FUNDAMENTAL PROCESSES GOVERNING OPERATION AND AGEING IN STATE OF THE ART P-OLEDS

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Talk overview

Simulation

- Model materials and device structure
- Electrical and optical models
- Design rules for high efficiency

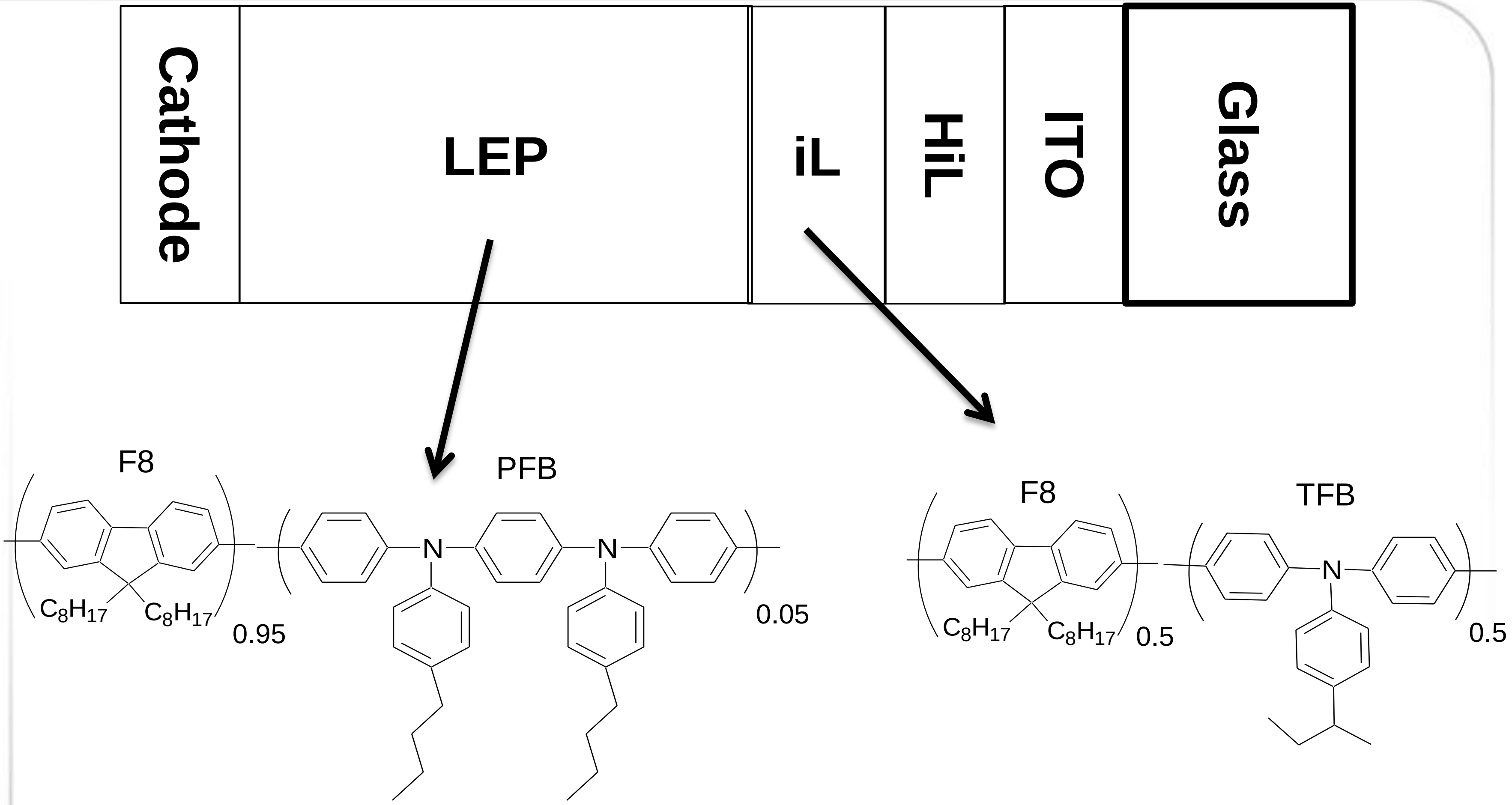
Reality

- Mobility and injection
- PGZ profiles
- Dipole orientation

Degradation

- Main reason for loss of efficiency
- Key observations
- The cause of degradation

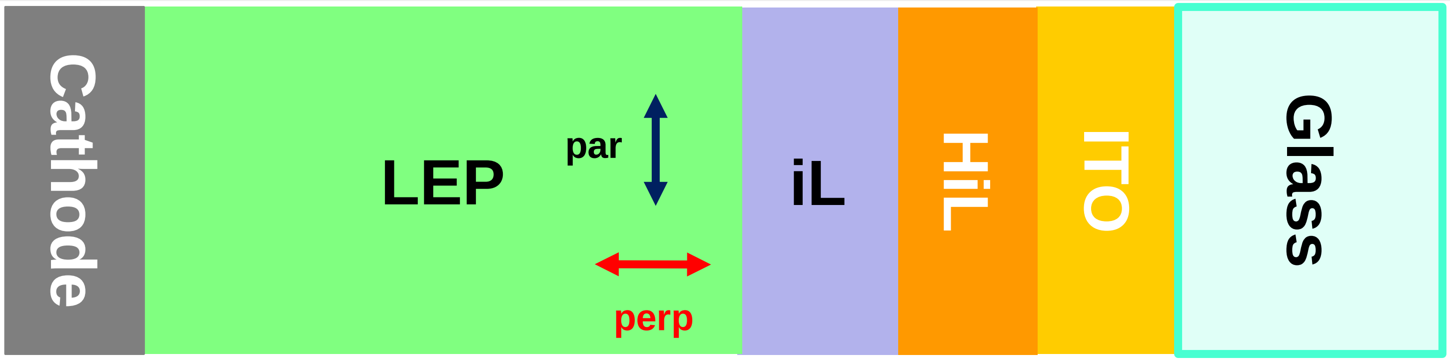
Model materials and device structure

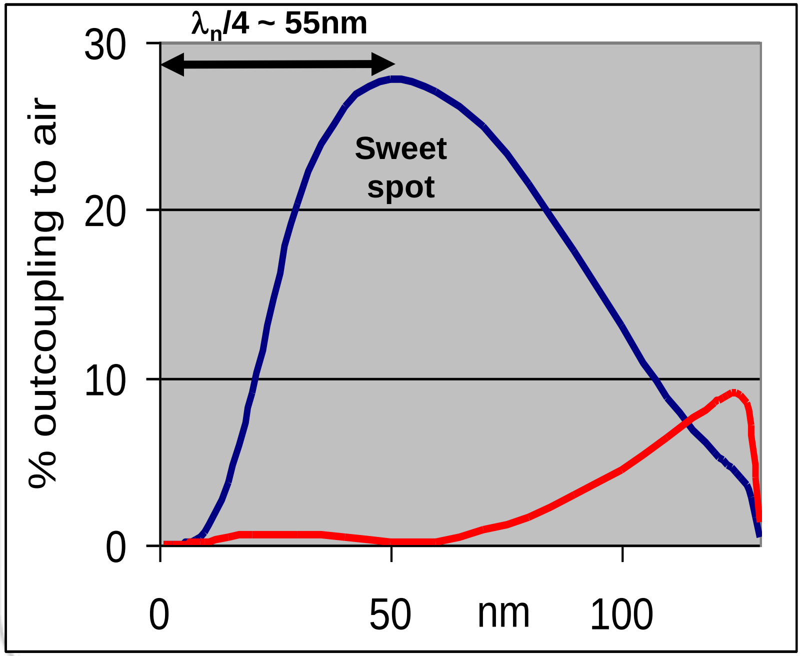


Random copolymer
F8:PFB 95:5

A-B copolymer
F8:TFB 50:50

Optical model – what do we want?

