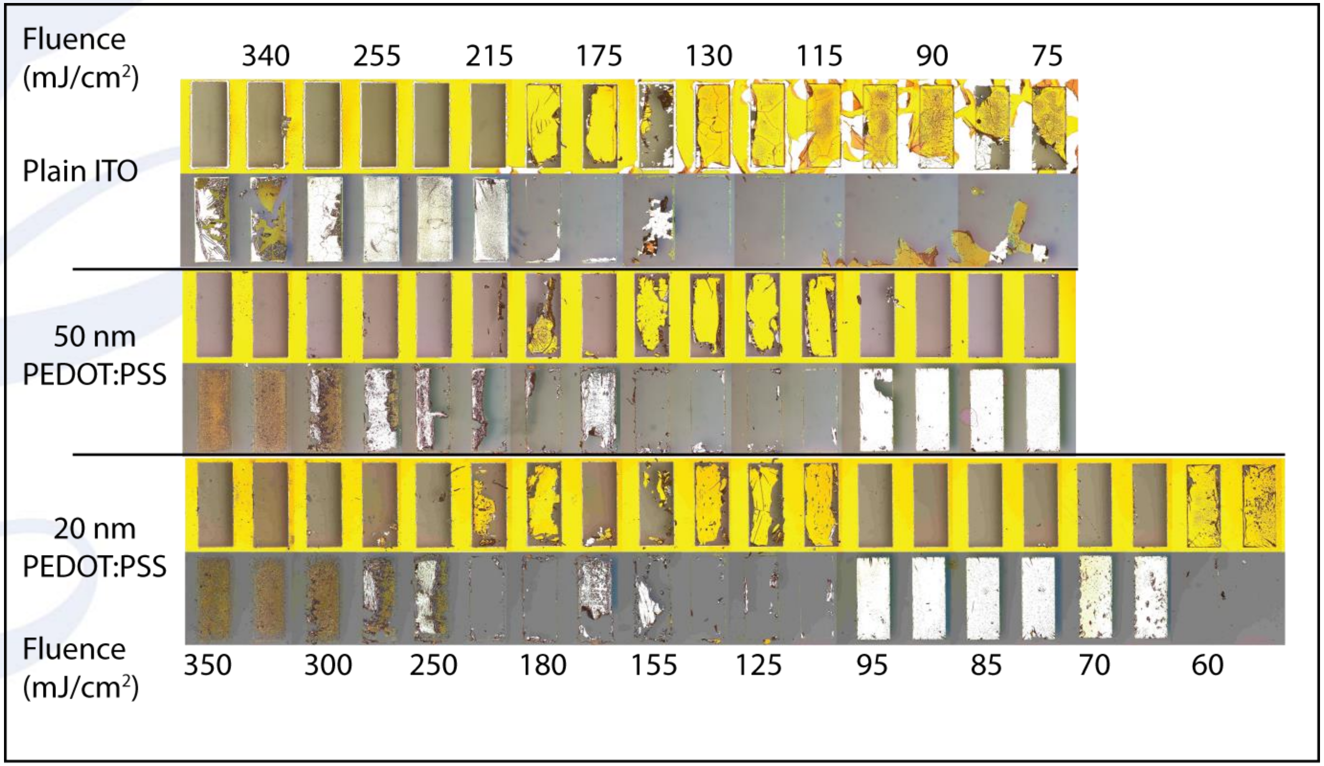
350 nm triazene

80 nm aluminium

Improved LIFT

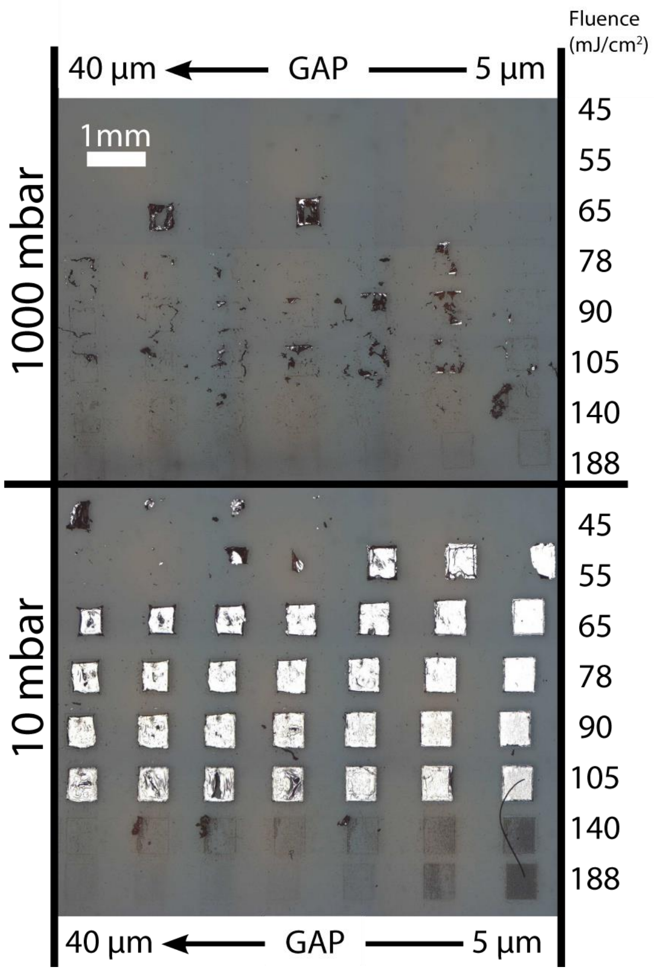
- The receiver substrate plays a significant role in assisting transfer

PEDOT:PSS improved transfer at low fluences



Improved LIFT

- The receiver substrate plays a significant role in assisting transfer.
  - PEDOT:PSS improved transfer at low fluences
- The substrate-substrate gap has been controlled
  - Enabling switching of donor substrate, and greater reproducibility
- Reduced pressure improves transfer success significantly.
  - Removes the reflected acoustic shock wave, and air drag



