OLEDs: the future of ambient lighting; from glass towards flexible substrates

University of Hasselt – Institute of Material Research

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Masterclass, 23/06/15

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Institute for Materials Research (IMO)

Engineering Materials & APplications (EMAP)

- Functional Materials Engineering (FME)
- Biomedical device engineering
- Energy systems engineering

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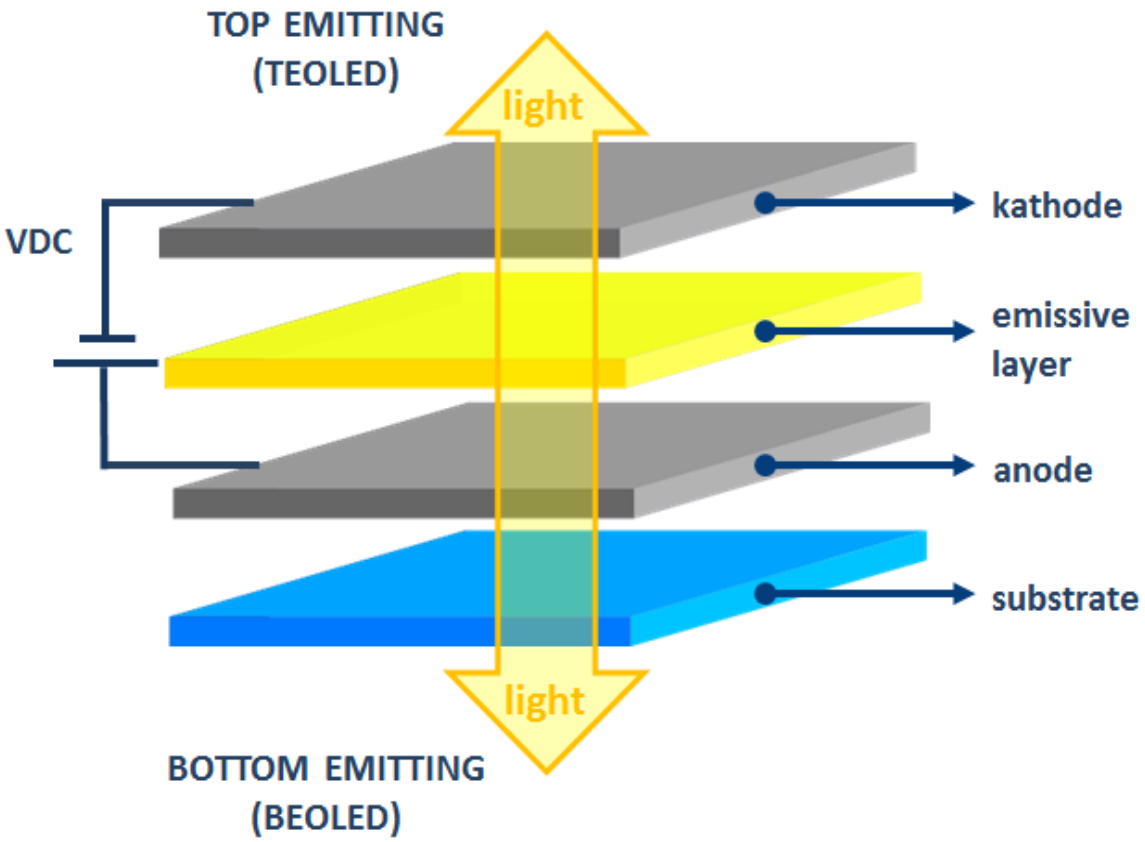
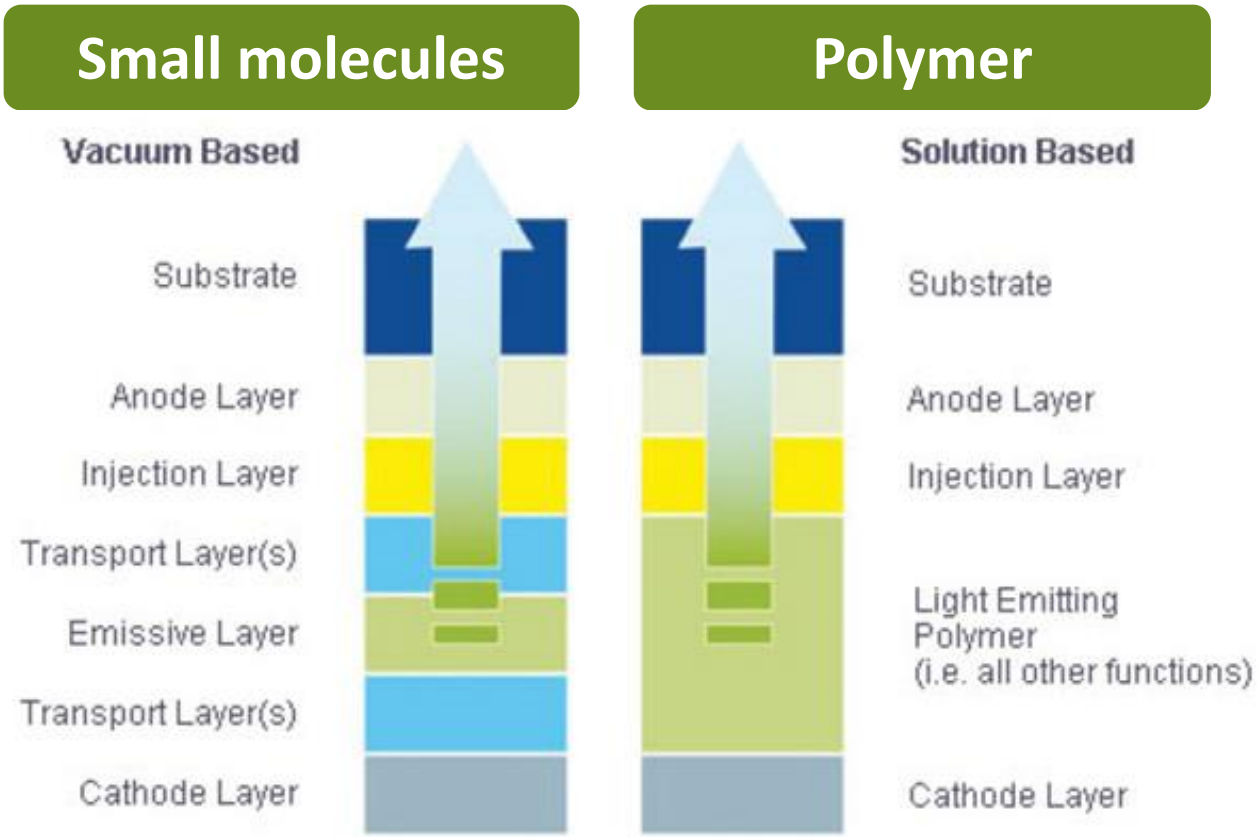
OLED

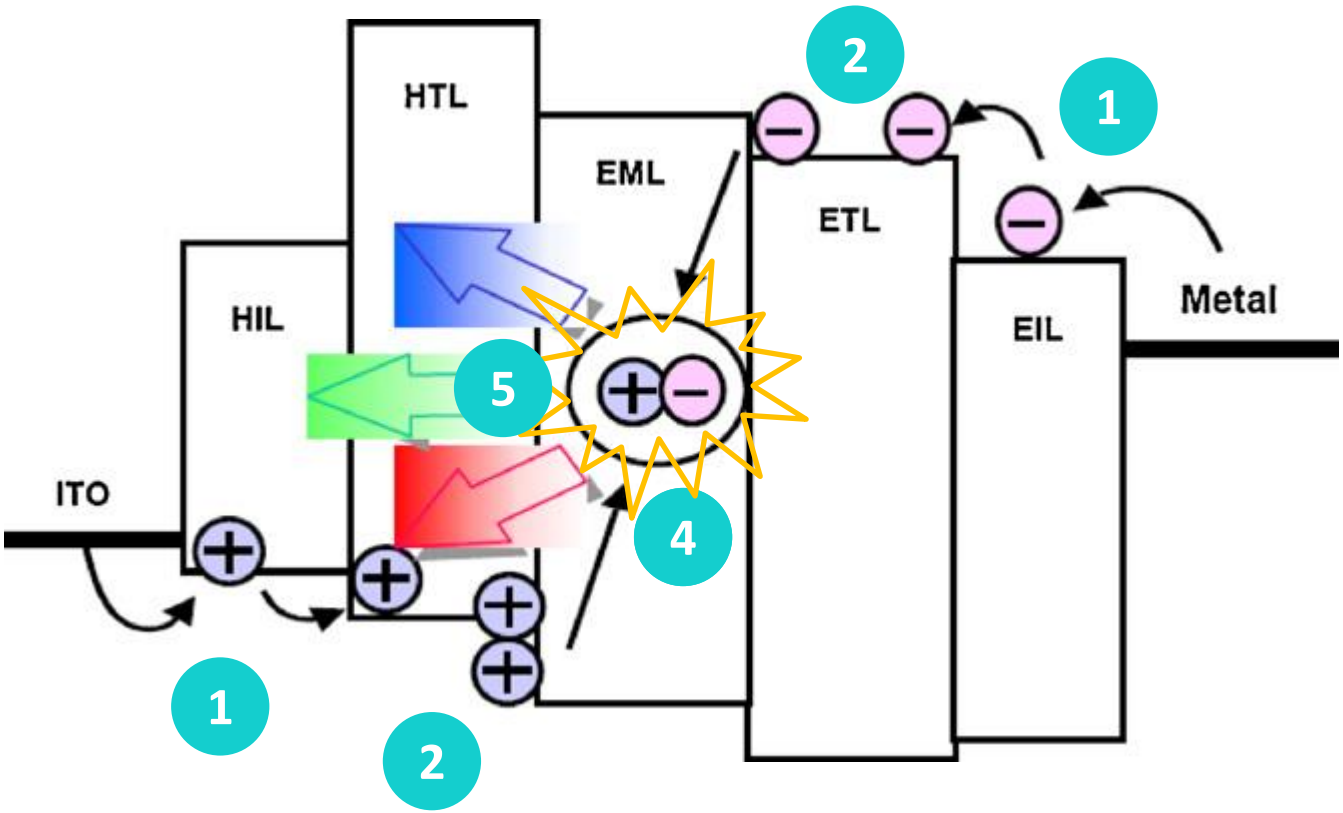

TOP EMITTING
(TEOLED)
light
VDC
kathode
emissive
layer
anode
substrate
light
BOTTOM EMITTING
(BEOLED)

OLED device architecture



http://www.digikey.com/en-US/articles/techzone/2011/oct/oled-displays-offer-brighter-images-save-power

OLED light emitting mechanism



1) Charge injection
2) Charge migration
3) Recombination
4) Exciton formation
5) Relaxation / light emission

Thejo Kalyani, N., & Dhoble, S. J. (2012). Organic light emitting diodes: Energy saving lighting technology—A review. *Renewable and Sustainable Energy Reviews*, *16*(5), 2696–2723. doi:10.1016/j.rser.2012.02.021

OLED materials

Layer of OLEDs	Materials generally used
Anode	**High work function**; ITO, IZO, ZNO; TCP (PANI, PEDOT); Au, Pt, Ni, p-Si; ITO; Surface treatment; Plasma (O2, NH3); Solution (Aquaregia); Thin insulator AlOx, SiOx; RuOx (4.9 eV); MoOx (5.4 eV)
Cathode	**Low work function**; Mg:Ag; Li:Al; Ca. . .; thin insulator; LiF; MgOx.
HIL	**HOMO level**; Spiro-TAD; CuPc; m-MTDATA; PTCDA; 2TNATA; TPD; NPD; DPVBi, . . .; PPV; PVK; Dendrimer
ETL	**LUMO level**; Alq3; Bebq2; PBD; OXD; TAZ; BCP
EML : Dopant	Alq3; CPB; Balq; DPVBi; Rubrene; Spiro DPVBi; Quinacridone; Coumarin; DSA; Ir(ppy)3; t(OEP); emitting assistant; rare earth complexes