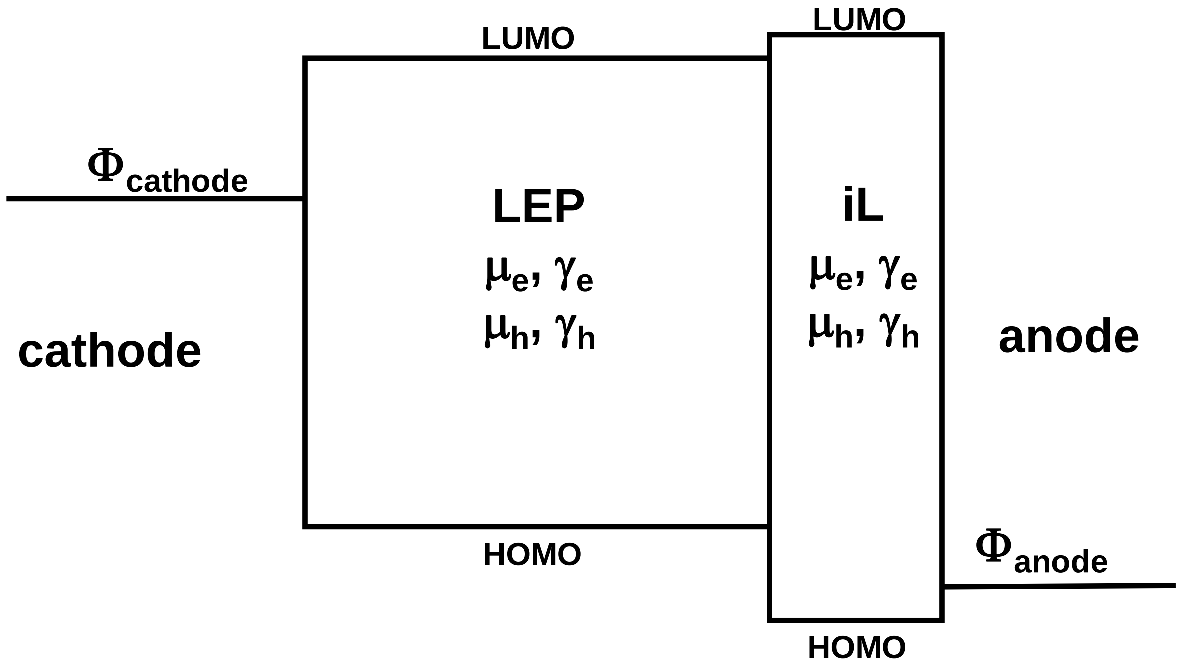




Design rules

- High reflectivity cathode
- PGZ ~$\lambda_n/4$ from cathode (LEP ~ 55nm)
- PGZ at least 10nm from HIL (iL > 10nm)
- Parallel dipoles
- HIL/ITO lossless, tune n, d to optimise cavity

Electrical model



LUMO

LUMO

$\Phi_{cathode}$

LEP

μ_e, γ_e

μ_h, γ_h

iL

μ_e, γ_e

μ_h, γ_h

cathode

anode

Φ_{anode}

HOMO

HOMO

$\varepsilon=3$

$N=10^{27}\ m^{-3}$

$\sigma=100meV$

→ Drift diffusion with Langevin recombination as Barker/Greenham PRB 075205 (2003)

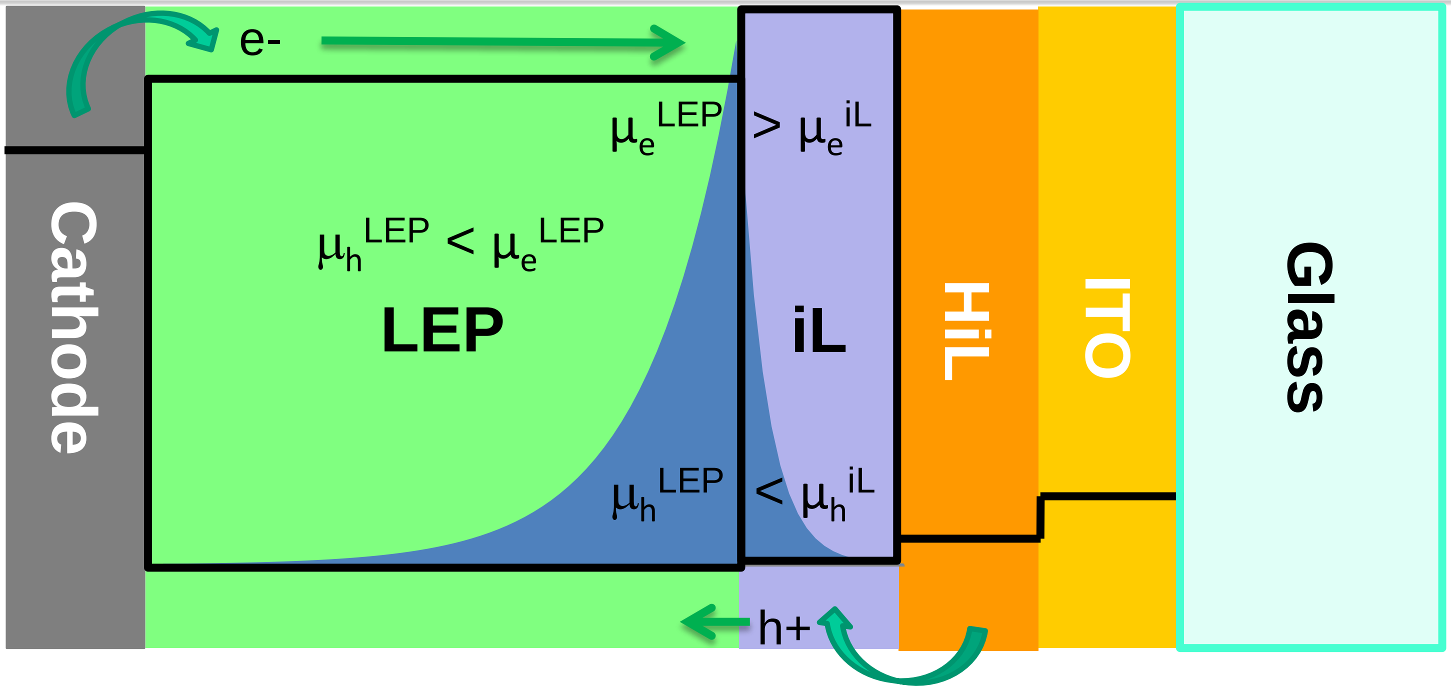
→ Self consistent solution

→ Field dependent mobility $\mu=\mu_0 \exp^{\gamma * sqrt(E)}$

→ Electrode : LEP interfaces as Ohmic or Scott/Malliaras Chem Phys Lett 299 (1999)

→ LEP:LEP interfaces as Arkhipov/Bassler J Appl Phys 90 (2001)

Electrical model – what do we need?