Receiver substrate

30 nm PEDOT:PSS
Glass substrate

1 mbar

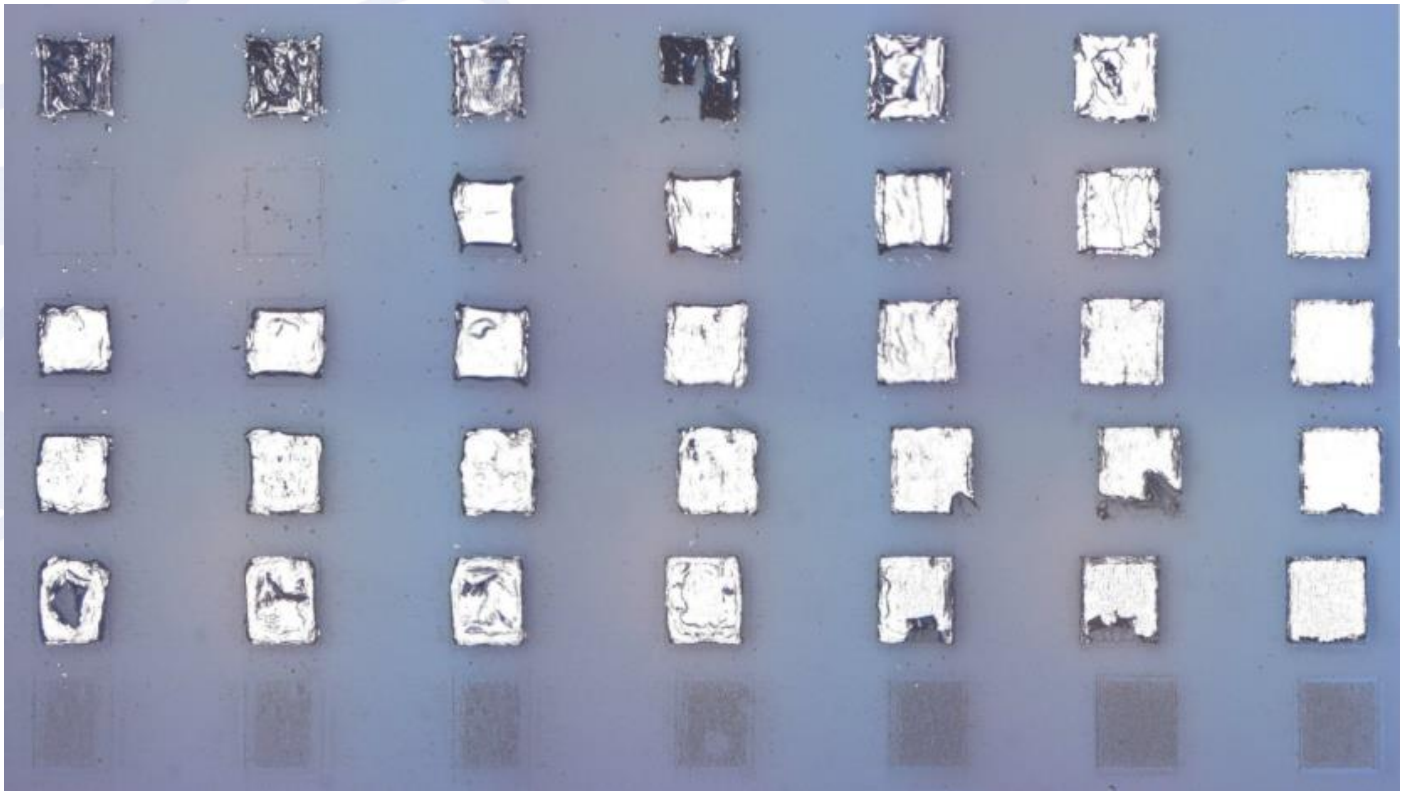
Donor substrate

80 nm PFO
80 nm Ag
190 nm TP
Fused Si substrate

Fluence
(mJ/cm^2)