Thejo Kalyani, N., & Dhoble, S. J. (2012). Organic light emitting diodes: Energy saving lighting technology—A review. *Renewable and Sustainable Energy Reviews*, *16*(5), 2696–2723. doi:10.1016/j.rser.2012.02.021

OLED advantages and disadvantages

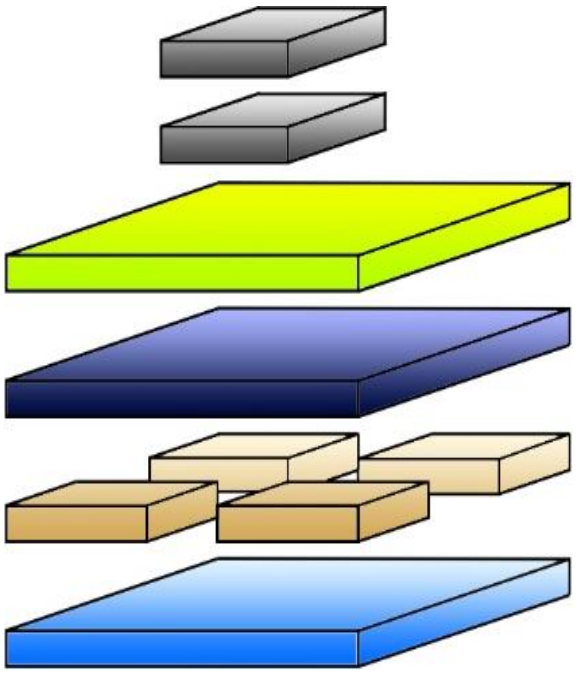
Thin layers	Encapsulation necessary (to avoid exposure to water vapor and oxygen)
Flexible substrates	Low lifetime
High brightness	Harmful solvents (toluene, chlorobenzene, …)
Low power supply (3-5 V)	Expensive production techniques (vacuum deposition, ..)
Low energy consumption	
Good efficacy	
Large fields of view	

OLED applications






Standard OLED structure at IMO



100 nm Al Evaporated

30 nm Ca Evaporated

80 nm Super Yellow
Spin coated

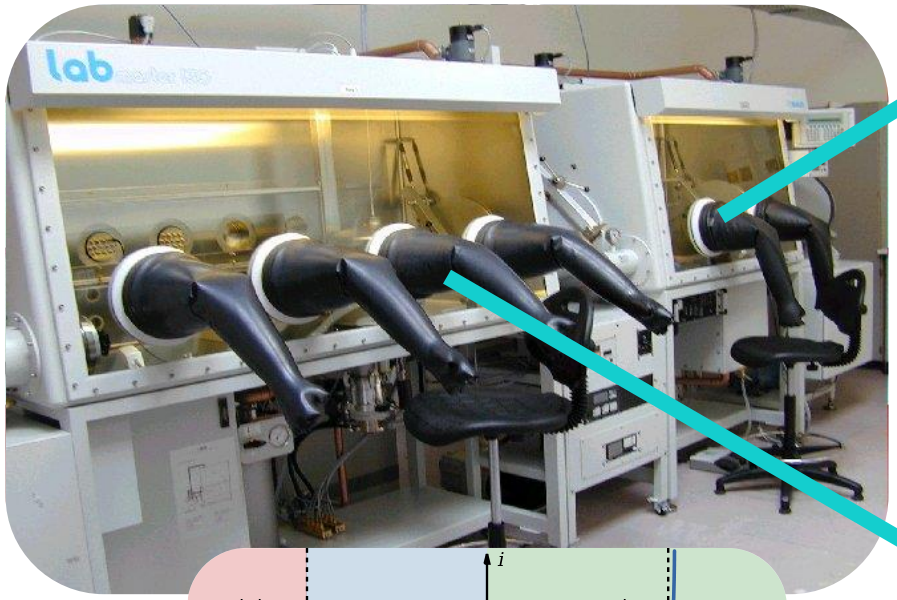
40 nm PEDOT:PSS
Spin coated

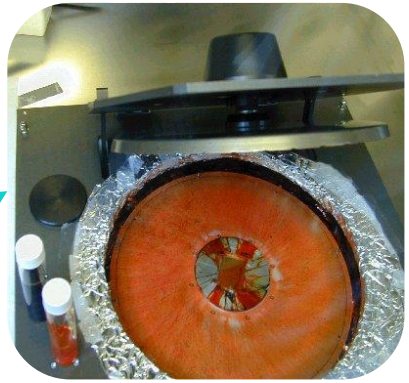
ITO

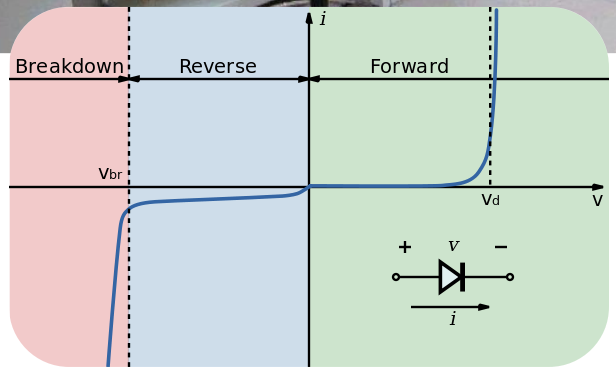
Glass substrate

Standard OLED structure at IMO

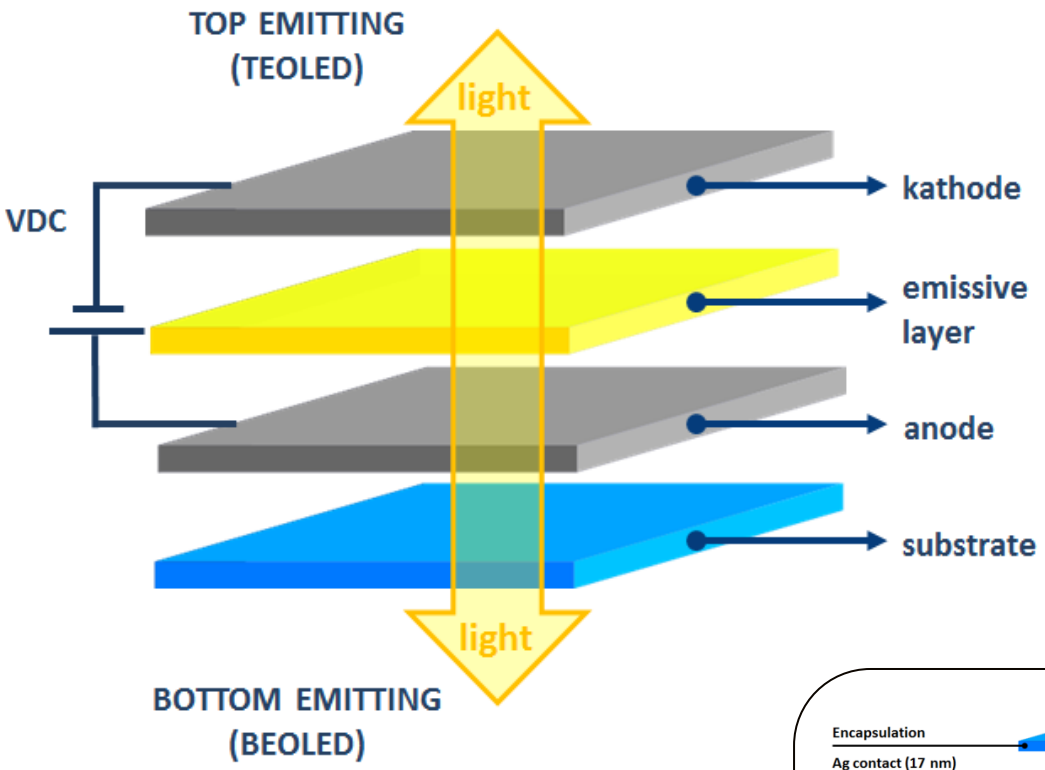
Integrated production and characterization in glovebox







TEOLED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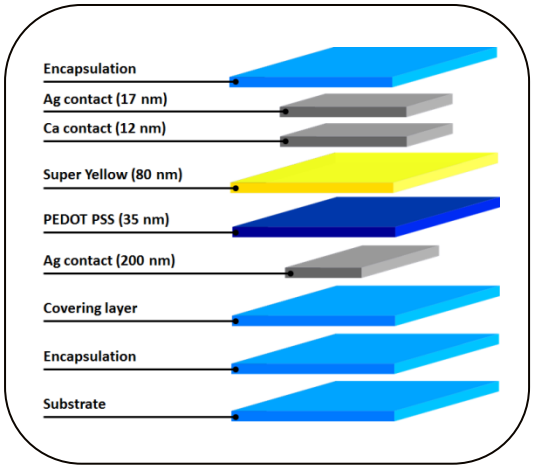
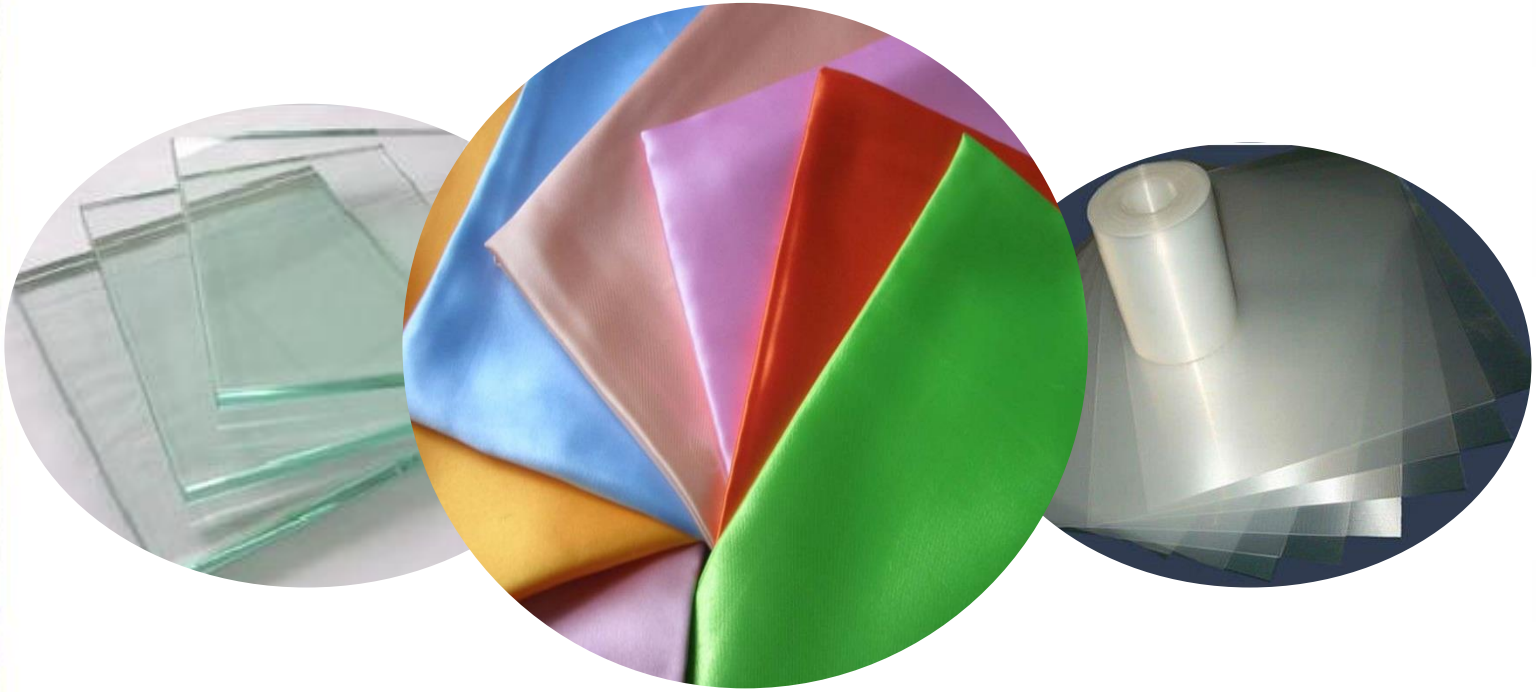
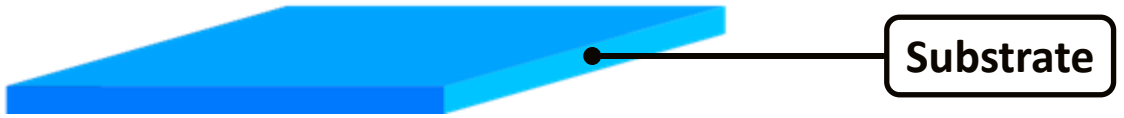
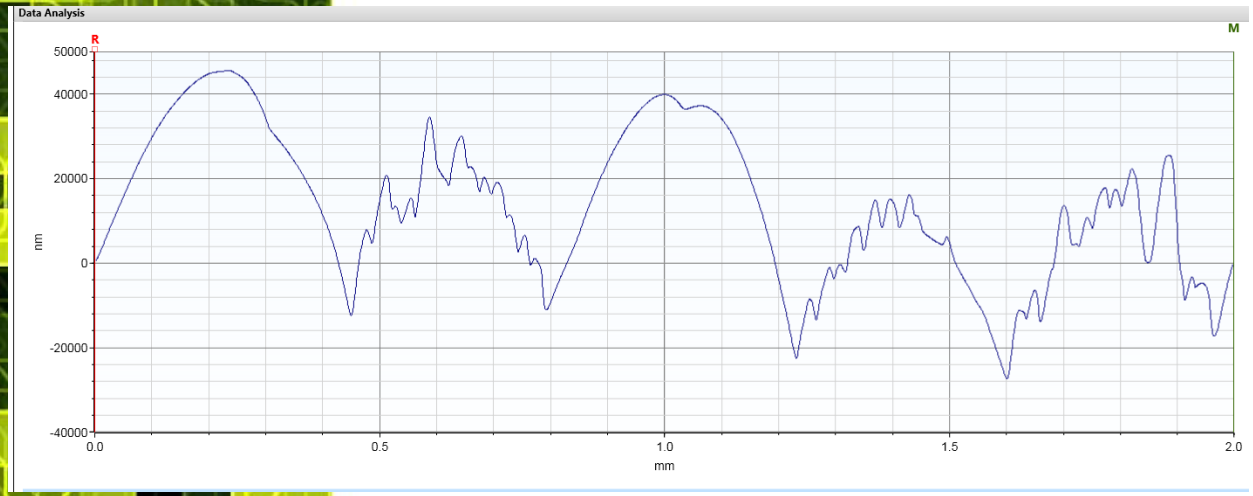