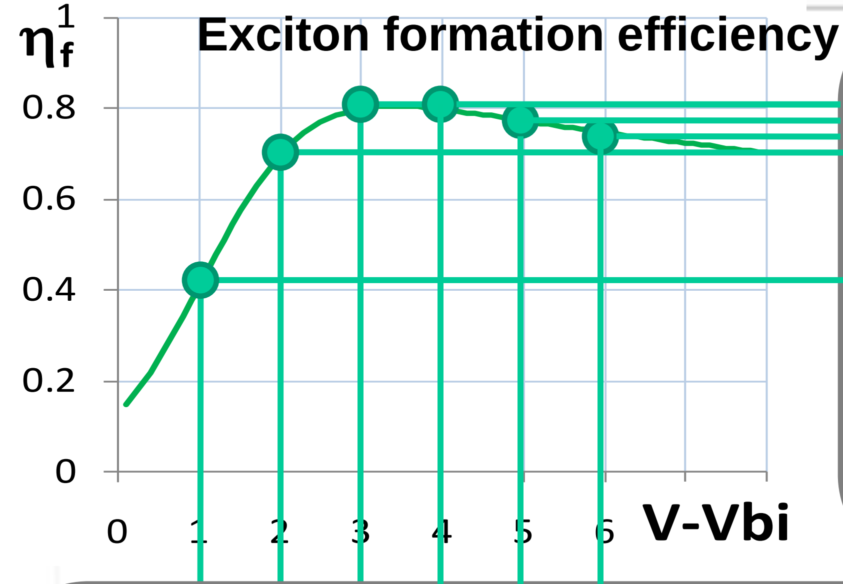


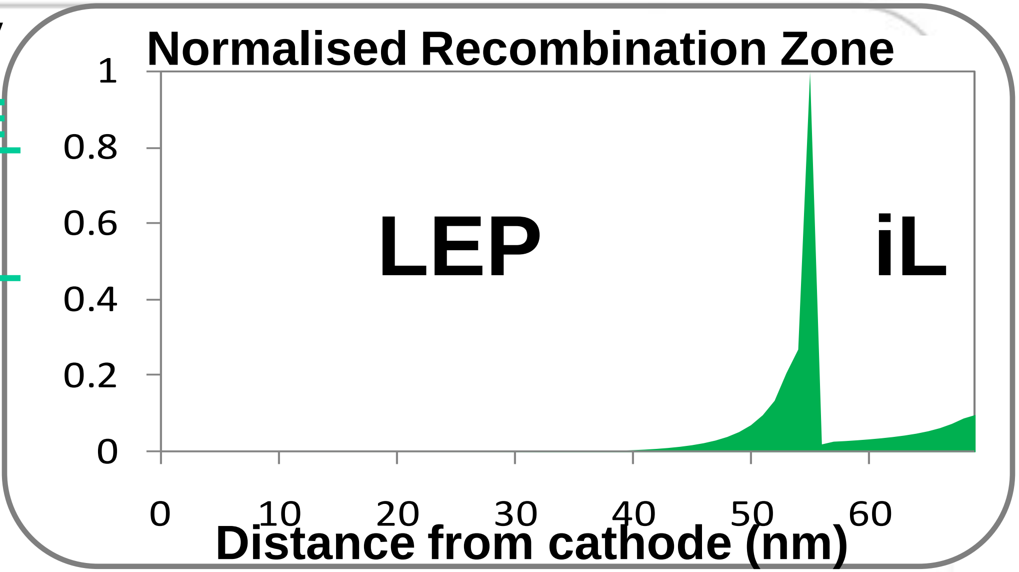
Design rules

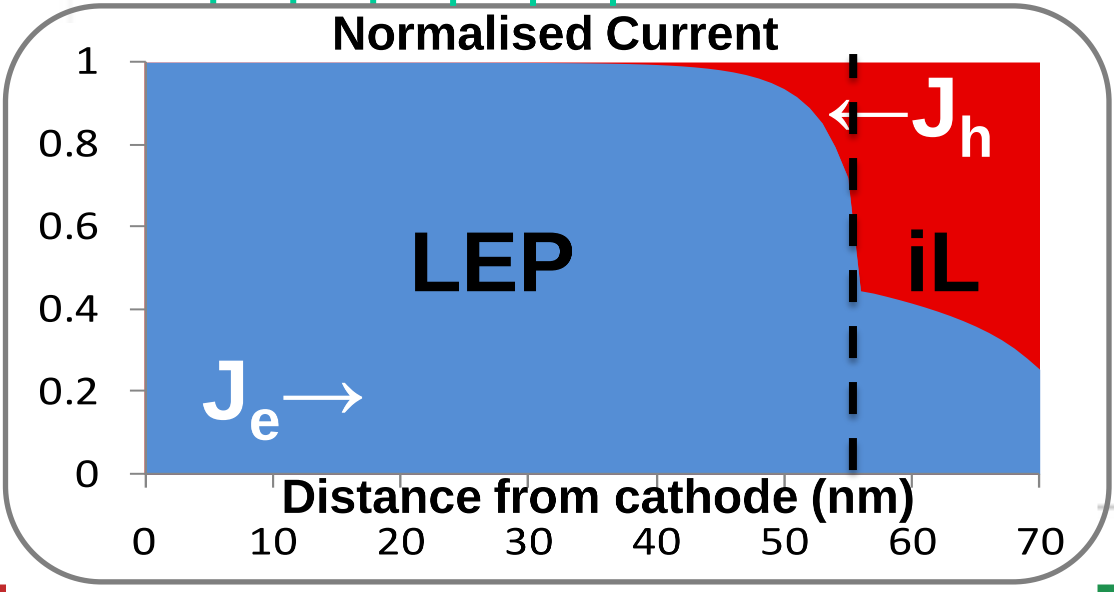
$$\mu_h^{LEP} < \mu_e^{iL} < \mu_e^{LEP} < \mu_h^{iL}$$

→ Low LEP hole mobility - to keep PGZ away from cathode
→ High iL hole mobility - to reduce hole buildup and PGZ in interlayer
→ Low iL electron mobility - to prevent electrons reaching HIL – but not too low…

Simulation – RZ and IQE



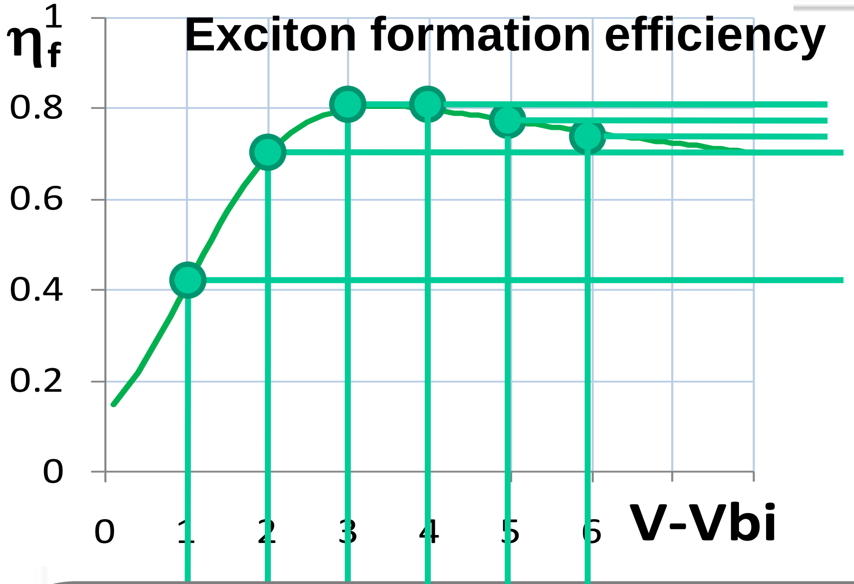


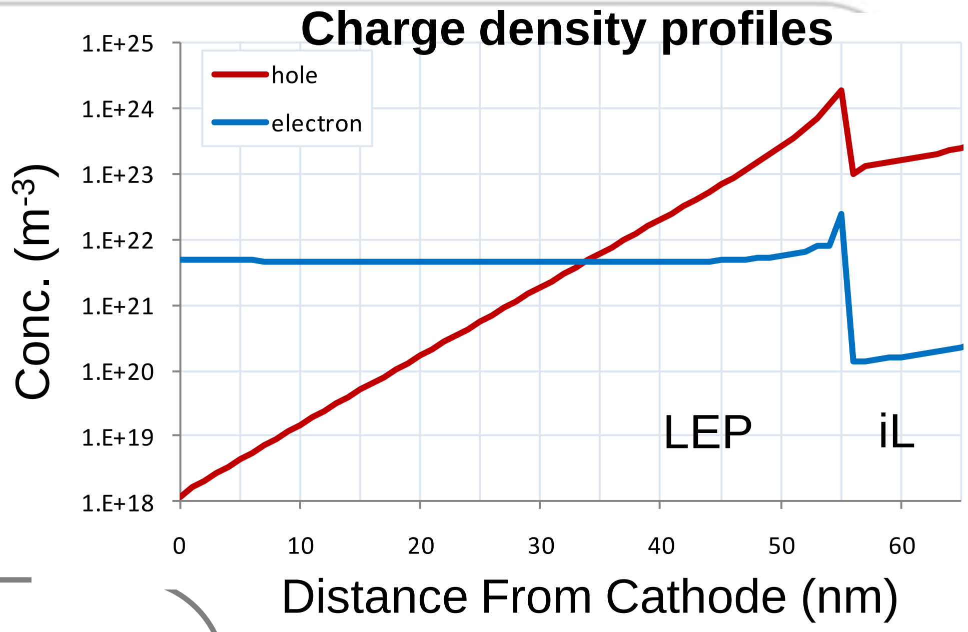


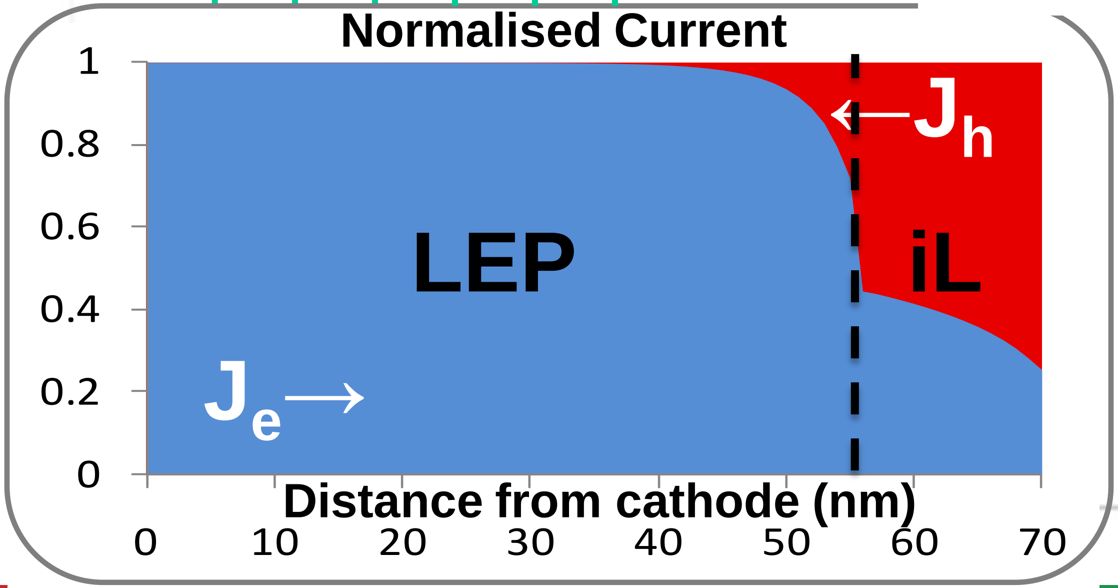
→PGZ zone gets narrower at higher fields