1 mm

55
65
78
90
105
140

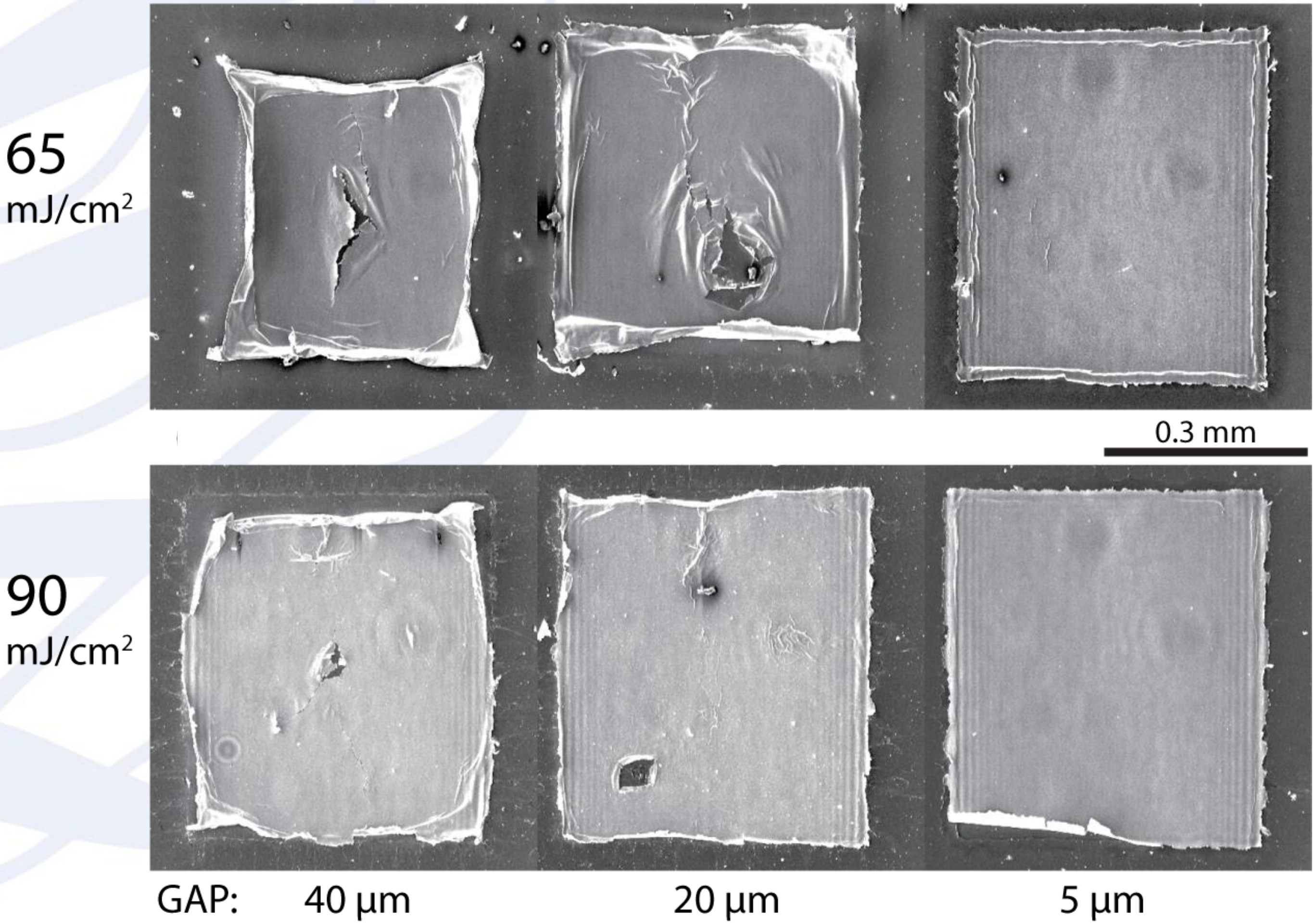


GAP

40 µm ⟷ 5 µm

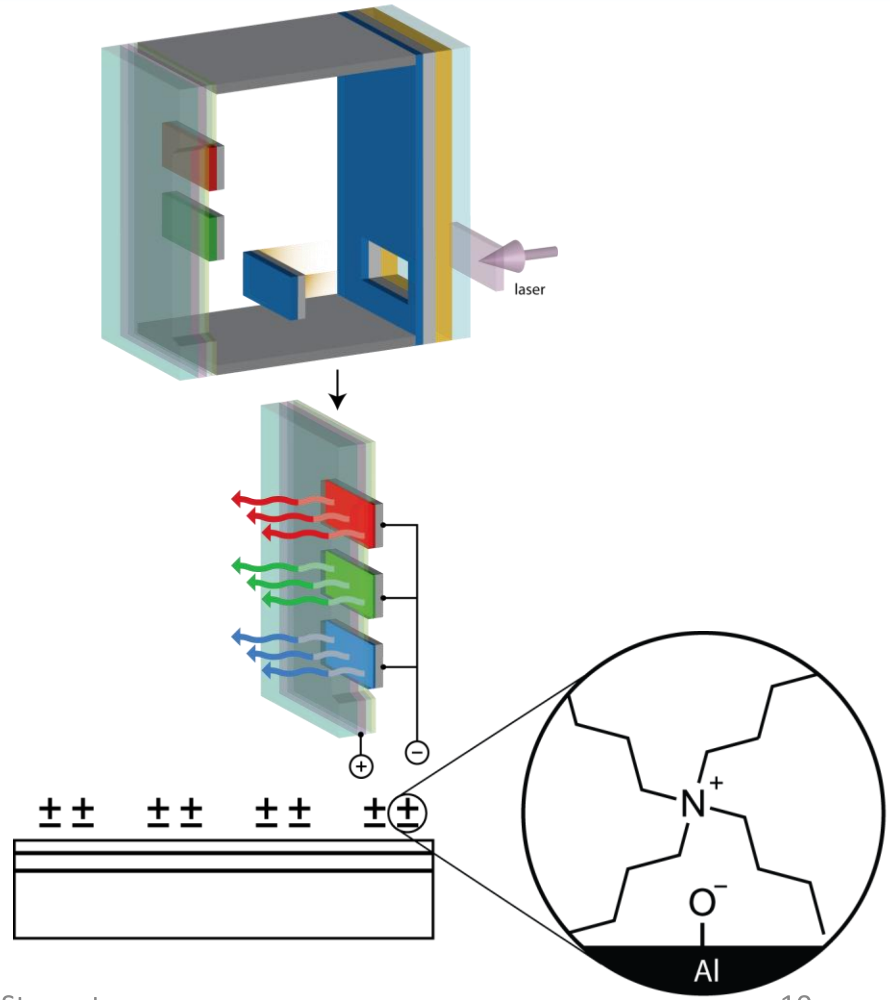
1 mbar transfer morphology

Shaw-Stewart et al. (2011). "Improved laser-induced forward transfer of organic semiconductor thin films by reducing the environmental pressure and controlling the substrate-substrate gap width." Applied Physics A 105(3): 713-722.



OLEDs

- Different types of OLEDs can be fabricated by LIFT:
  - PLEDs
  - PhOLEDs
  - SMOLEDs
- Charge injecting and transporting layers can be added to improve performance.
  - More flexibility is available in terms of surface modification.



OLEDs

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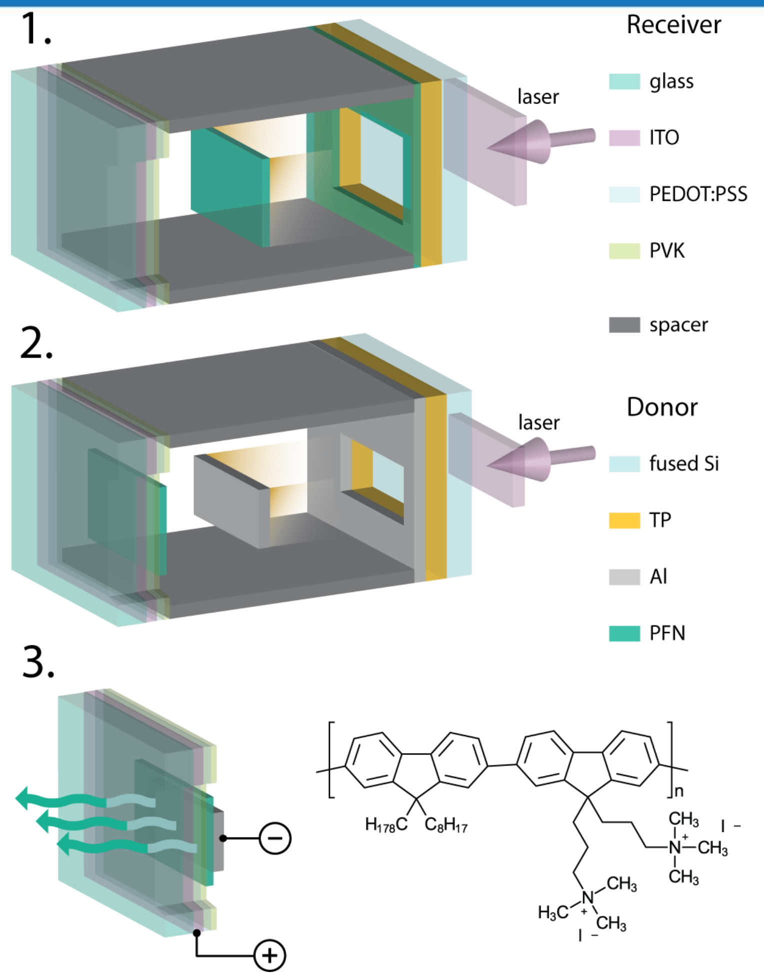
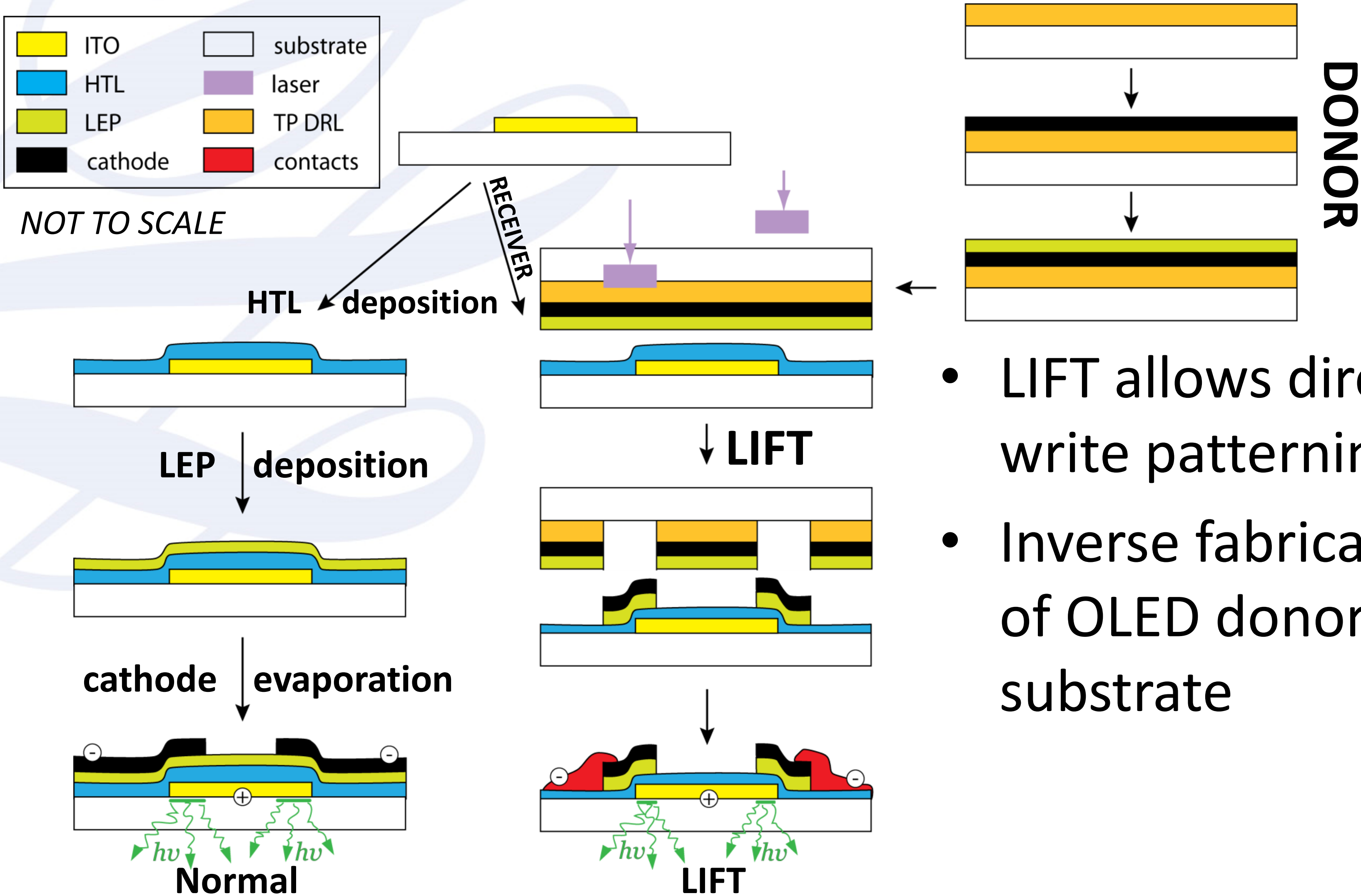
  - PLEDs
  - PhOLEDs
  - SMOLEDs
- Charge injecting and transporting layers can be added to improve performance.
  - More flexibility is available in terms of surface modification.
- Sequential layer-by-layer deposition of a working PLED has been demonstrated.