Encapsulation
Ag contact (17 nm)
Ca contact (12 nm)
Super Yellow (80 nm)
PEDOT PSS (35 nm)
Ag contact (200 nm)
Covering layer
Encapsulation
Substrate

Making a TEOLED

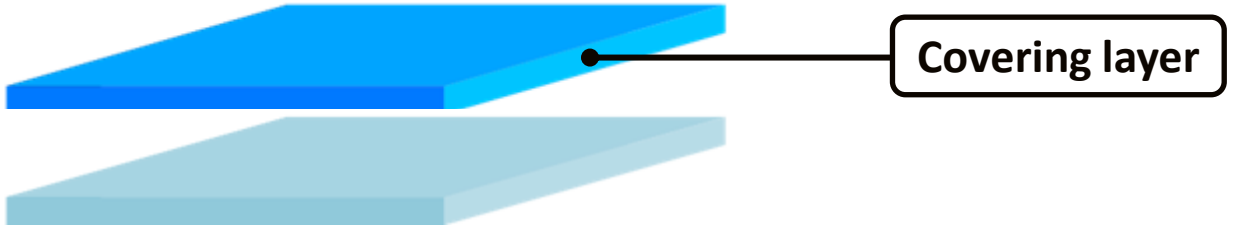




Making a TEOLED



Dektak surface profile measurement on polyester



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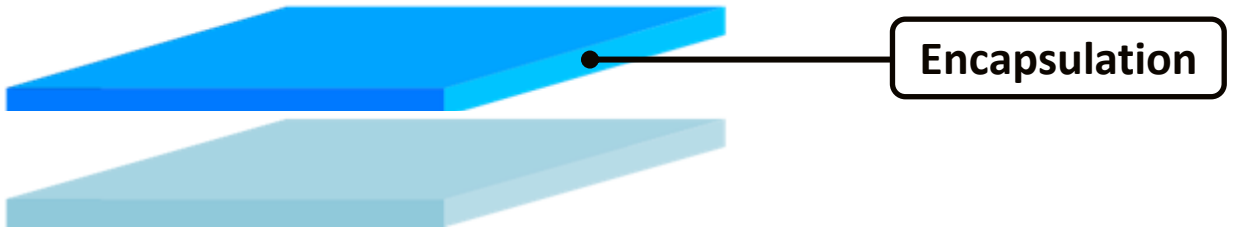
Plasma techniques



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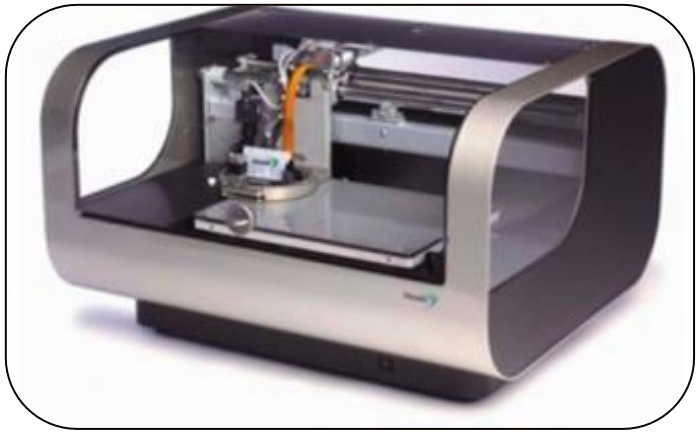
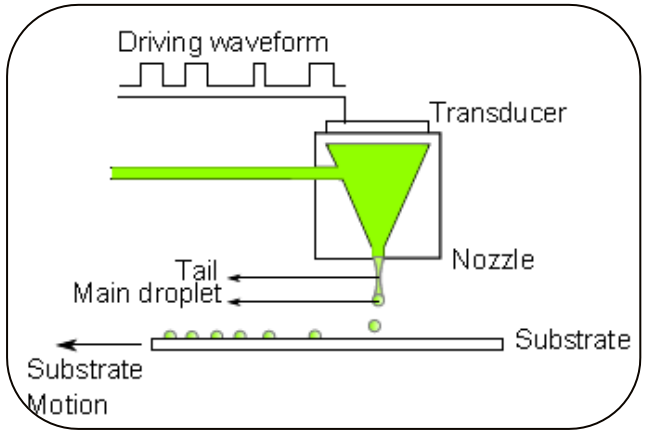
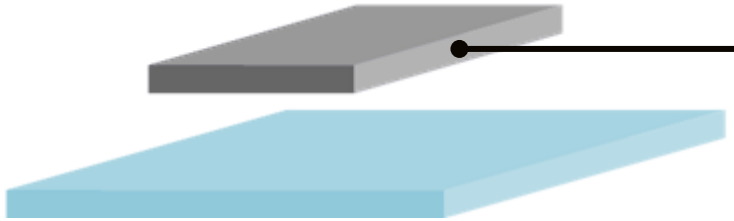
Inkjet printing



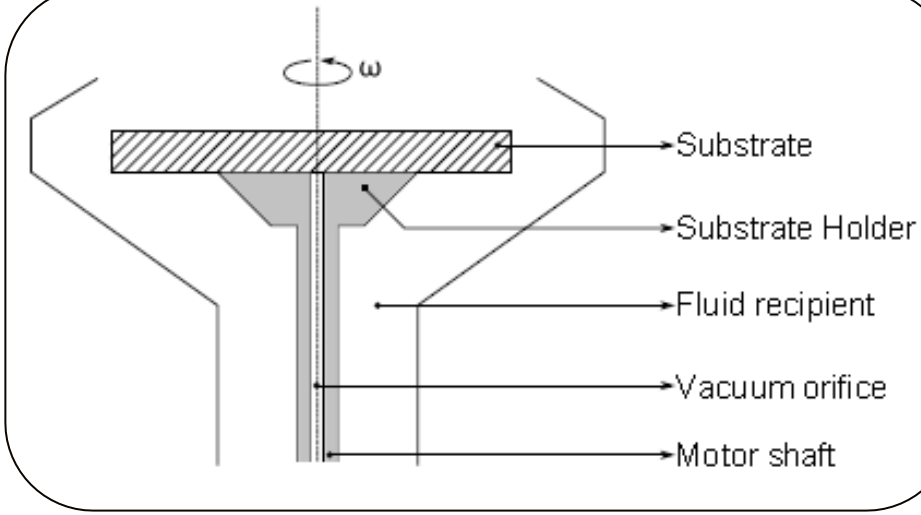


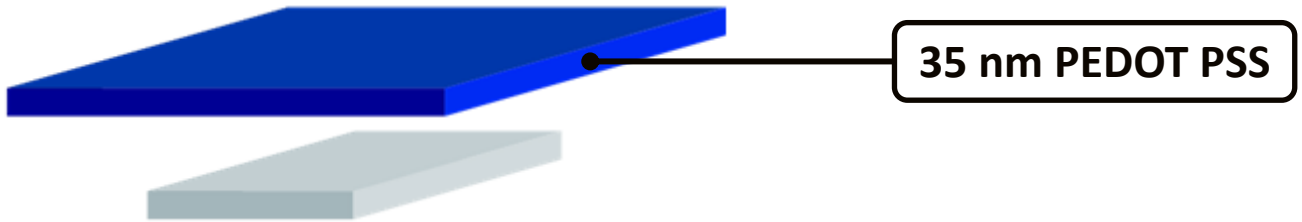


200 nm Ag contact

Making a TEOLED

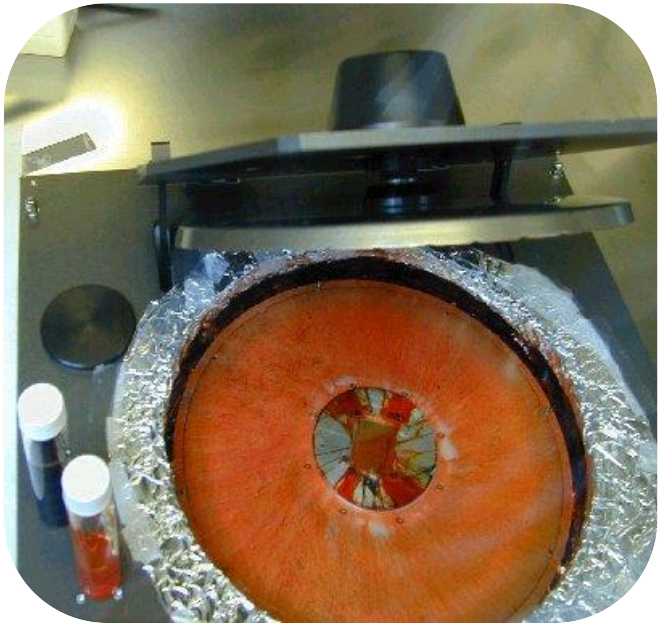
Spin coating





Making a TEOLED

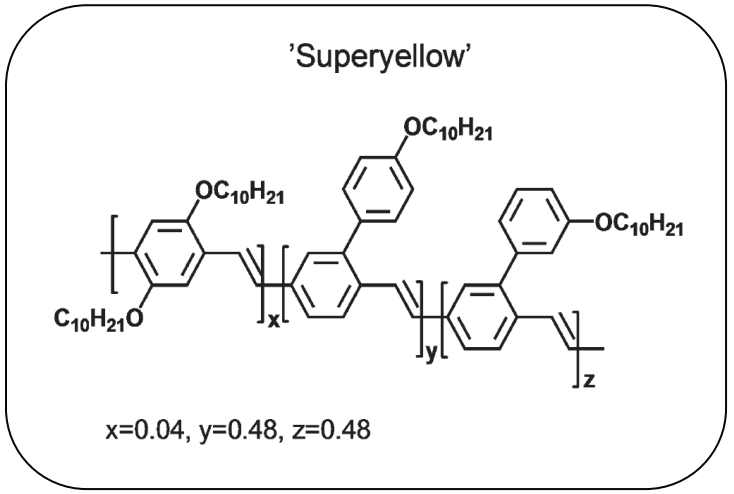
Spin coating and ultrasonic spray coating