→'hole rich' at low voltage, 'electron rich' at high voltage

Simulation – charge buildup profiles

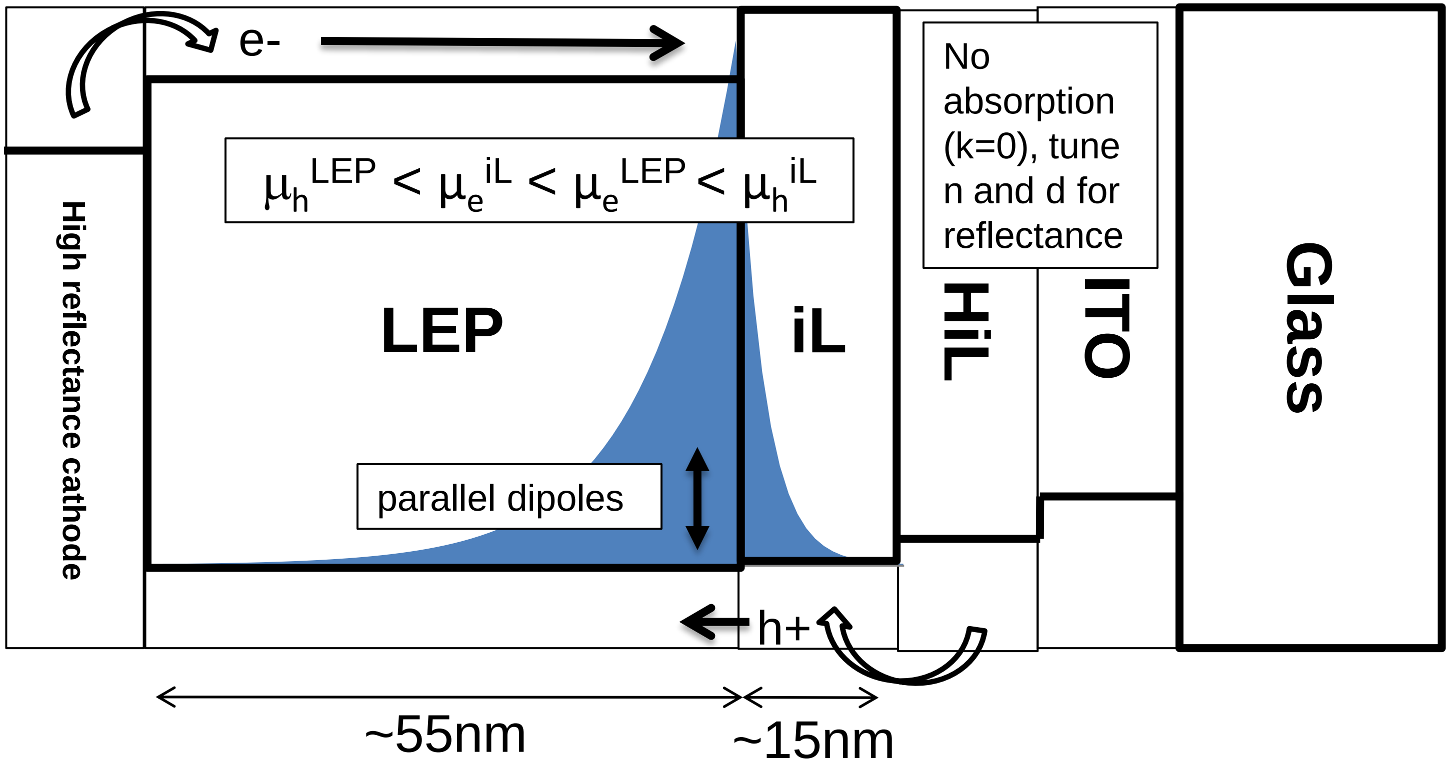






- Holes build up within LEP at concentrations > electrons for all voltages
- Hole accumulation profile determines PGZ

Design rule summary



$\mu_h^{LEP} < \mu_e^{iL} < \mu_e^{LEP} < \mu_h^{iL}$

No absorption (k=0), tune n and d for reflectance

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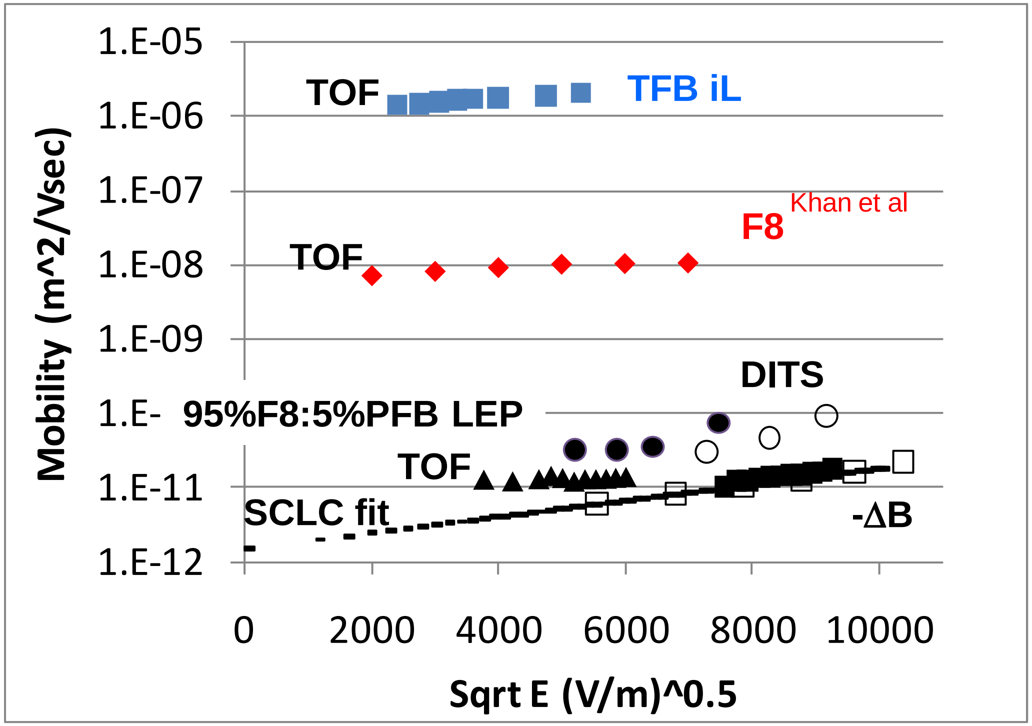
Hole mobility : μ_h (LEP) < μ_h (iL)?



→ 5%PFB in LEP acts as a hole trap and dramatically reduces hole mobility

Khan et al, Physical Review B 75(3), 035215 (2007)
Van Mensfoort et al, PRB 78(8), 085208 (2008)

→ Low hole mobility in LEP vs iL confirmed with many methods

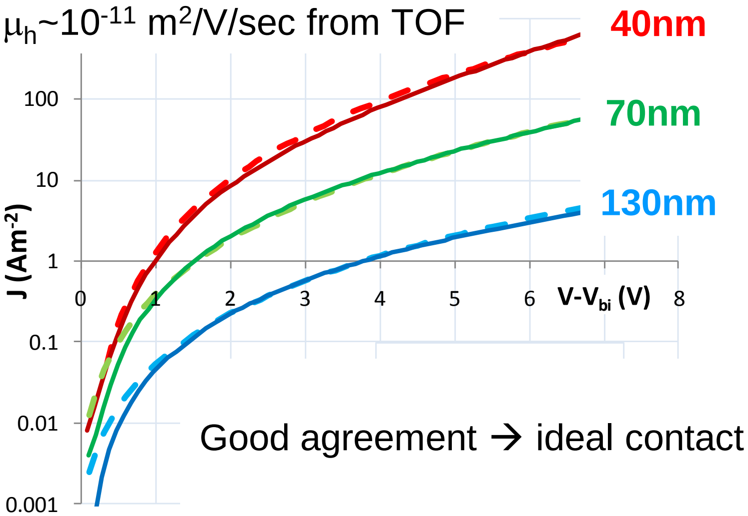
→ **μ_h (LEP) << μ_h (iL)**

DITS: Campbell et al, JAP 89(6), 3343 (2001)
-ΔB: Martens et al, PRB 60(12), R8489 (1999)

HIL:TFB interface – Ohmic contact?

LEP: F8-PFB (95:5) Hole only devices

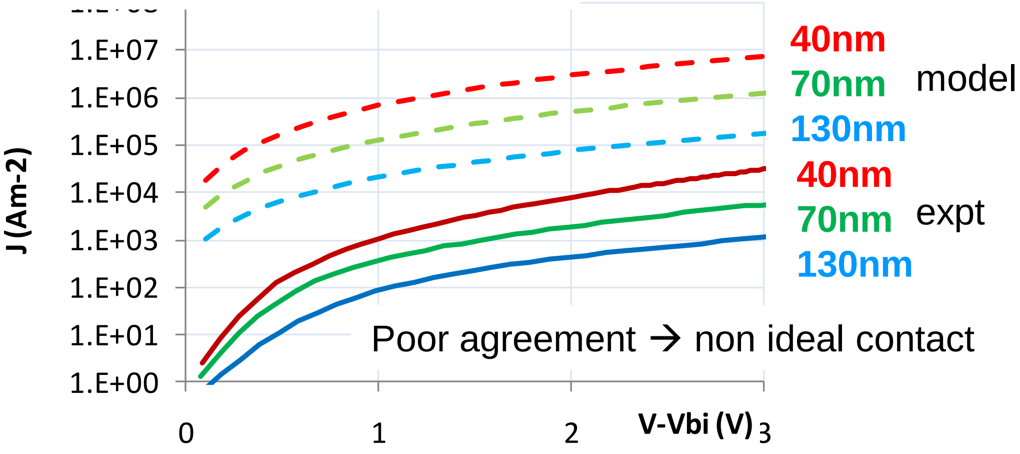
model assuming
μ_h~10^{-11} m^2/V/sec from TOF