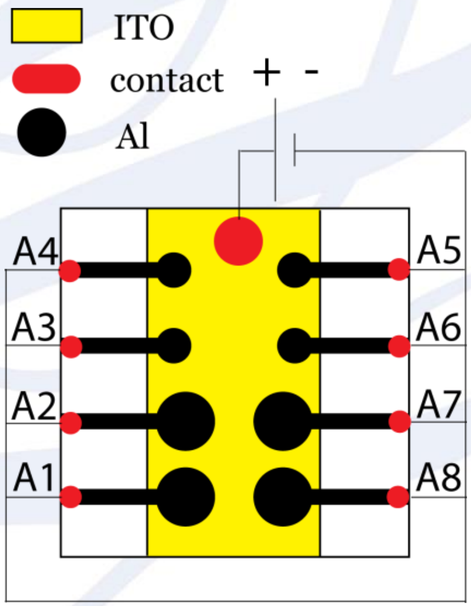
Normal vs LIFTed device architecture



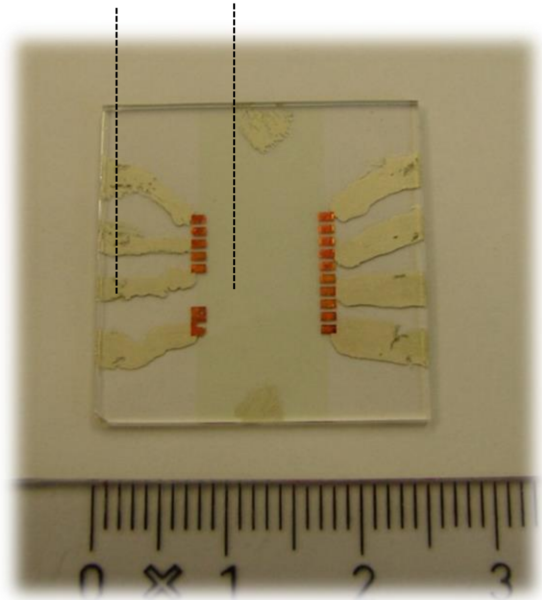
- LIFT allows direct-write patterning
- Inverse fabrication of OLED donor substrate

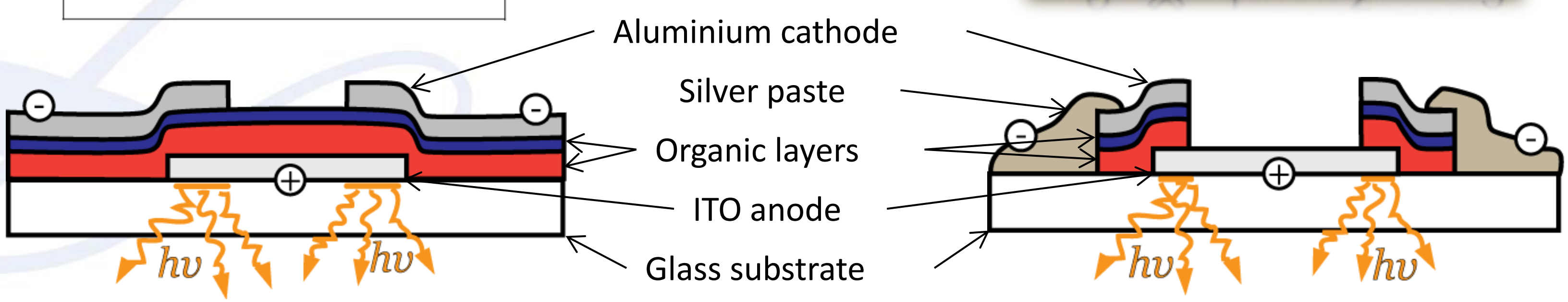
OLED device fabrication

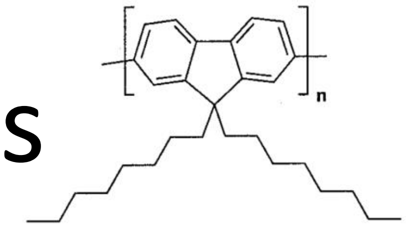
- Standard:



- Laser transferred:

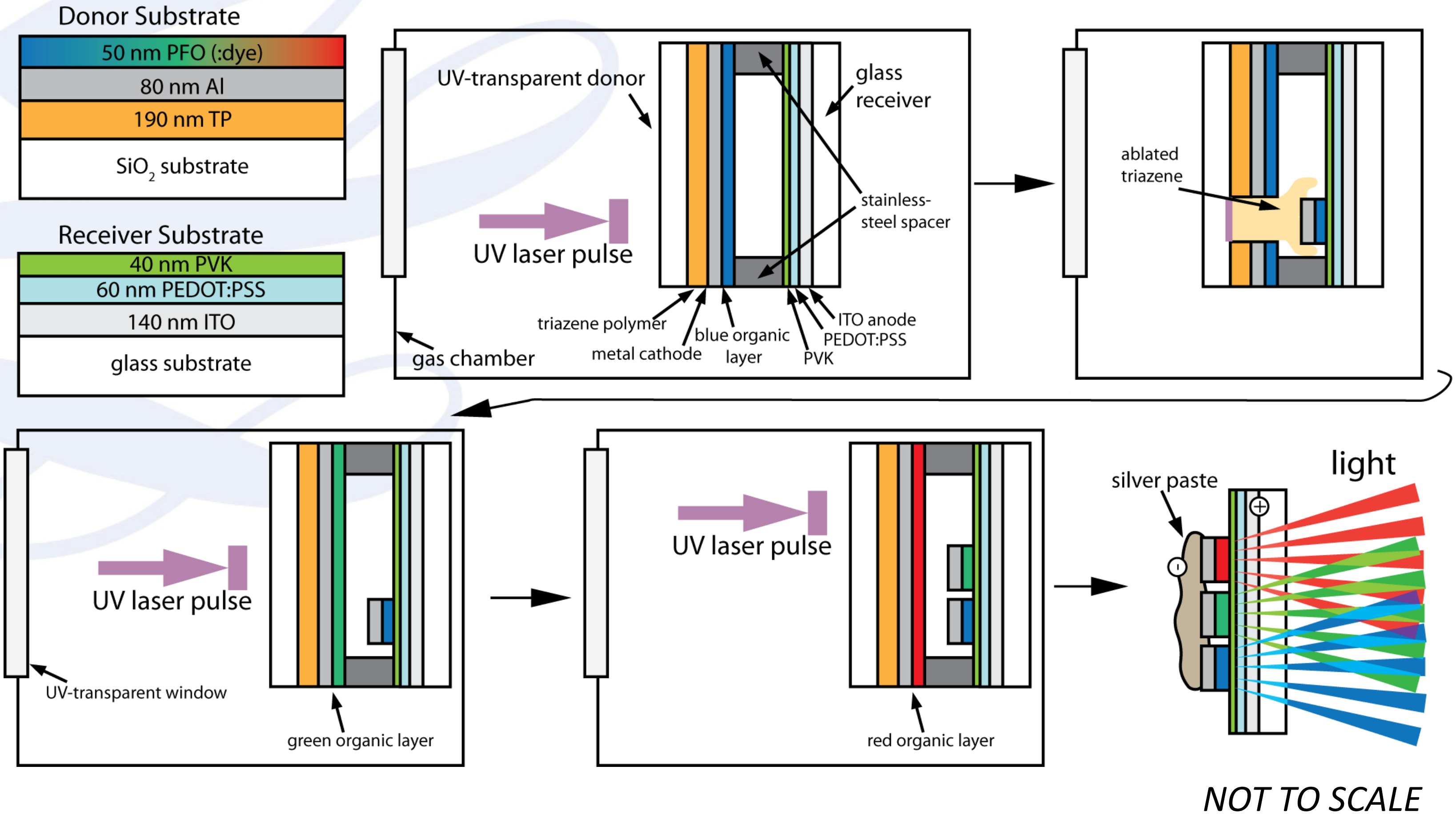






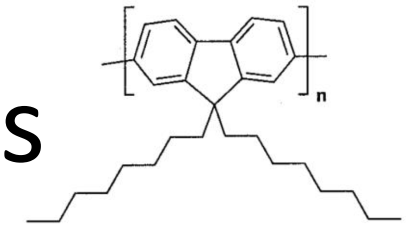
Optimized PFO devices

Shaw-Stewart et al. (2012). "Red-green-blue polymer light-emitting diode pixels printed by optimized laser-induced forward transfer." Applied Physics Letters 100(20): 203303-203304.



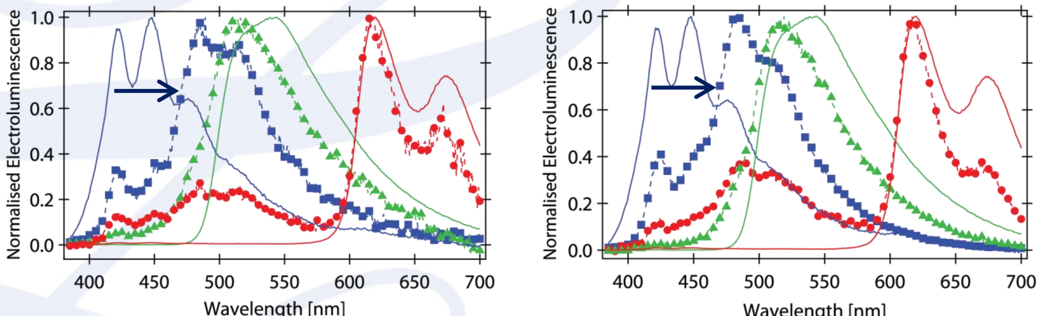
- All at 1 mbar, with 12 µm gap

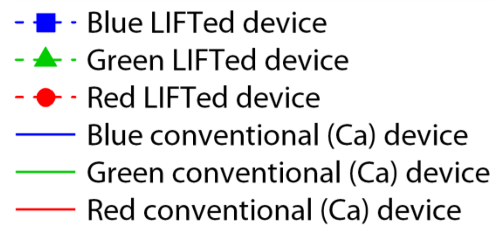
Optimized PFO devices

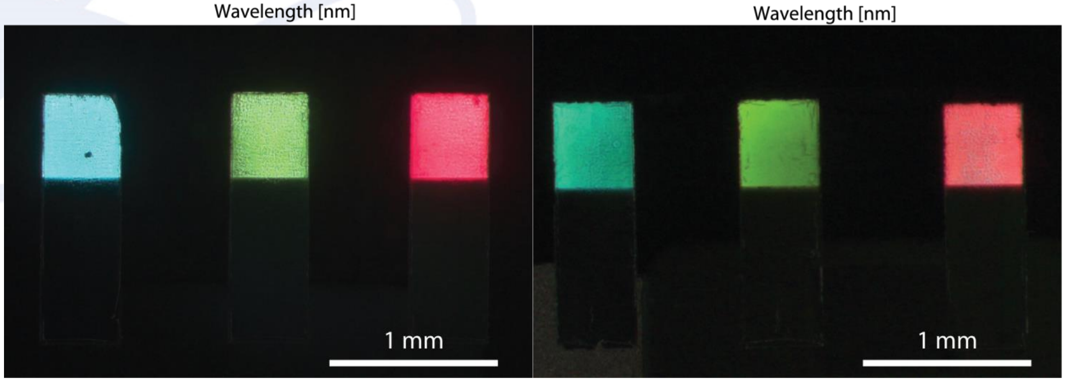


With tba (tetrabutylammonium)