80 nm Super Yellow

Making a TEOLED

Super Yellow PDY-12

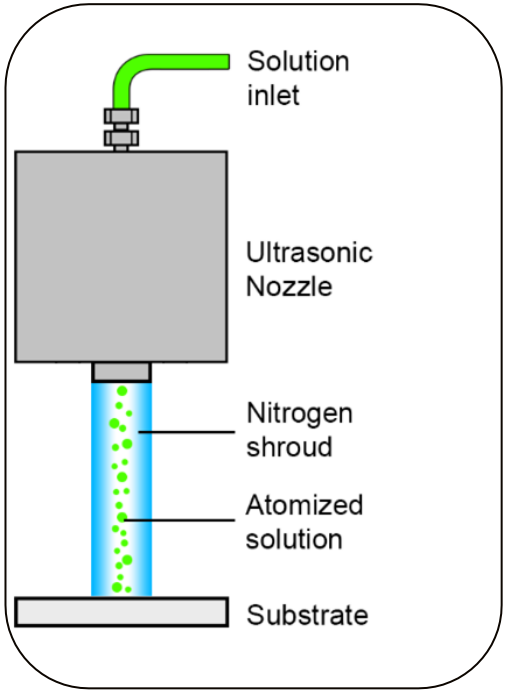


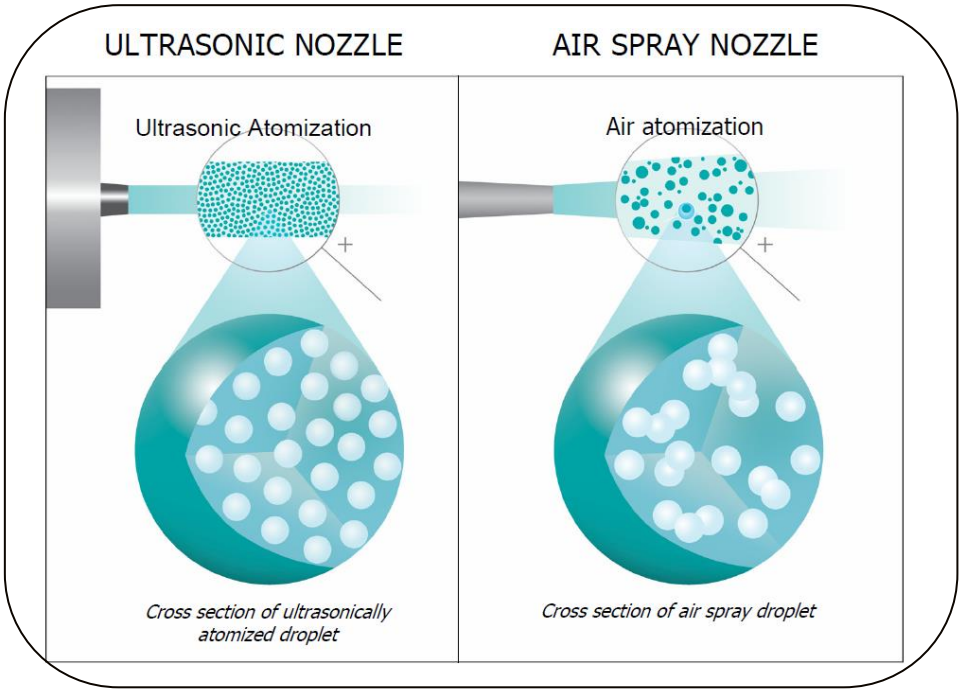
Parameter	Technique	Value	Unit	Ref.
Maj. Carrier Mobility	Time Of Flight (TOF)	$10^{-7} – 10^{-6}$	cm^2/Vs	[2]
External Quantum Efficiency (EQE)	n/a	5.3	%	[2]
Dielectric Constant ε_r	Impedance Spectroscopy	3.1	unit less	[3]
HOMO	n/a	4.8/5.2/5.4	eV	[4]/[5]/[6]
LUMO	n/a	2.4/2.7/3.0	eV	[4]/[5]/[6]

[1] M. Al-Sa'di, et. al., "Electrical and optical simulations of a polymer-based phosphorescent organic light-emitting diode with high efficiency," *J. Polym. Sci. Part B Polym. Phys.*, vol. 50, no. 22, pp. 1567–1576, Nov. **2012**.
[2] S. Gambino, et. al., "Comparison of hole mobility in thick and thin films of a conjugated polymer," *Org. Electron.*, vol. 11, no. 3, pp. 467–471, Mar. **2010**.
[3] A. Munar, et. al., "Shedding Light on the Operation of Polymer Light-Emitting Electrochemical Cells Using Impedance Spectroscopy," *Adv. Funct. Mater.*, vol. 22, no. 7, pp. 1511–1517, Apr. **2012**.
[4] E. B. Namdas, et. al., "Organic light emitting complementary inverters," *Appl. Phys. Lett.*, vol. 96, no. 4, p. 043304, **2010**.
[5] H. J. Bolink, et. al., "Efficient Polymer Light-Emitting Diode Using Air-Stable Metal Oxides as Electrodes," *Adv. Mater.*, vol. 21, no. 1, pp. 79–82, Jan. **2009**.
[6] W. Syu, et. al., "Efficient multilayer red fluorescent polymer light-emitting diodes by host and guest blend system," *Synth. Met.*, vol. 160, no. 9–10, pp. 871–875, **2010**.

Techniques

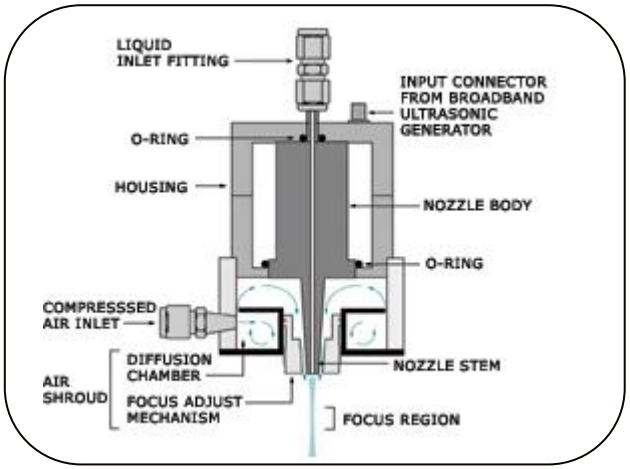
Ultrasonic spray coating

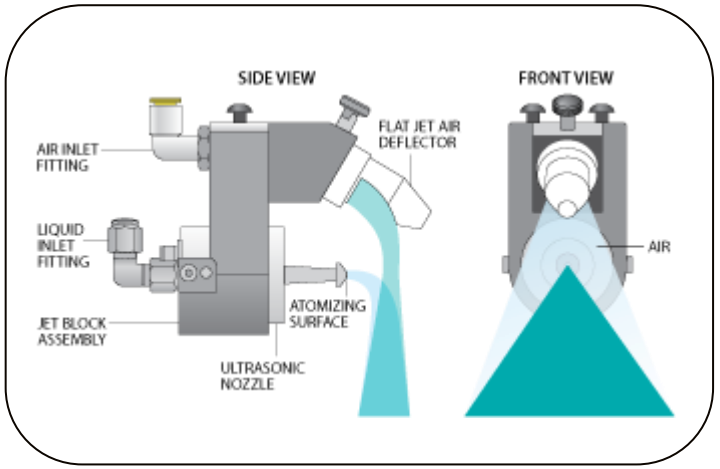


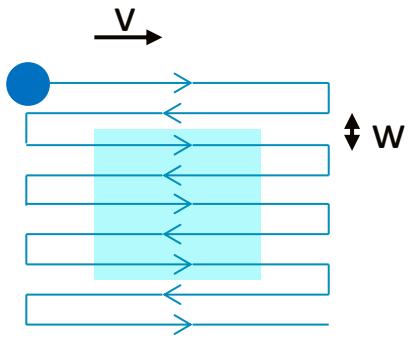


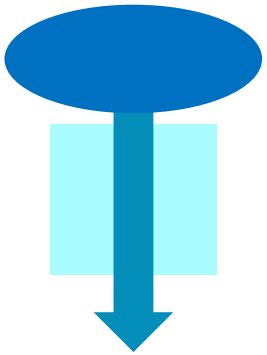
Techniques

Ultrasonic spray coating



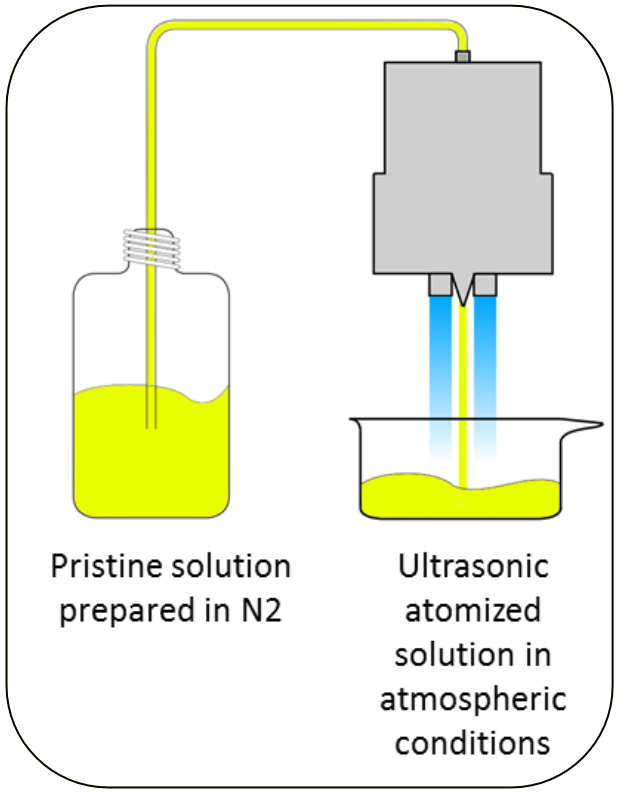






Techniques

Ultrasonic spray coating of SY



Effect of ultra sonication on polymer chain

side-chain scission?
backbone cleavage?