Good agreement → ideal contact

iL: F8-TFB (50:50) Hole only devices

model assuming
μ_h~10^{-6} m^2/V/sec from TOF



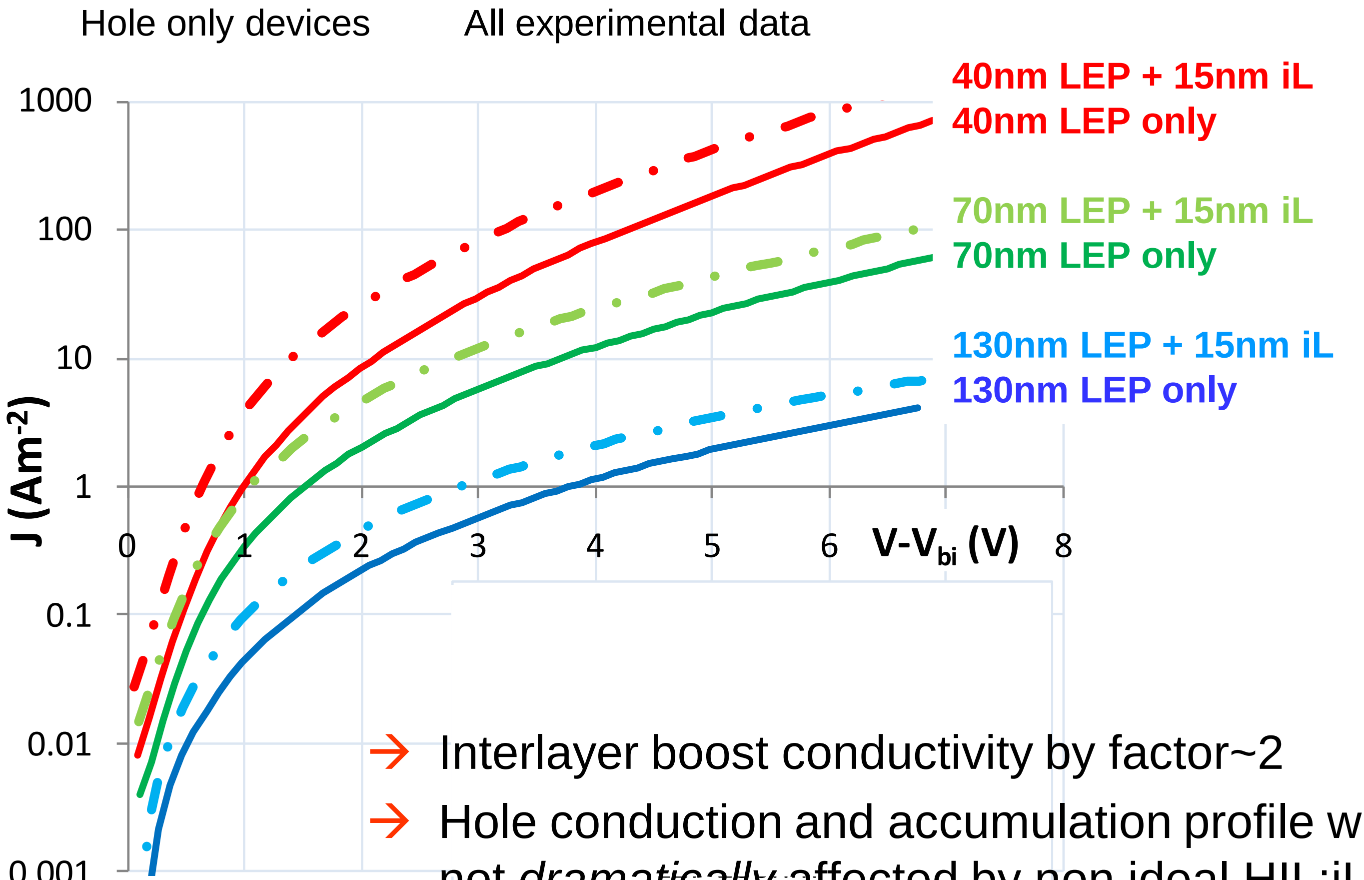
Poor agreement → non ideal contact

- → HIL:TFB contact is not ideal – Injection efficiency ~ 10^{-2} - 10^{-3}

Fong et al Adv Func Mat 19 304 (2009)

- → Need to know what impact non ideal HIL:TFB interface has on hole conductivity of bilayer device

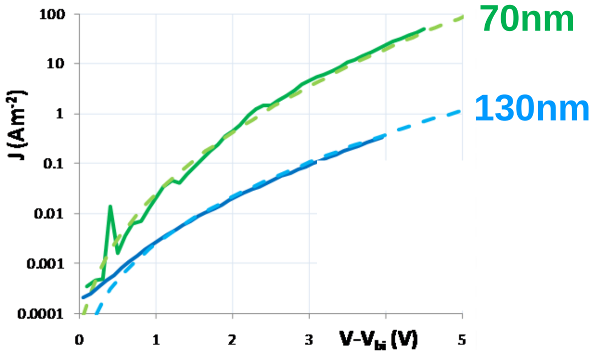
Impact of non ideal HIL:iL on hole current and density profile



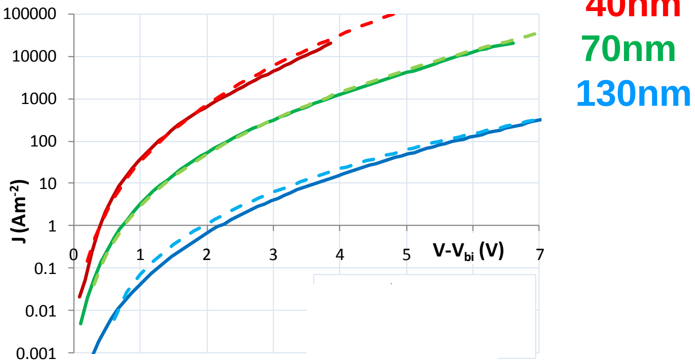
- → Interlayer boost conductivity by factor~2
- → Hole conduction and accumulation profile within LEP layer not *dramatically* affected by non ideal HIL:iL interface

Electron mobility: μ_e (LEP) > μ_h (LEP) ?

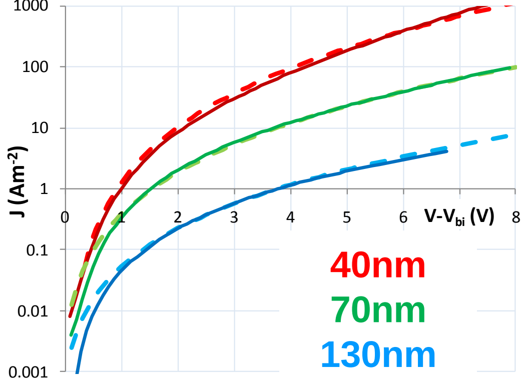
TFB EOD

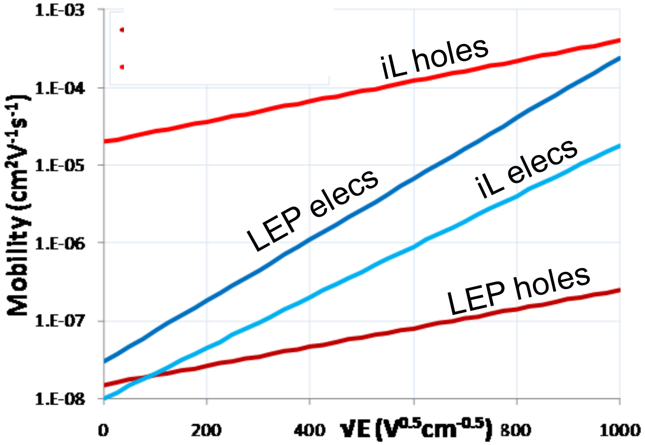


LEP EOD



LEP HOD



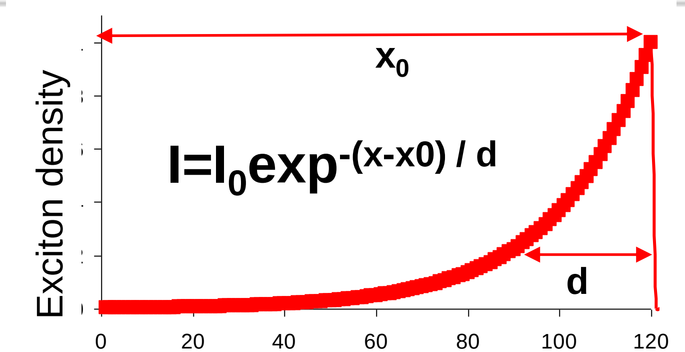


μ_h (LEP) < μ_e (iL) < μ_e (LEP) < μ_h (iL)