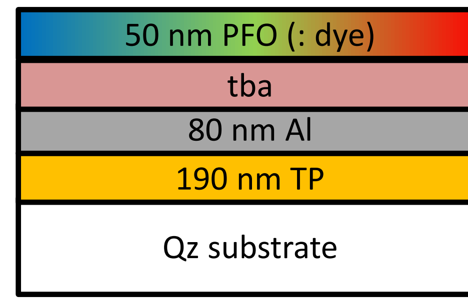
Original



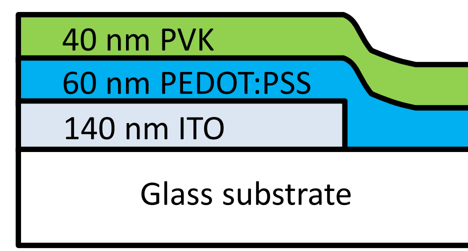




Donor Substrate

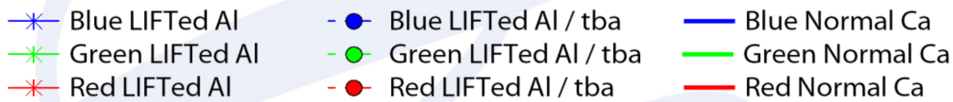


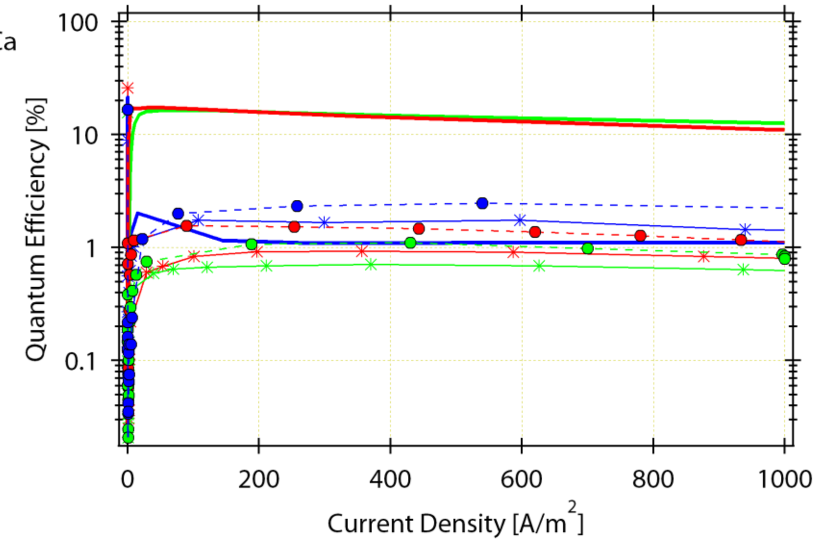
Receiver Substrate



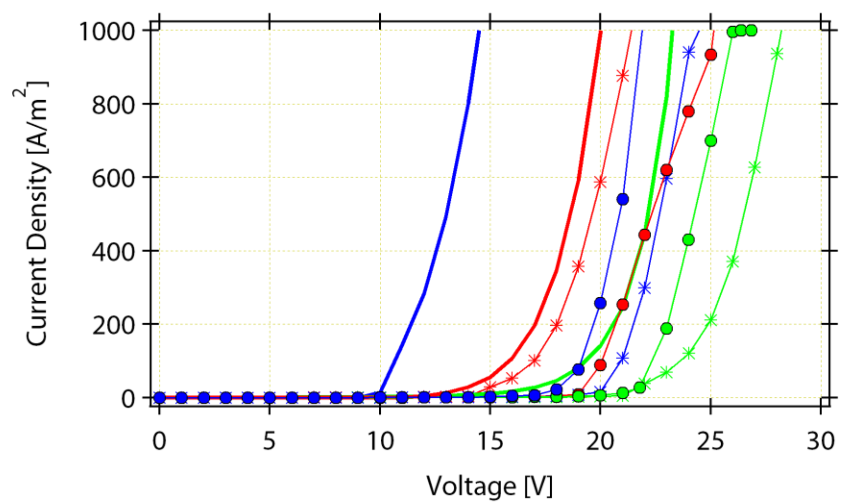
- Good tri-colour LIFTed OLEDs
- Only blue EL spectrum is a bit shifted

PFO functionality



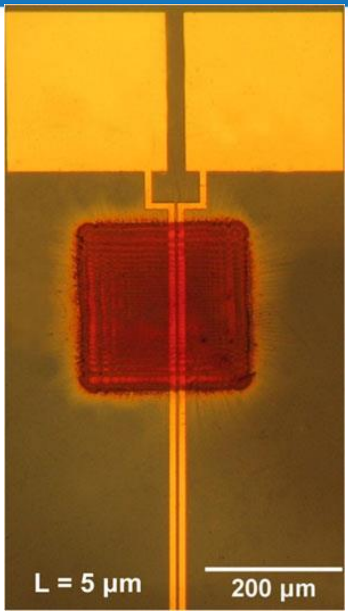


- Normal phosphorescent PLEDs with Ca electrode are most efficient
- LIFTed devices have efficiencies around 1-2 %
- Tetrabutylammonium noticeably improves device efficiencies
- Normal blue device with lowest operating voltage

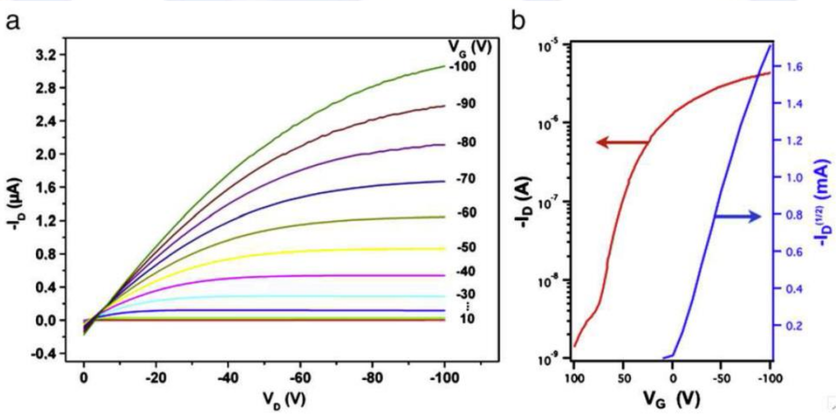


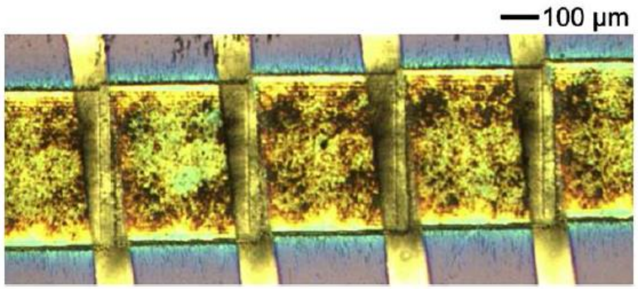
Thin film transistors

- Concurrently, as part of the e-LIFT project, a lot of work has been carried out on the transfer of organic TFT materials