Gilissen, K., Stryckers, J., Verstappen, P., Drijkoningen, J., Heintges, G. H. L., Lutsen, L., … Deferme, W. (2015). Ultrasonic spray coating as deposition technique for the light-emitting layer in polymer LEDs. *Organic Electronics*, *20*(February), 31–35. doi:10.1016/j.orgel.2015.01.015

Techniques

Ultrasonic spray coating of SY

Layer thickness optimization: Ink formulation

Solvent(s)	[SY] (mg/ml)	film properties	η_P [min/max] (Lumen / Watt)
THF	1	Coffee ring effect visible	n/a
oDCB	1	Terassed Hill effect	n/a
oDCB + mesitylene 10 v/v%	2.5	smooth film	[2.5/3.75]
oDCB + mesitylene 20 v/v%	2.5	smooth film	[1.75/3.5]
oDCB + mesitylene 30 v/v%	2.5	smooth film	[0.5/1.5]
oDCB + mesitylene 40 v/v%	2.5	smooth film	[0.3/1.4]
oDCB	3 - 1	smooth film	[3.6/4.2]
CB	2.5	smooth film	[0.6/0.7]
CB + Toluene 10 v/v%	2.5	smooth film	[1.35/1.75]
CB + Toluene 20 v/v%	2.5	smooth film	[1.5/2.6]
CB + Toluene 30 v/v%	2.5	smooth film	[0.4/0.6]

Gilissen, K., Stryckers, J., Verstappen, P., Drijkoningen, J., Heintges, G. H. L., Lutsen, L., … Deferme, W. (2015). Ultrasonic spray coating as deposition technique for the light-emitting layer in polymer LEDs. *Organic Electronics*, *20*(February), 31–35. doi:10.1016/j.orgel.2015.01.015

Techniques

Ultrasonic spray coating of SY

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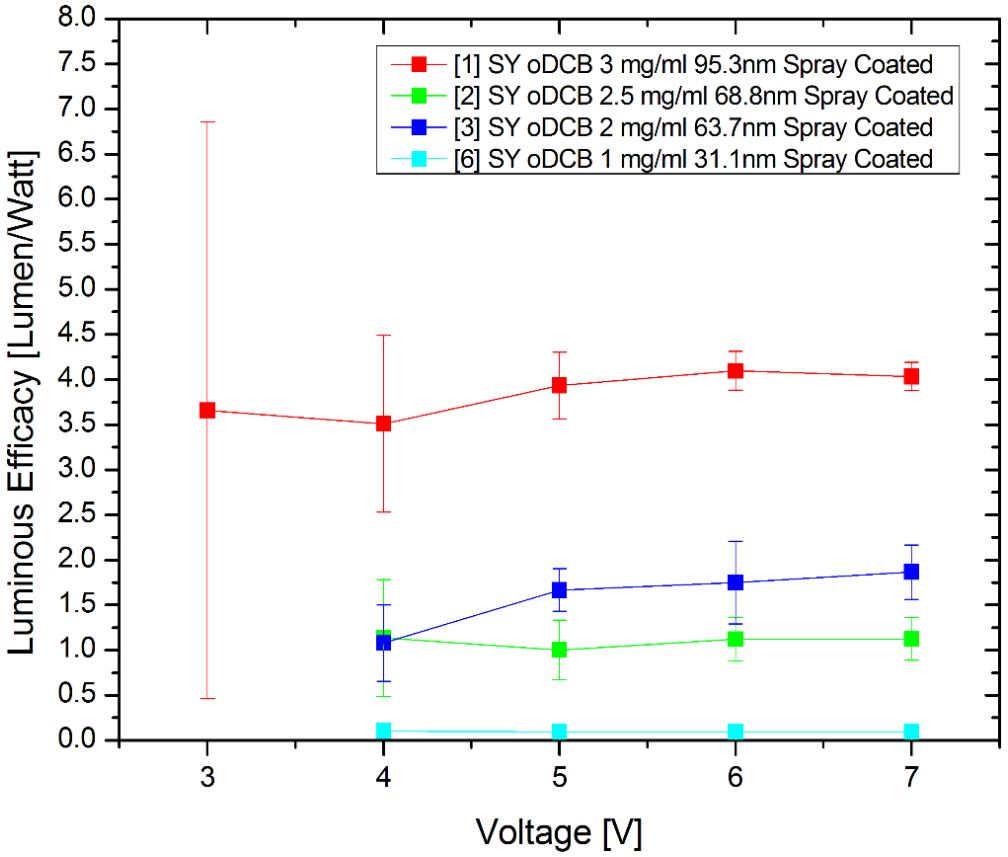

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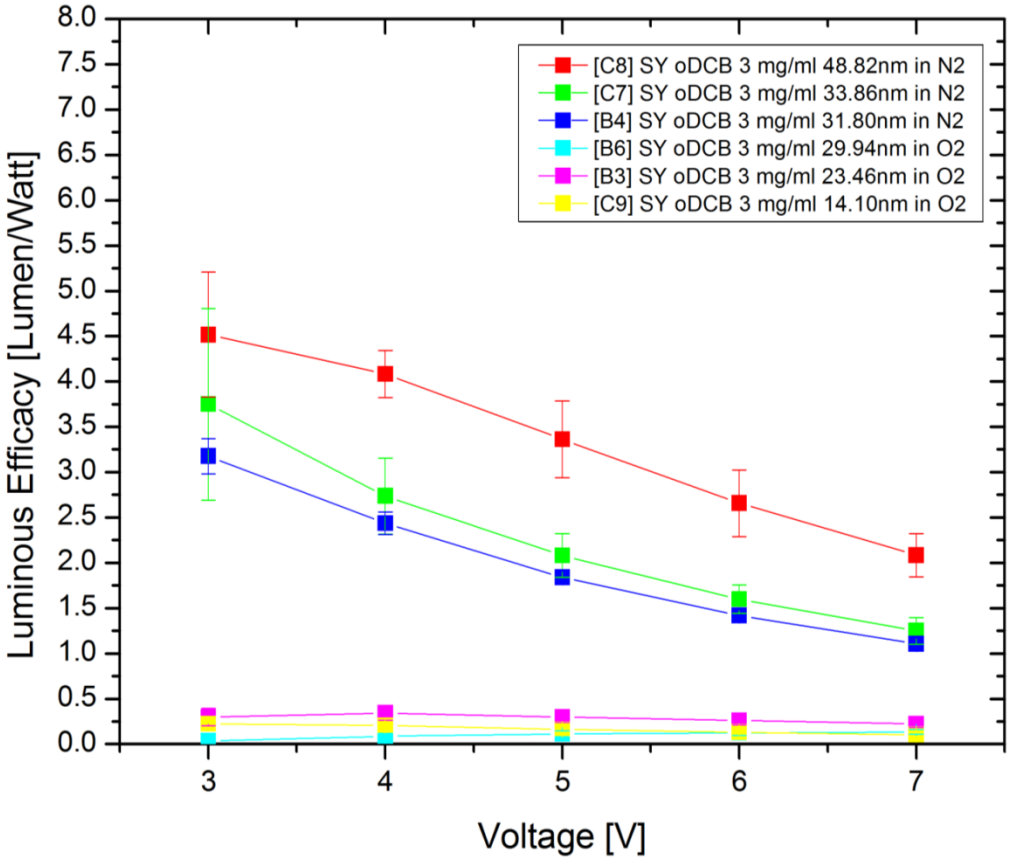

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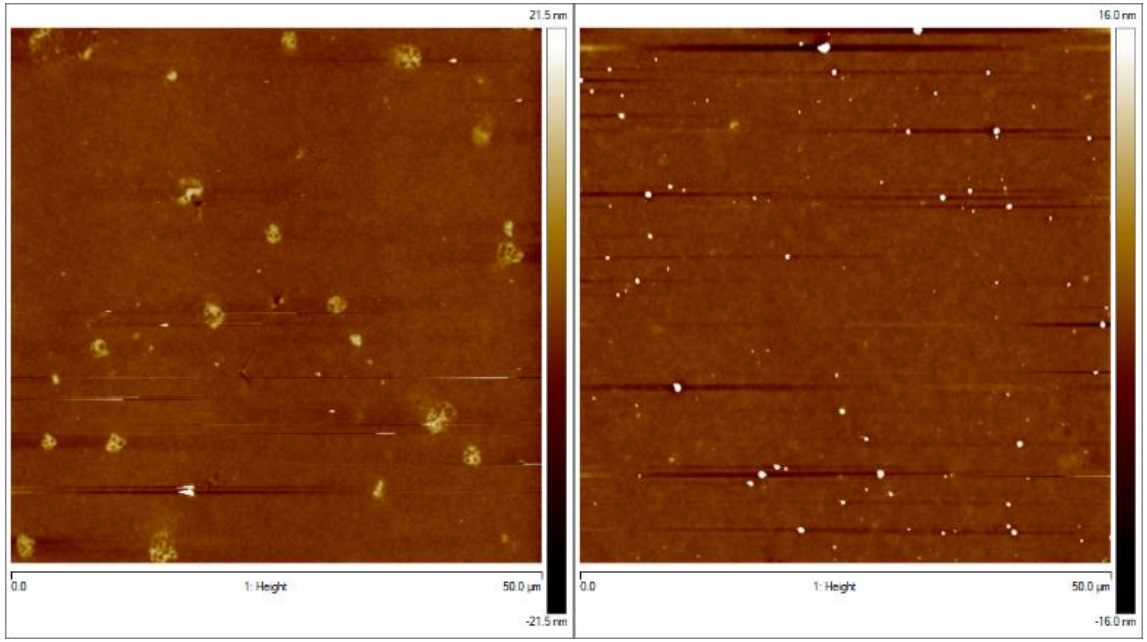
Techniques

Ultrasonic spray coating of SY

Layer thickness optimization: Morphology



AFM topography of Super Yellow film from Super Yellow - oDCB with 40v/v% mesitylene solution. (left) Deposited by spin coating Ra = 0.72 nm. (right) Deposited by ultrasonic spray coating Ra = 0.87 nm.

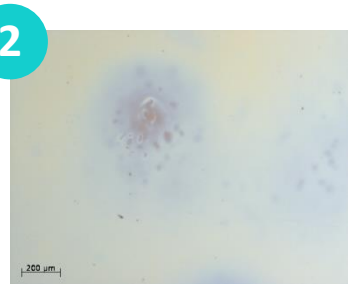
Gilissen, K., Stryckers, J., Verstappen, P., Drijkoningen, J., Heintges, G. H. L., Lutsen, L., … Deferme, W. (2015). Ultrasonic spray coating as deposition technique for the light-emitting layer in polymer LEDs. *Organic Electronics*, *20*(February), 31–35. doi:10.1016/j.orgel.2015.01.015

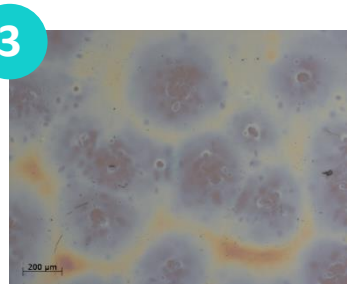
Techniques

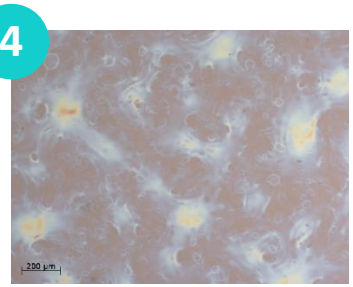
Ultrasonic spray coating of SY

Layer thickness optimization: Spray coating parameters

Sample	Solution	Substrate	Surface Treatment	Nozzle Power [W]	Speed [mm/s]	Area Spacing [mm]	Z-Axis [mm]	Accumist [PSI]	Flowrate [ml/min]	Temp Heater [° C]
1	SY oDCB 2.5mg/ml	glass	none	3	100	3	20	1.4	0.60	60
2	SY oDCB 2.5mg/ml	glass	none	3	100	3	20	1.4	0.45	60
3	SY oDCB 2.5mg/ml	glass	none	3	100	3	20	1.4	0.30	60
4	SY oDCB 2.5mg/ml	glass	none	3	100	3	20	1.4	0.10	60