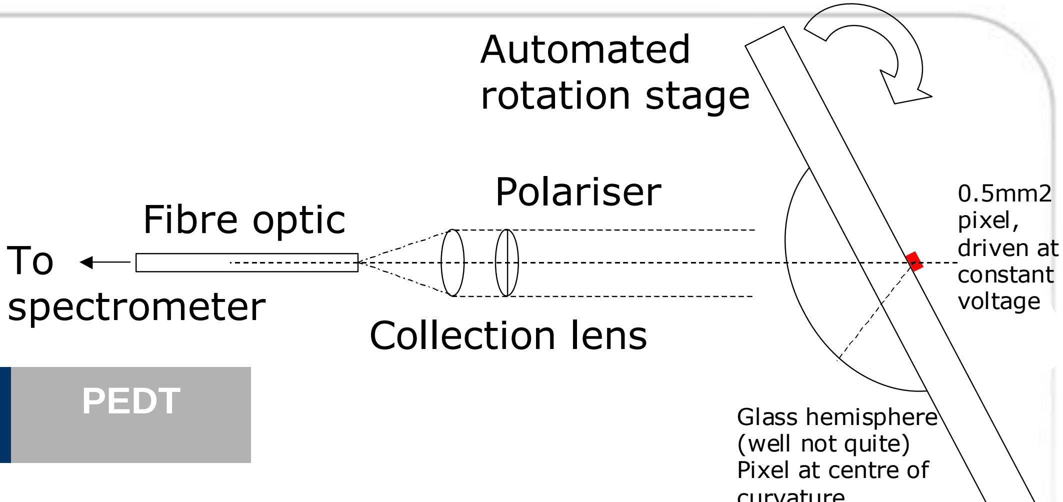
→ Model materials satisfy mobility requirements for ideal PGZ

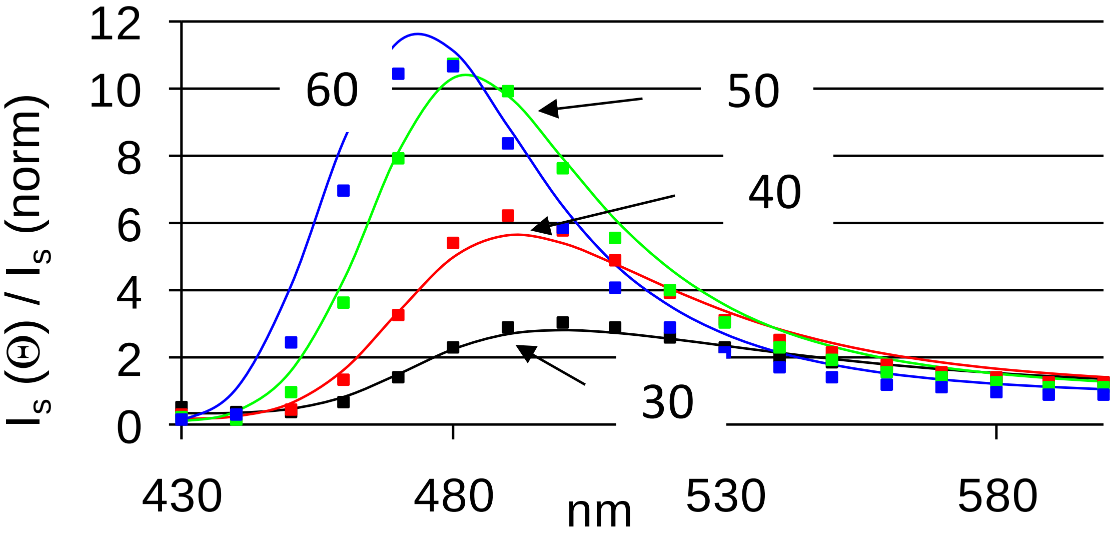
μ_h (LEP) similar to S.L.M de Mensfoort et al PRB 80 033202 for 7.5%amine
→ μ_h (LEP) ~1-10x10^{-5} cm^2/V/sec

Photon Generation Zone - method



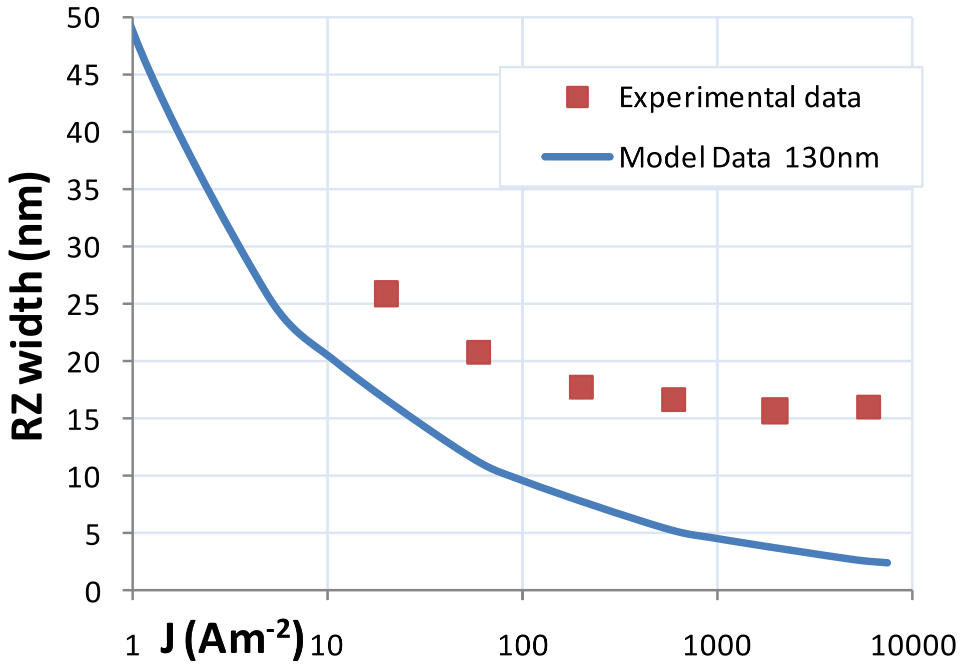
Al | **LEP** | **iL** | **PEDT**





→ x_0 and d free parameters
→ PGZ profile fits very well to exponential decay within LEP peaking at iL:LEP interface

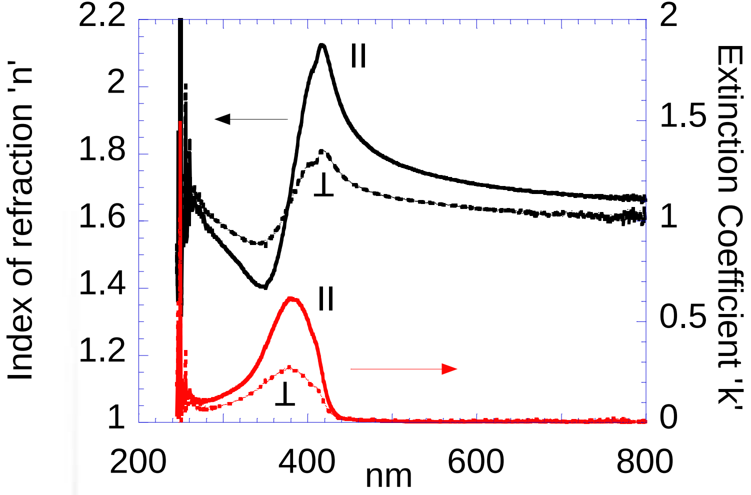
Photon Generation Zone – Current density dependence



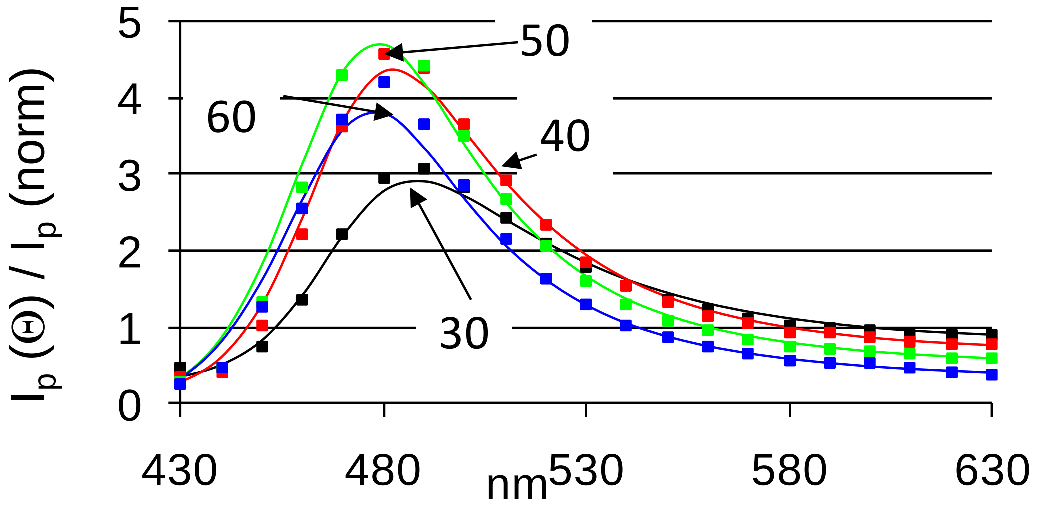
- → Clear experimental evidence of RZ narrowing at higher voltages
- → Offset :10-15nm exciton diffusion?

Dipole orientation – in plane?