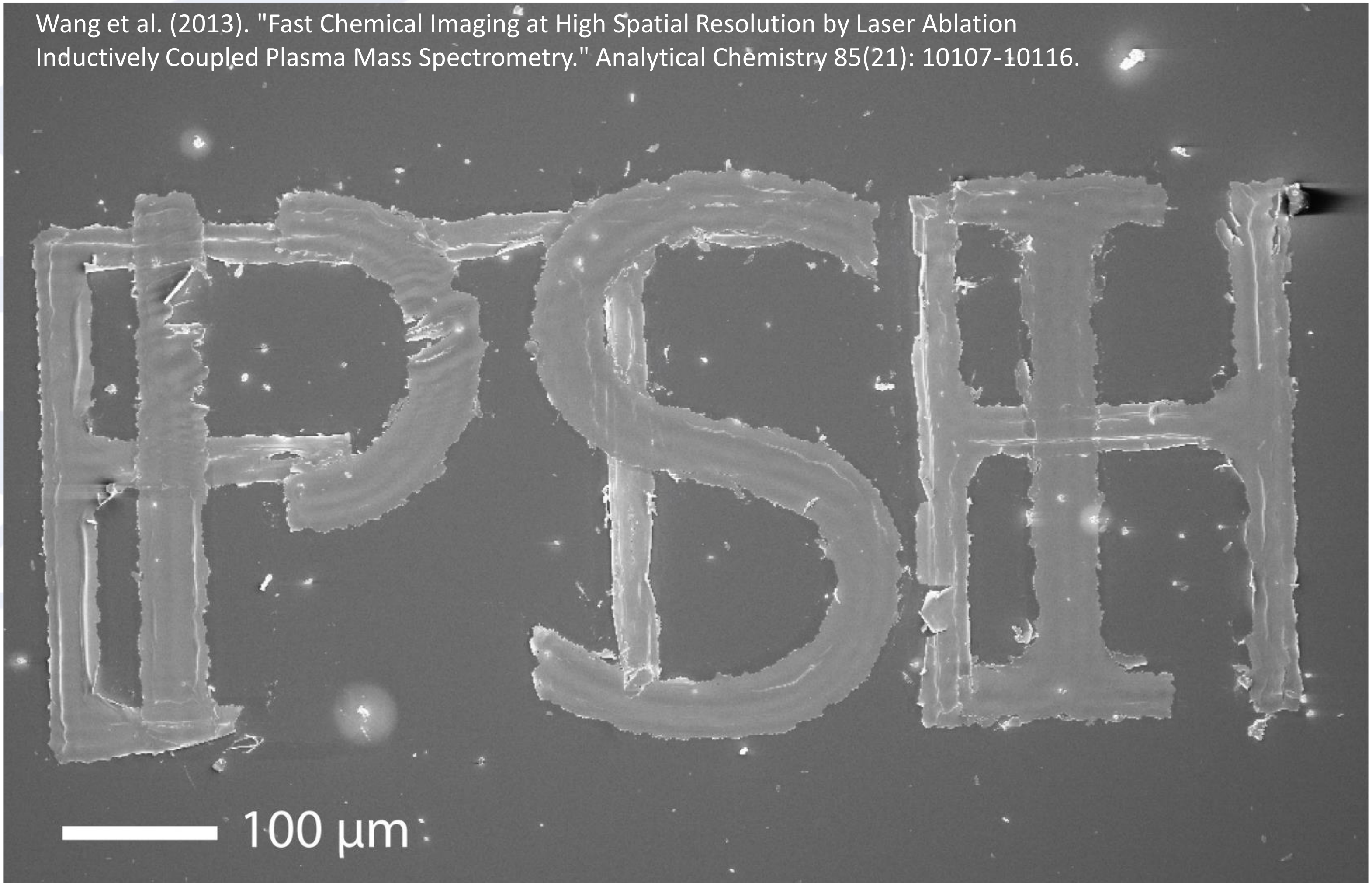


M. Makrygianni et al., Applied Physics A (2013), doi:10.1007/s00339-012-7134-9





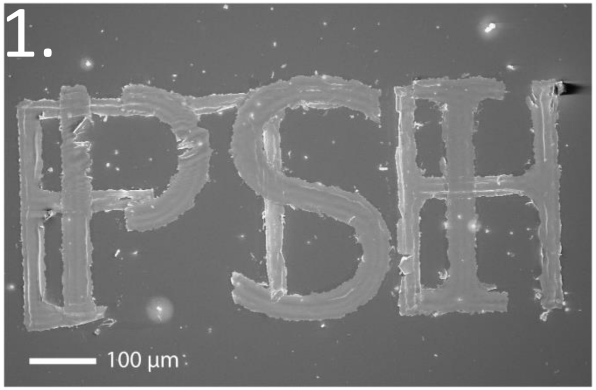
L. Rapp, et al., Thin Solid Films (2011), doi:10.1016/j.tsf.2011.10.159

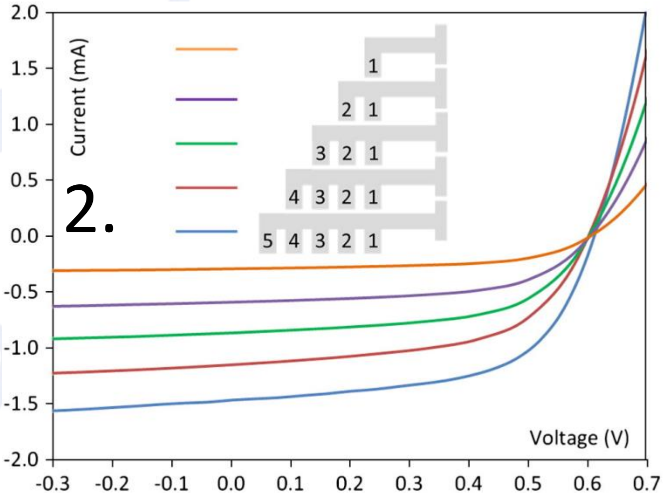


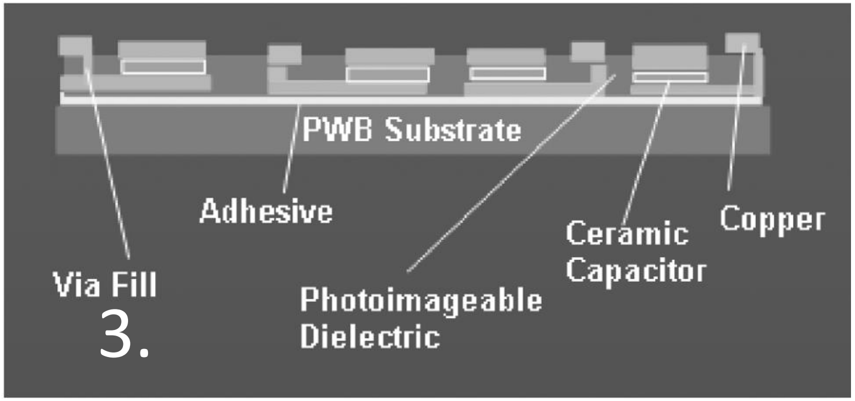
Wang et al. (2013). "Fast Chemical Imaging at High Spatial Resolution by Laser Ablation Inductively Coupled Plasma Mass Spectrometry." Analytical Chemistry 85(21): 10107-10116.

New applications

- Other applications include:
  1. Scientific research
  2. Organic photovoltaic arrays
  3. Printed circuit boards with embedded passive components