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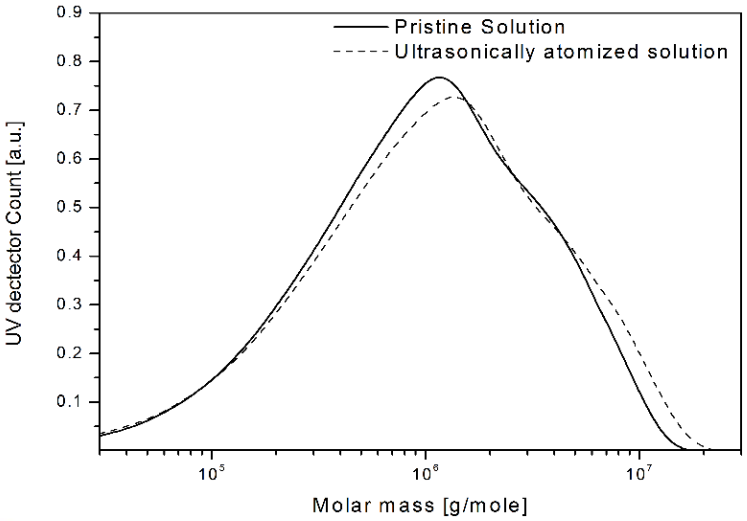
Techniques

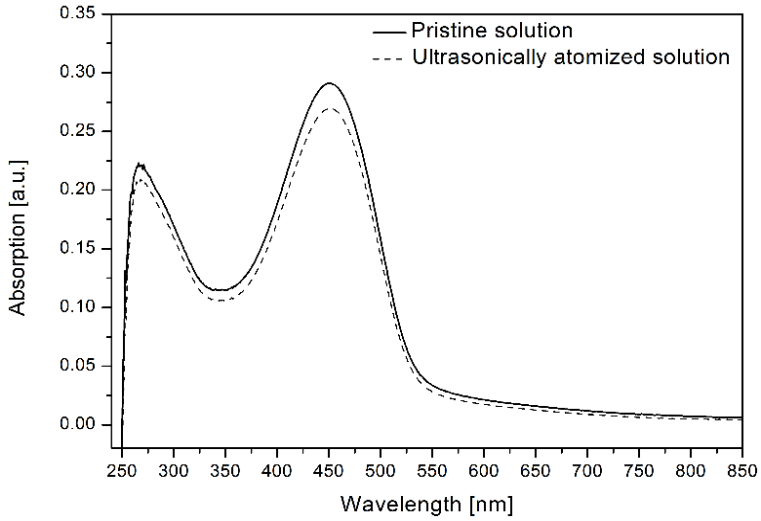
Ultrasonic spray coating of SY

Polymer Backbone

GPC size exclusion



Thin film UV/VIS absorption



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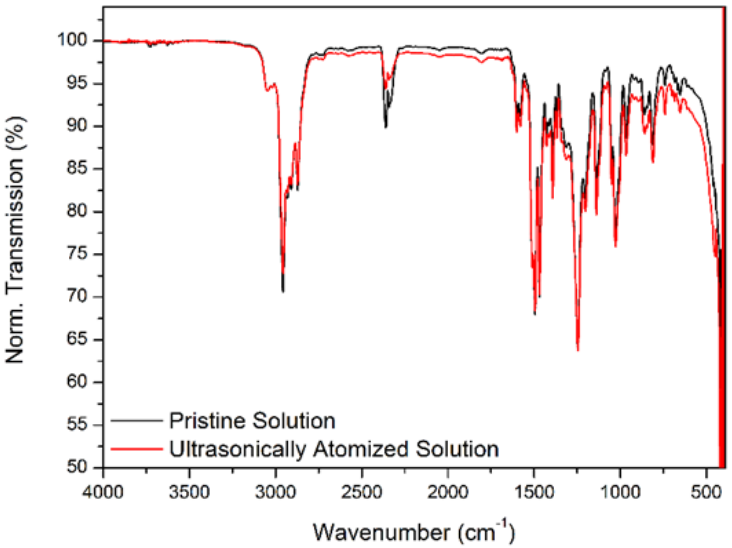
Techniques

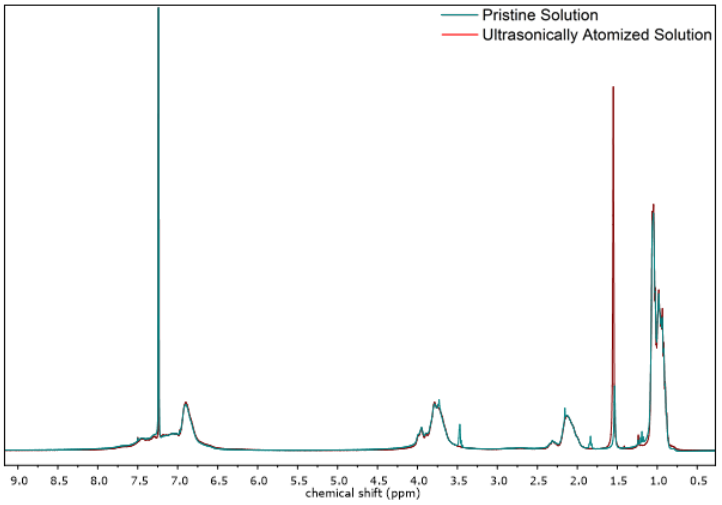
Ultrasonic spray coating of SY

Side Chains

Normalized FTIR absorption spectra



NMR spectra

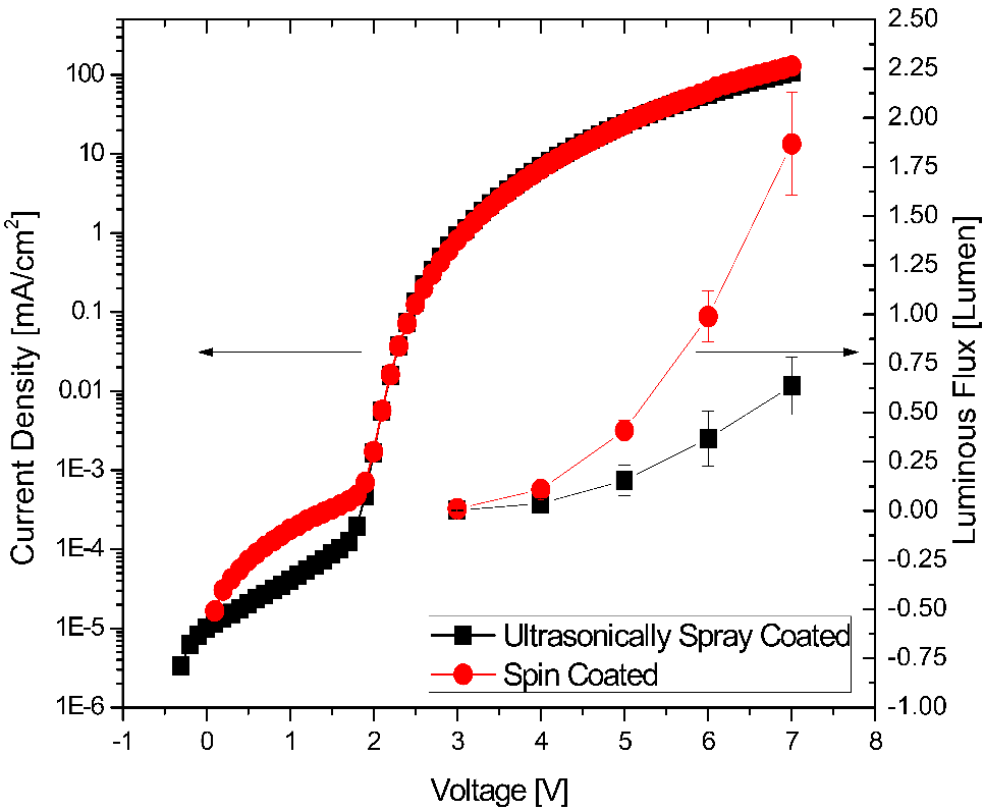


Gilissen, K., Stryckers, J., Verstappen, P., Drijkoningen, J., Heintges, G. H. L., Lutsen, L., … Deferme, W. (2015). Ultrasonic spray coating as deposition technique for the light-emitting layer in polymer LEDs. *Organic Electronics*, *20*(February), 31–35. doi:10.1016/j.orgel.2015.01.015

Techniques

Ultrasonic spray coating of SY

OLED



Spray coated OLED

Gilissen, K., Stryckers, J., Verstappen, P., Drijkoningen, J., Heintges, G. H. L., Lutsen, L., … Deferme, W. (2015). Ultrasonic spray coating as deposition technique for the light-emitting layer in polymer LEDs. *Organic Electronics*, *20*(February), 31–35. doi:10.1016/j.orgel.2015.01.015

Techniques

Ultrasonic spray coating of SY

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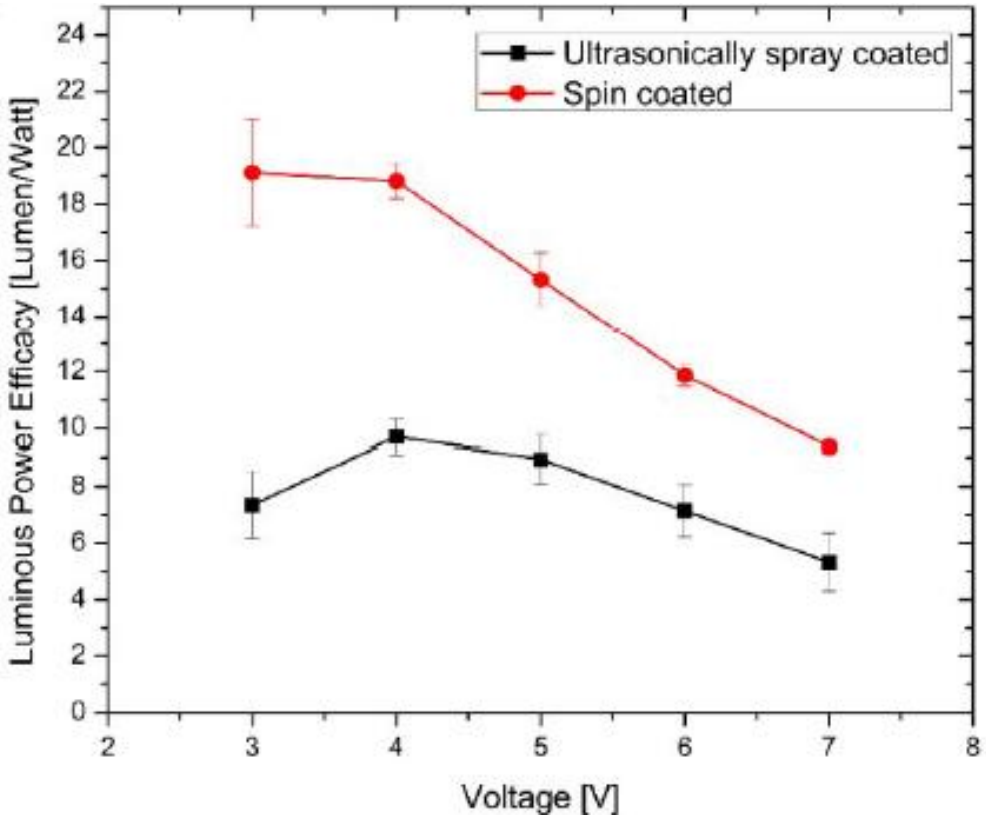