Absorption



Emission



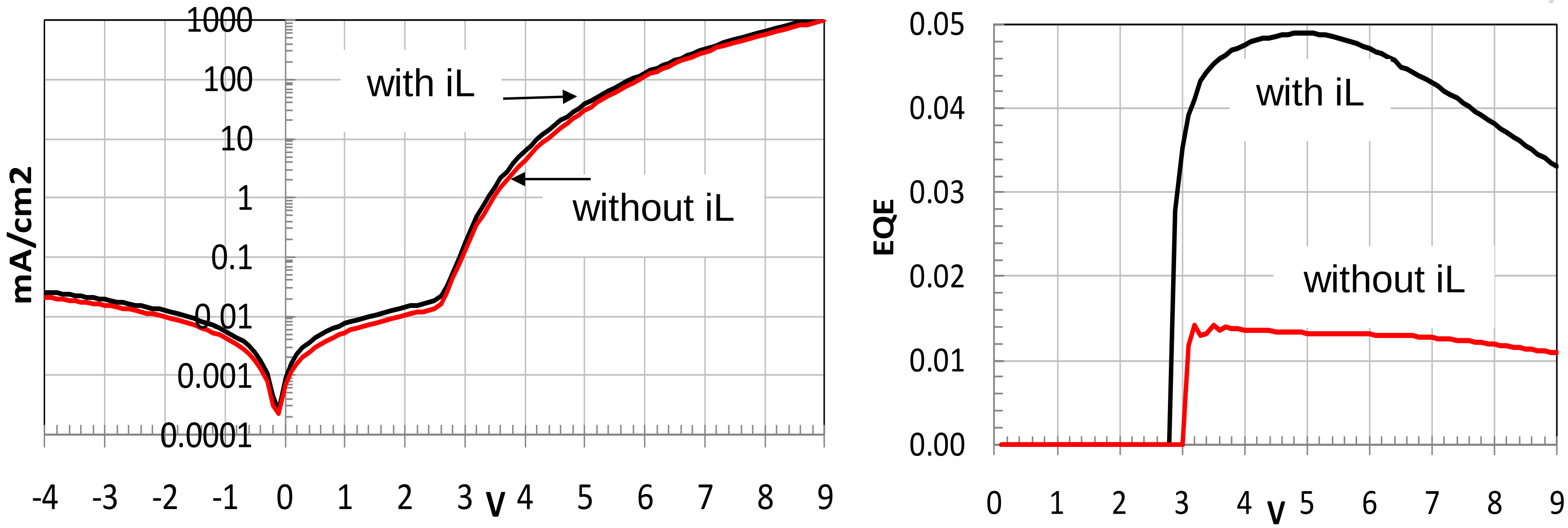
(x,y,z) ~ (0.42, 0.42, 0.16)

→ Ellipsometry and angular EL both suggest that >80% dipoles are in-plane

→ Suggests both F8 absorption and PFB emission have significant in-plane character

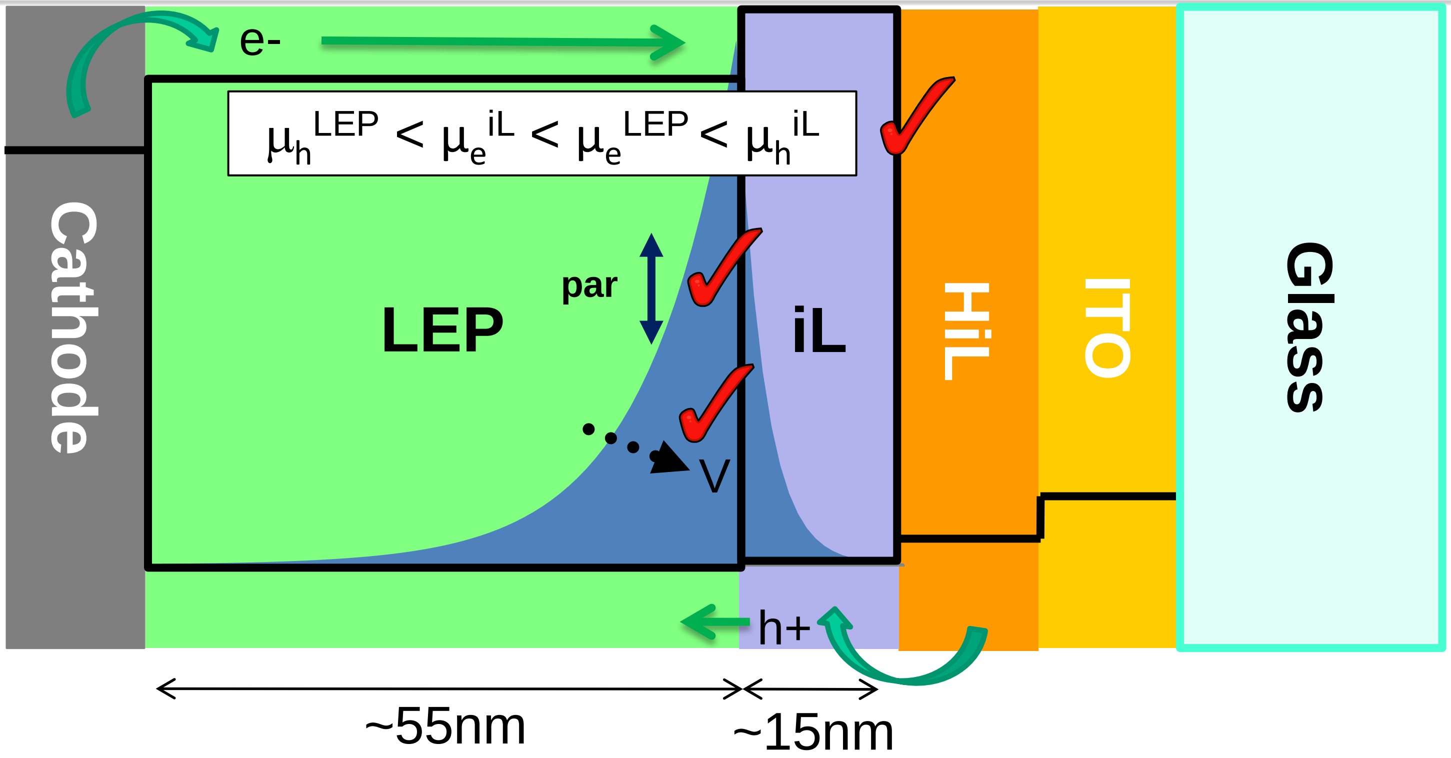
Ellipsometry method: Ramsdale and Greenham, Adv Mat 14, p212 (2002)

Model materials – Device IVL



→ 5% EQE can be achieved in optimised device

Recap – Design rules and operation



→ Simple model gives rules of thumb for material and device design

→ Measurements of mobilities, hole density, dipole orientation and PGZ in good agreement with simple model

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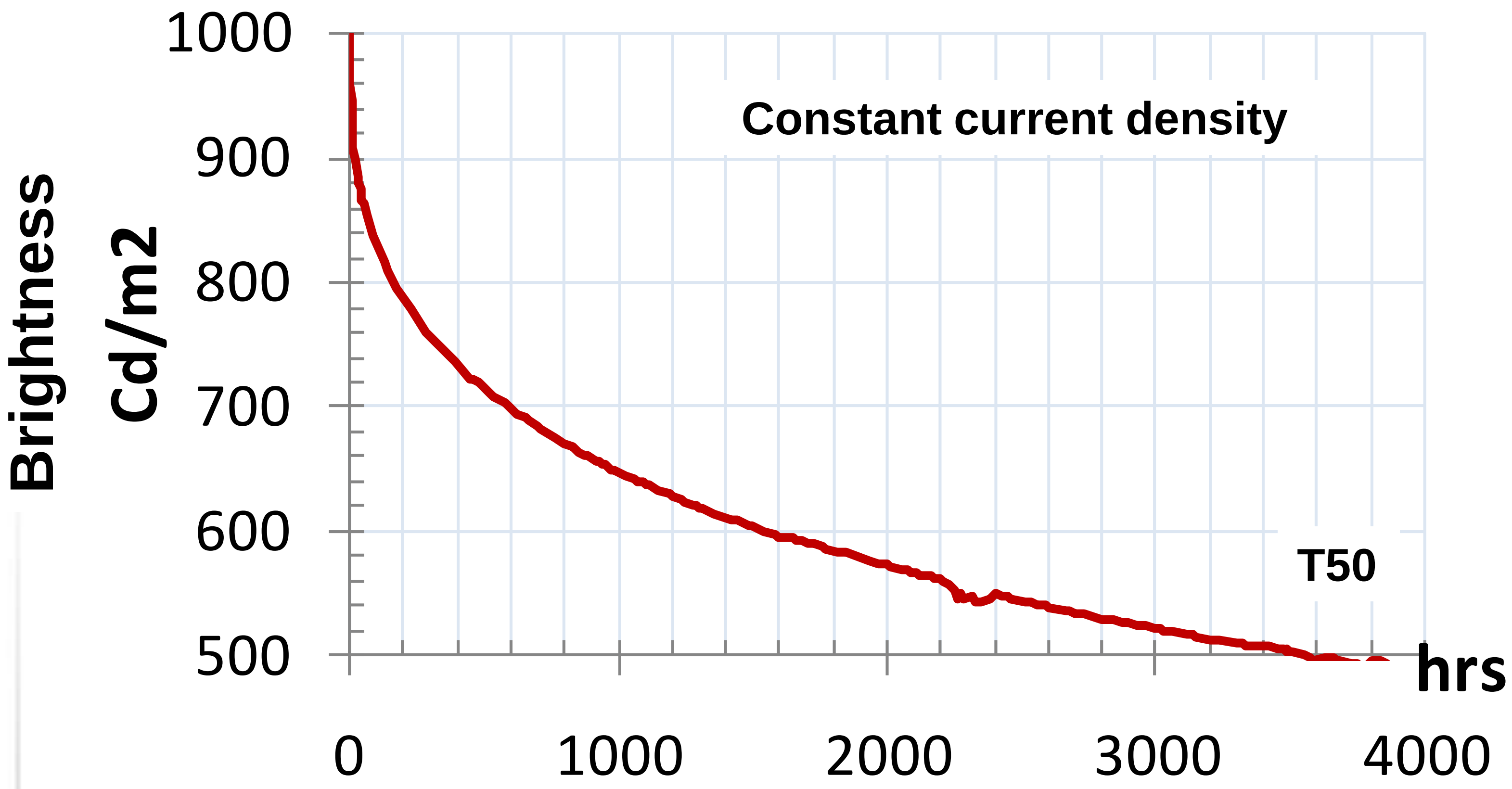
Lifetime testing of P-OLED devices