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FNSNF

SWISS NATIONAL SCIENCE FOUNDATION

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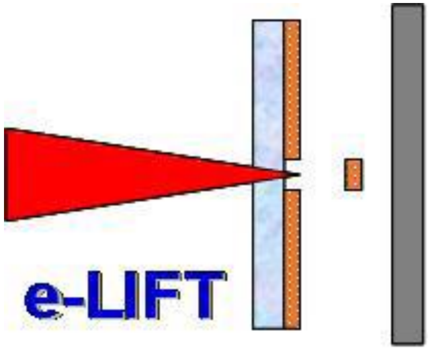
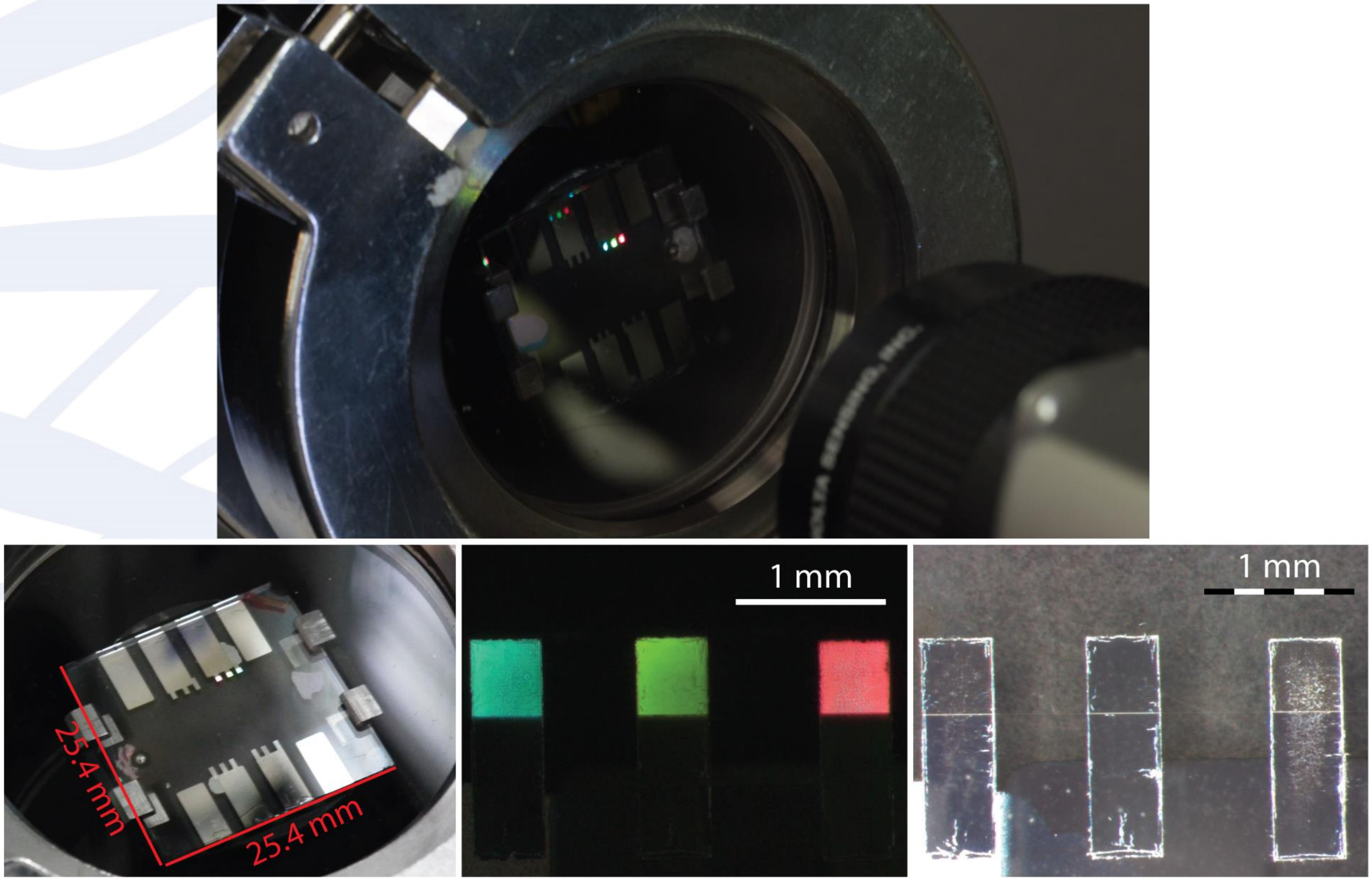


THANK YOU!



First-author publications

- Shaw Stewart, J., R. Fardel, et al. (2010). "The effect of laser pulse length upon laser-induced forward transfer using a triazene polymer as a dynamic release layer." Journal of Optoelectronics and Advanced Materials 12(3): 605-609.
- Shaw Stewart, J., T. Lippert, et al. (2010). "Laser-Induced Forward Transfer Using Triazene Polymer Dynamic Releaser Layer." AIP Conference Proceedings 1278(1): 789-799.
- Shaw-Stewart, J., B. Chu, et al. (2011). "Improved laser-induced forward transfer of organic semiconductor thin films by reducing the environmental pressure and controlling the substrate-substrate gap width." Applied Physics A: Materials Science & Processing 105(3): 713-722.
- Shaw-Stewart, J., T. Lippert, et al. (2011). "Laser-Induced Forward Transfer of Polymer Light-Emitting Diode Pixels with Increased Charge Injection." ACS Applied Materials & Interfaces 3(2): 309-316.
- Shaw-Stewart, J. R. H., T. Lippert, et al. (2012). "A simple model for flyer velocity from laser-induced forward transfer with a dynamic release layer." Applied Surface Science 258(23): 9309-9313.
- Shaw-Stewart, J., T. Lippert, et al. (2012). "Sequential Printing by Laser-Induced Forward Transfer to Fabricate a Polymer Light-Emitting Diode Pixel." ACS Applied Materials & Interfaces 4(7): 3535-3541.
- Shaw Stewart, J., T. Lippert, et al. (2012). "Red-green-blue polymer light-emitting diode pixels printed by optimized laser-induced forward transfer." Applied Physics Letters 100(20): 203303-203304.
- Shaw Stewart, J. R. H. S. (2012). Optimising the fabrication of organic light-emitting diodes by laser-induced forward transfer, ETH Zürich.
- Shaw-Stewart, J., T. Mattle, et al. (2013). "The optimisation of the laser-induced forward transfer process for fabrication of polyfluorene-based organic light-emitting diode pixels." Applied Surface Science(in press).
- Shaw-Stewart, J. R. H., T. Mattle, et al. (2013). "The fabrication of small molecule organic light-emitting diode pixels by laser-induced forward transfer." Journal of Applied Physics 113(4): 043104-043107.

Co-author publications

- Dinca, V., R. Fardel, et al. (2010). "Laser-Induced Forward Transfer: An Approach to Single-Step Polymer Microsensor Fabrication." Sensor Letters 8: 436-440.
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- Palla-Papavlu, A., V. Dinca, et al. (2010). "Laser induced forward transfer of soft materials." Journal of Optics 12(12): 124014.
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- Frank, P., J. Shaw-Stewart, et al. (2011). "Laser-induced ablation dynamics and flight of thin polymer films." Applied Physics A: Materials Science & Processing 104(2): 579-582.
- Palla-Papavlu, A., I. Paraico, et al. (2011). "Liposome micropatterning based on laser-induced forward transfer." Applied Physics A: Materials Science & Processing 102(3): 651-659.
- Mattle, T., J. Shaw-Stewart, et al. (2012). "Laser induced forward transfer aluminum layers: Process investigation by time resolved imaging." Applied Surface Science 258(23): 9352-9354.
- Mattle, T., J. Shaw-Stewart, et al. (2013). "Shadowgraphic investigations into the laser-induced forward transfer of different SnO2 precursor films." Applied Surface Science 278: 77-81.
- Wang, H. A. O., D. Grolimund, et al. (2013). "Fast Chemical Imaging at High Spatial Resolution by Laser Ablation Inductively Coupled Plasma Mass Spectrometry." Analytical Chemistry 85(21): 10107-10116.

e-LIFT http://www.e-lift-project.eu/

Coventry University

E-LIFT

- Laser printing of organic/inorganic material for the fabrication of electronic devices
- 3 year project from 2010-2012
- €4.2M budget project

PARTNERS

- CNRS - LP3 (FR)
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SEVENTH FRAMEWORK PROGRAMME