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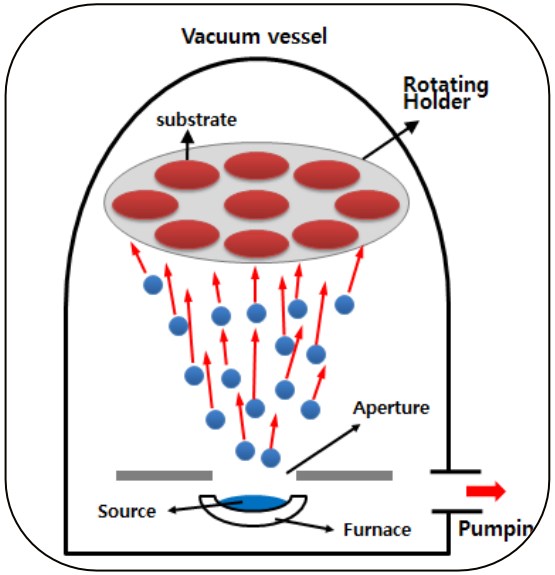
Making an TEOLED

Thermal evaporation



12 nm Ca/ 17 nm Al contact

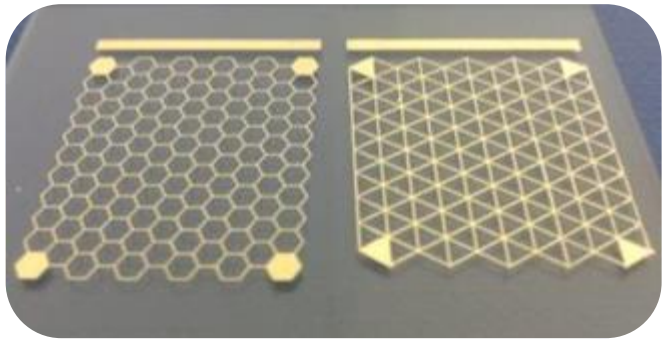
Making an TEOLED

Optimal transparent top contact

Au layers

- Thermal evaporation
- **Layer thickness 1-15 nm**
- Sheet resistance 3,2-123,7 Ω/□
- Transparency 25-70 %

Ag grids

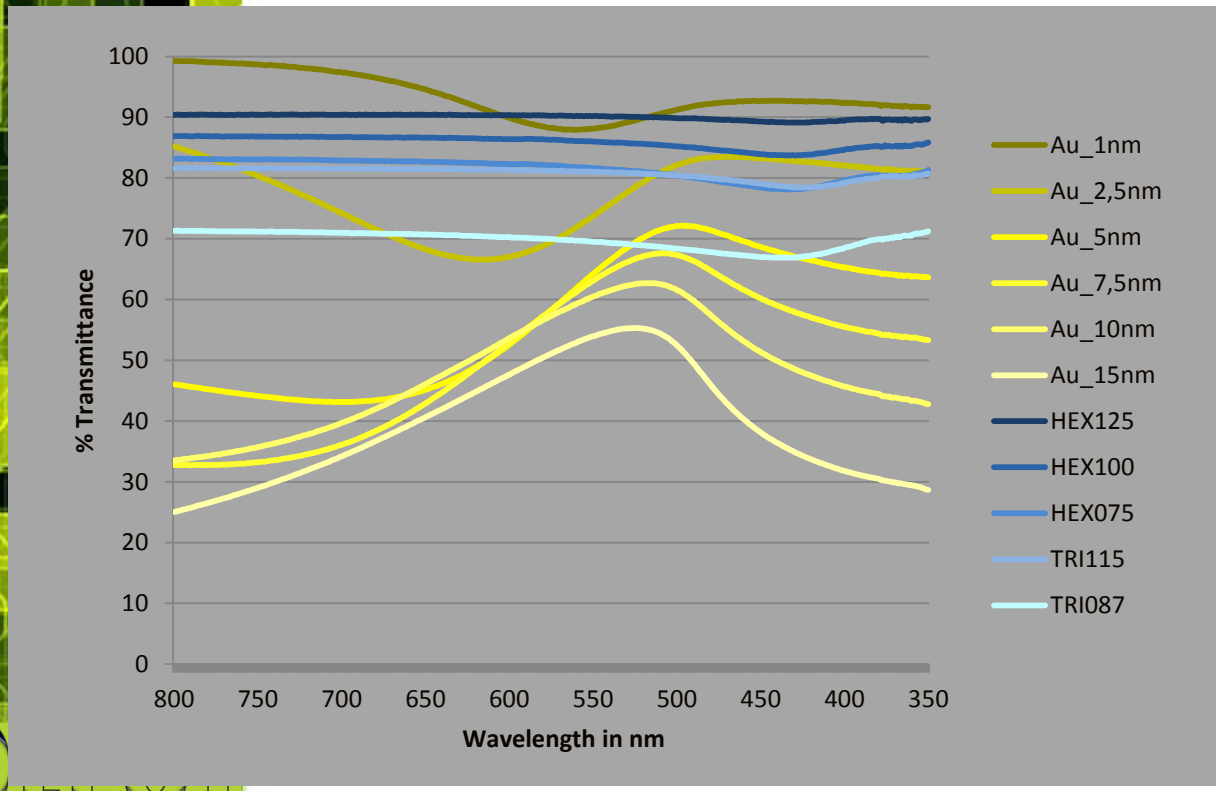


- **Ink jet printing**
- Layer thickness 150-250 nm
- **Sheet resistance 0,82-2,7 Ω/□**
- **Transparency 70-90 %**

Making an TEOLED

Optimal transparent top contact

Transmittance



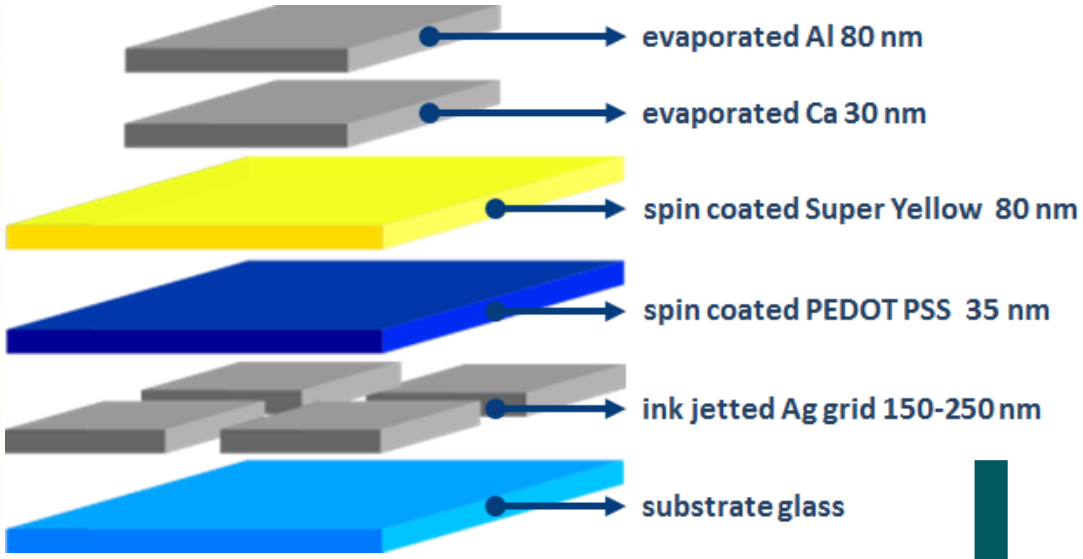
Conductivity

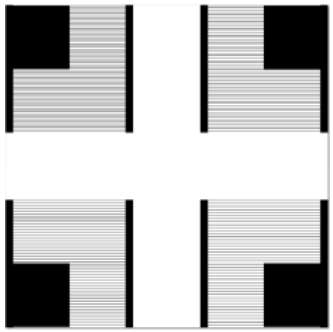
	Rs (Ω/□)
HEX125	2,7
HEX100	1,5
HEX075	1,5
TRI115	1,2
TRI087	0,82
Au 1nm	> 20M
Au 2,5nm	> 20M
Au 5nm	> 20M
Au 7,5nm	123,7
Au 10nm	11,5
Au 15nm	3,2

Making an TEOLED

Optimal transparent top contact

Testing of a BEOLED with Ag grid



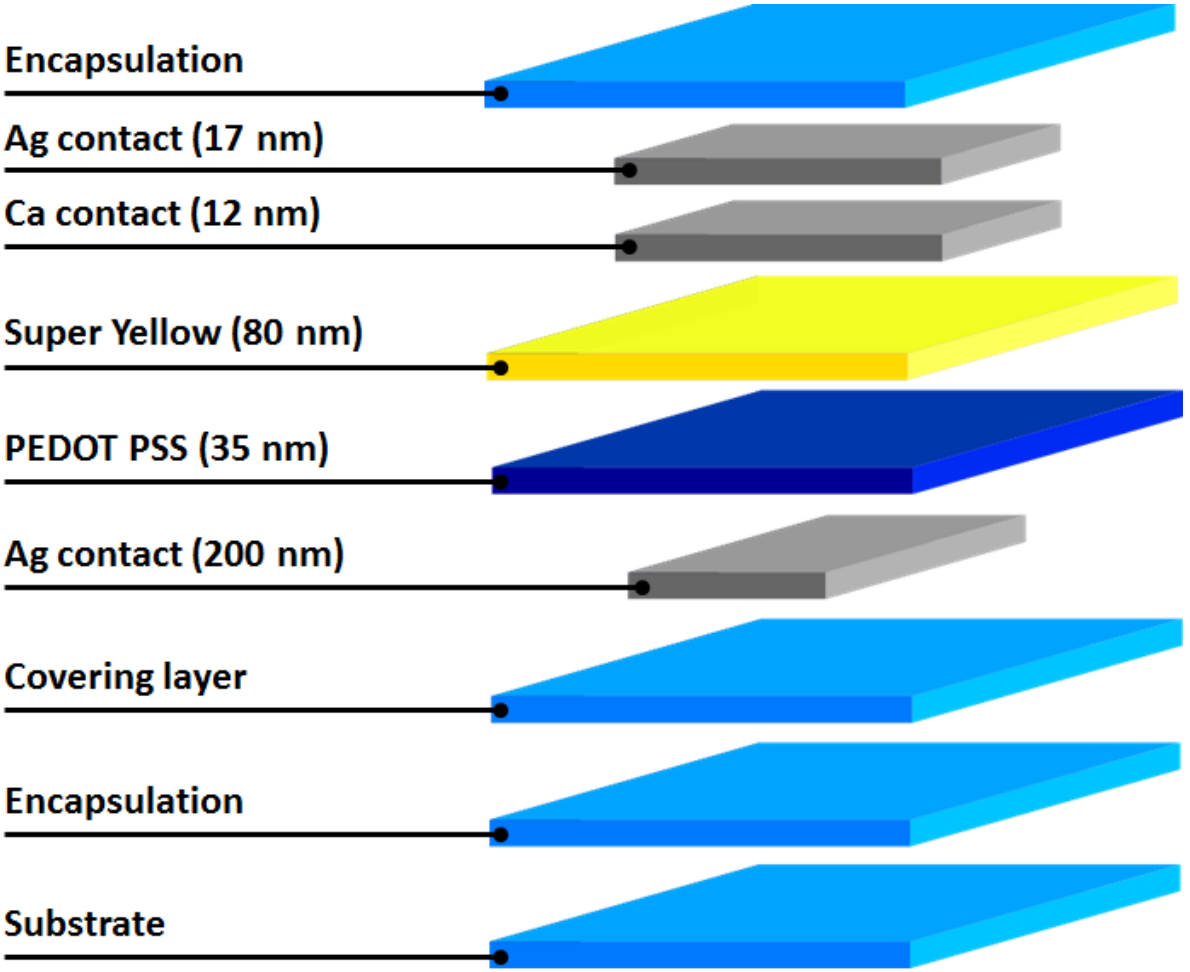


Sintered at 200 °C
Problem with TEOLED!
Sintering damages other layers!

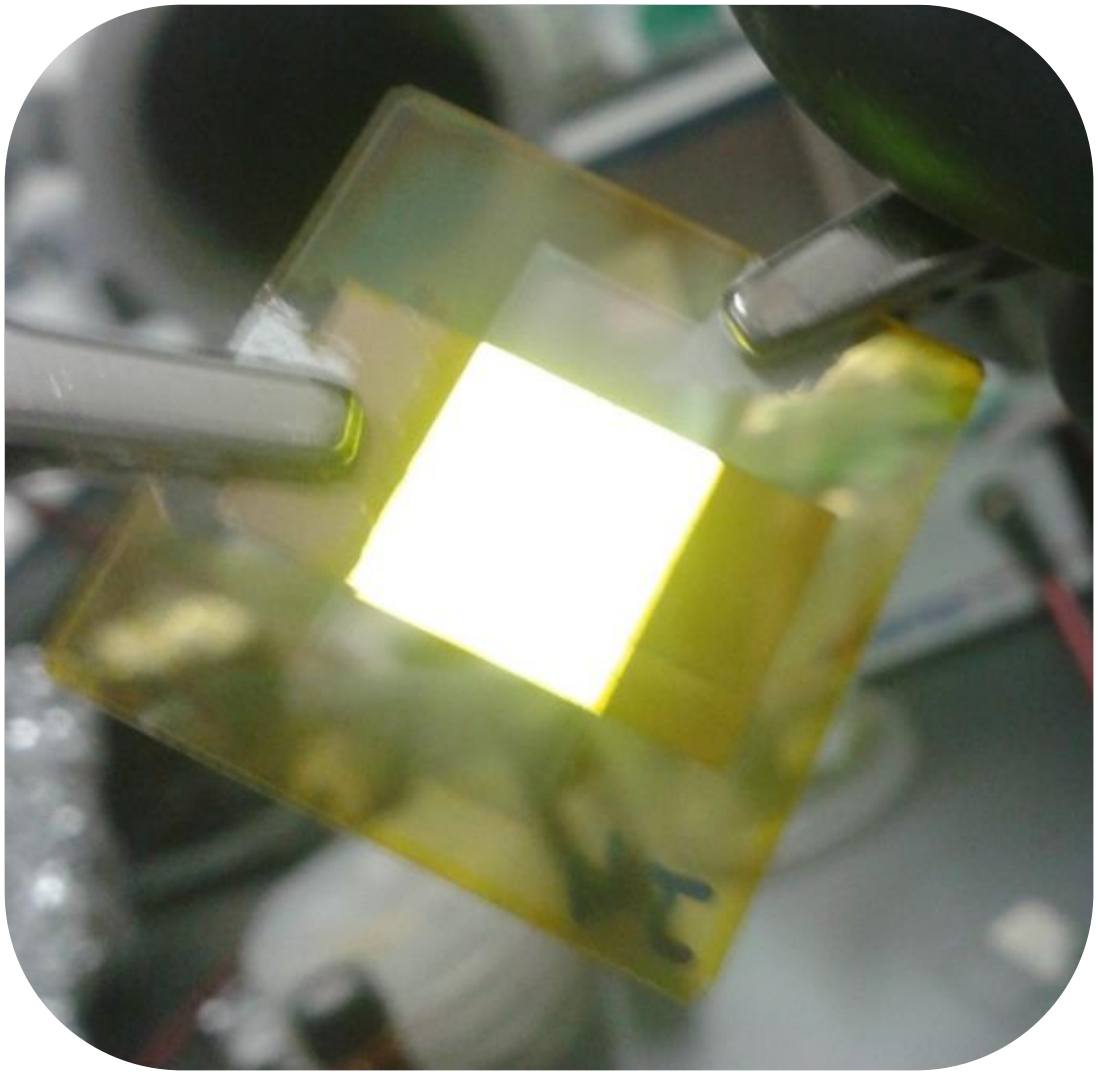
Making an TEOLED

Plasma techniques

Structure TEOLED

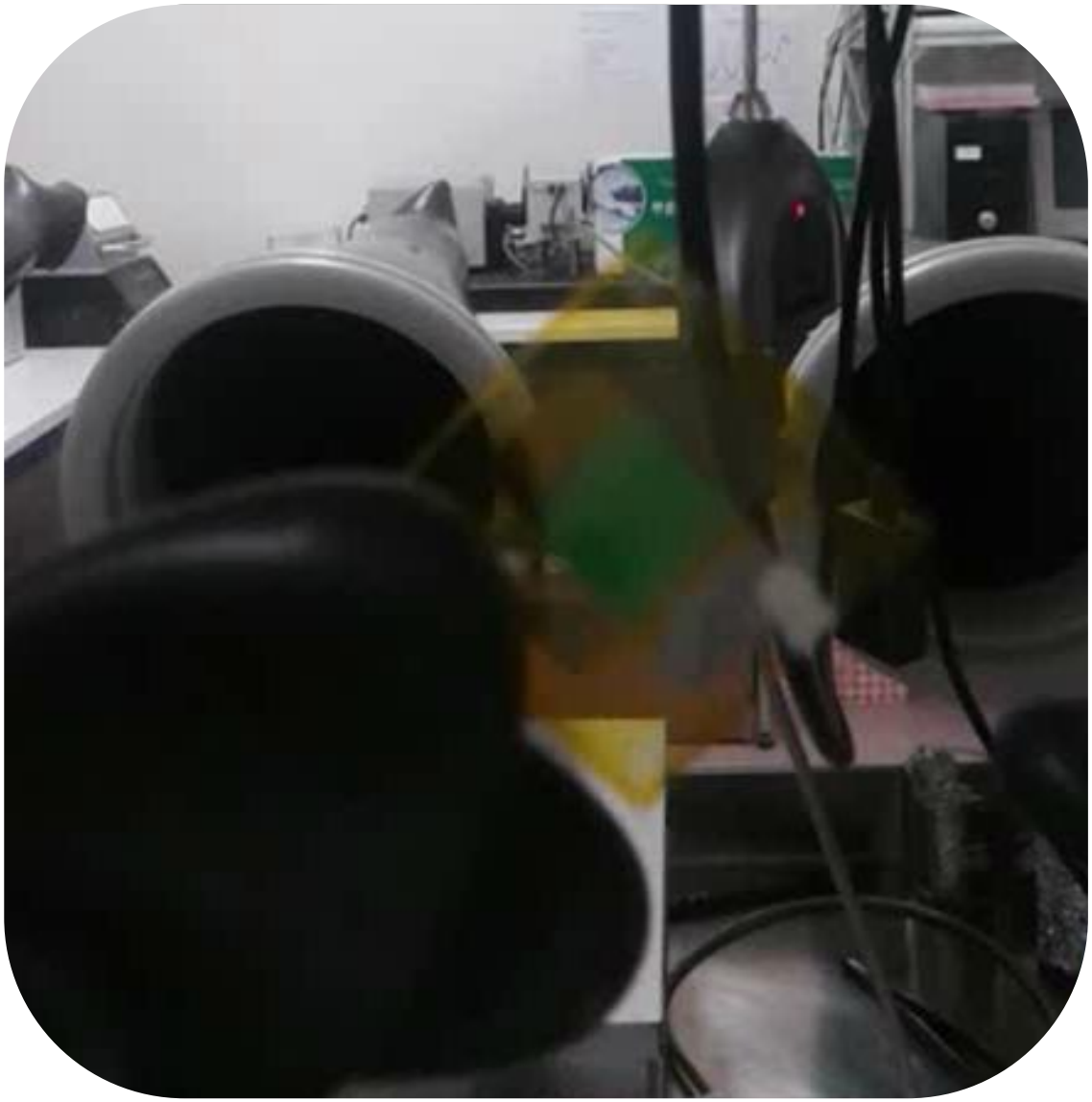


TEOLED on glass

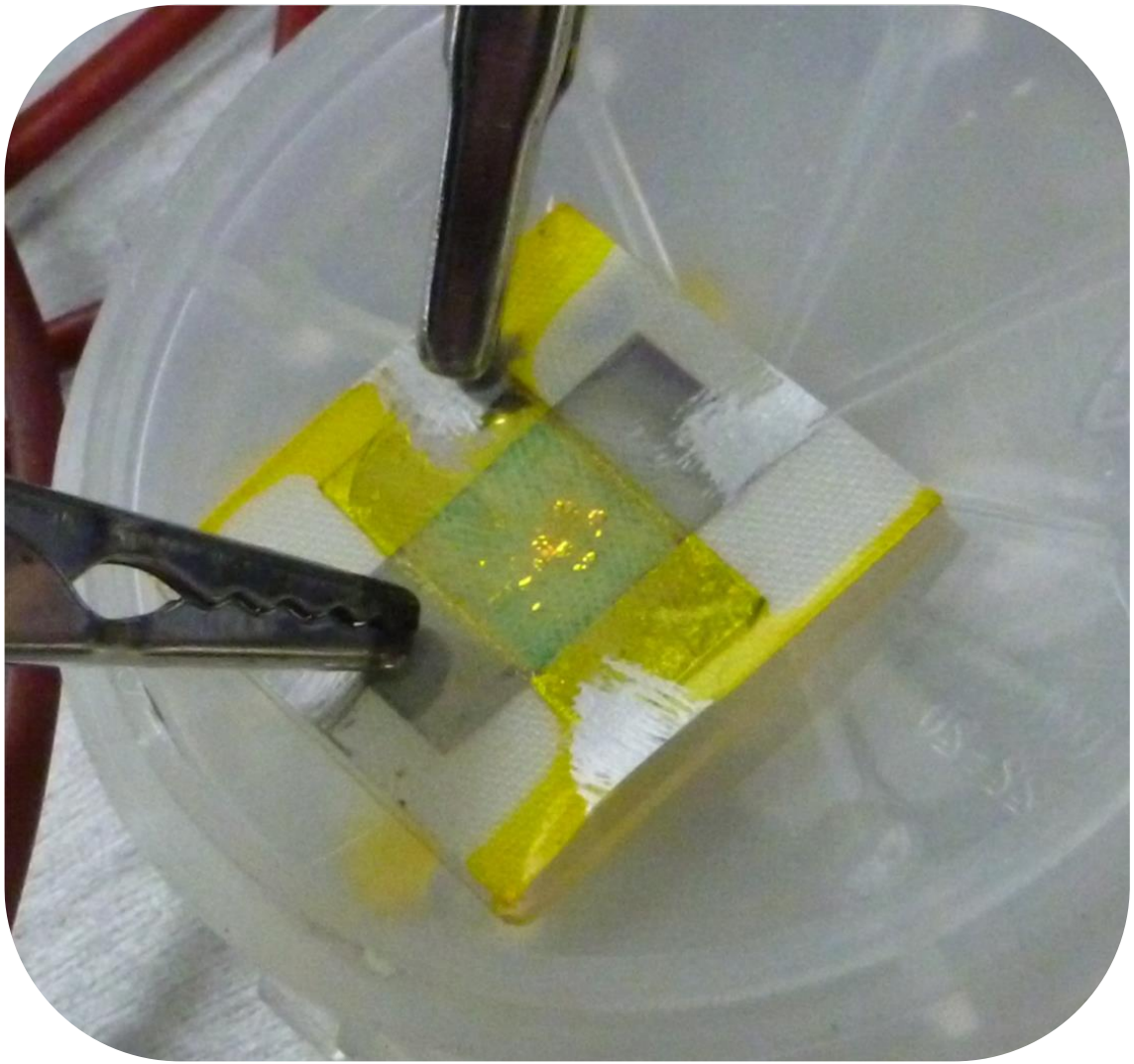


TEOLED on PET

TEOLED on PET



TEOLED on textile



Outlook

Further development of flexible and encapsulated OLEDs on PET

Research best suitable covering and smoothing layer on textile

Development of flexible and encapsulated OLEDs on textile


Future's So Bright
I Gotta Wear SHADES

More information

OLED material

PEDOT PSS ► Heraeus
Super Yellow ► Merck Group

Contact information

POLEOT
Masterclass, 23/06/15
ESMA
Driving Print Excellence