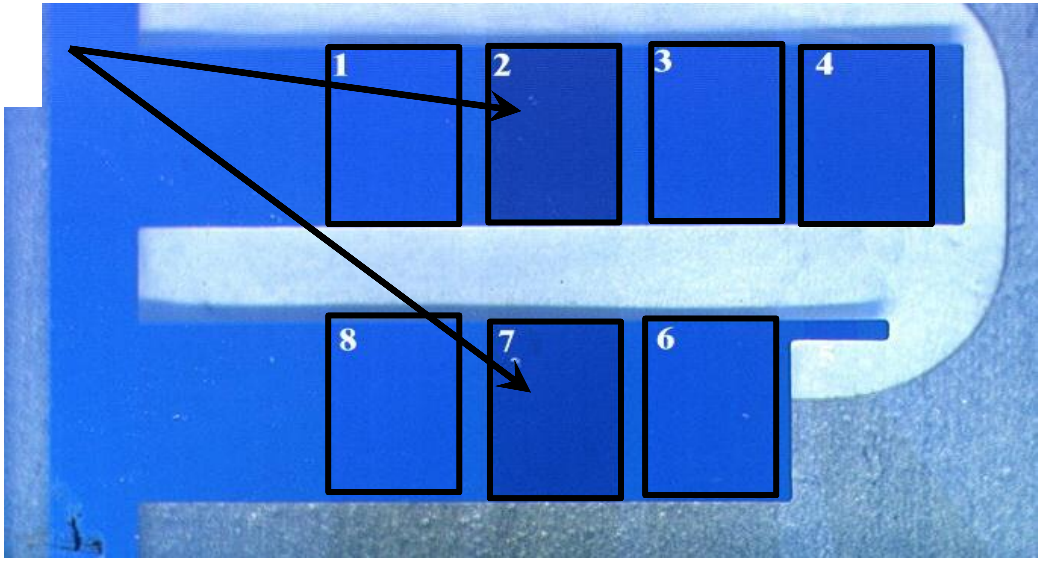


→ Key challenge for P-OLED is extending T50

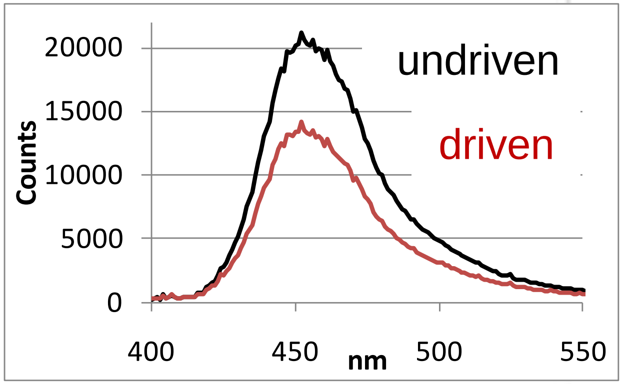
PL degradation

Device PL fluorescence

Driven pixels



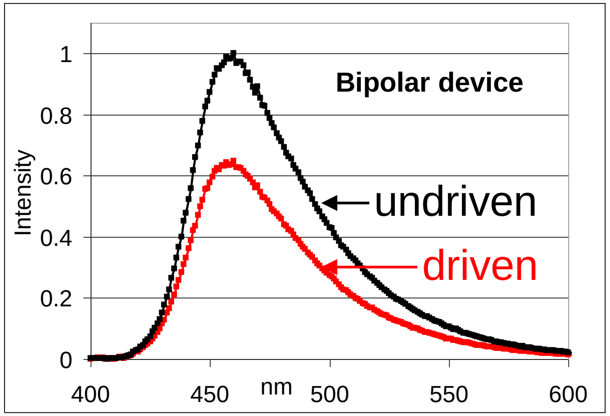
PL intensity

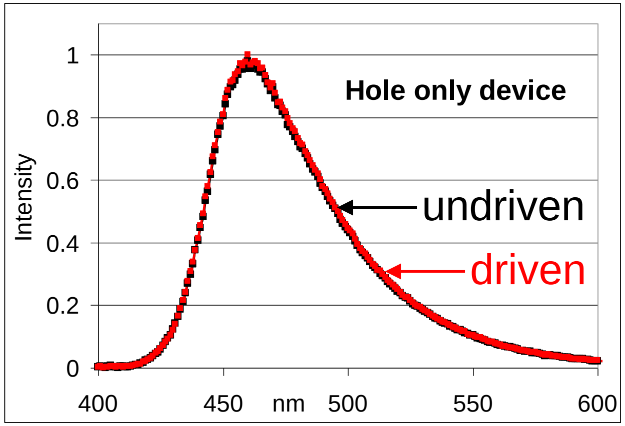


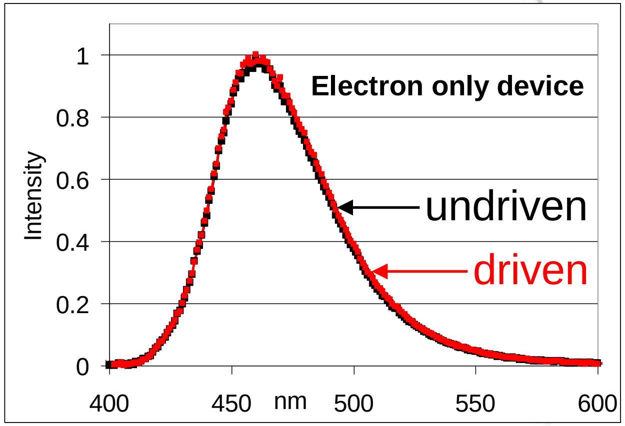
No change in colour

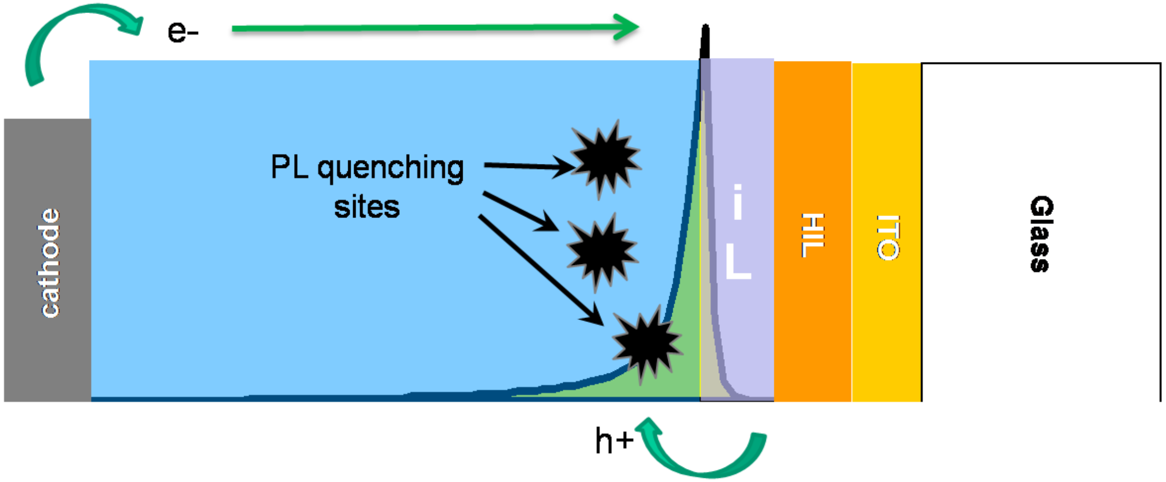
→ PL quenching site formation is dominant degradation mechanism

Cause of PL decay



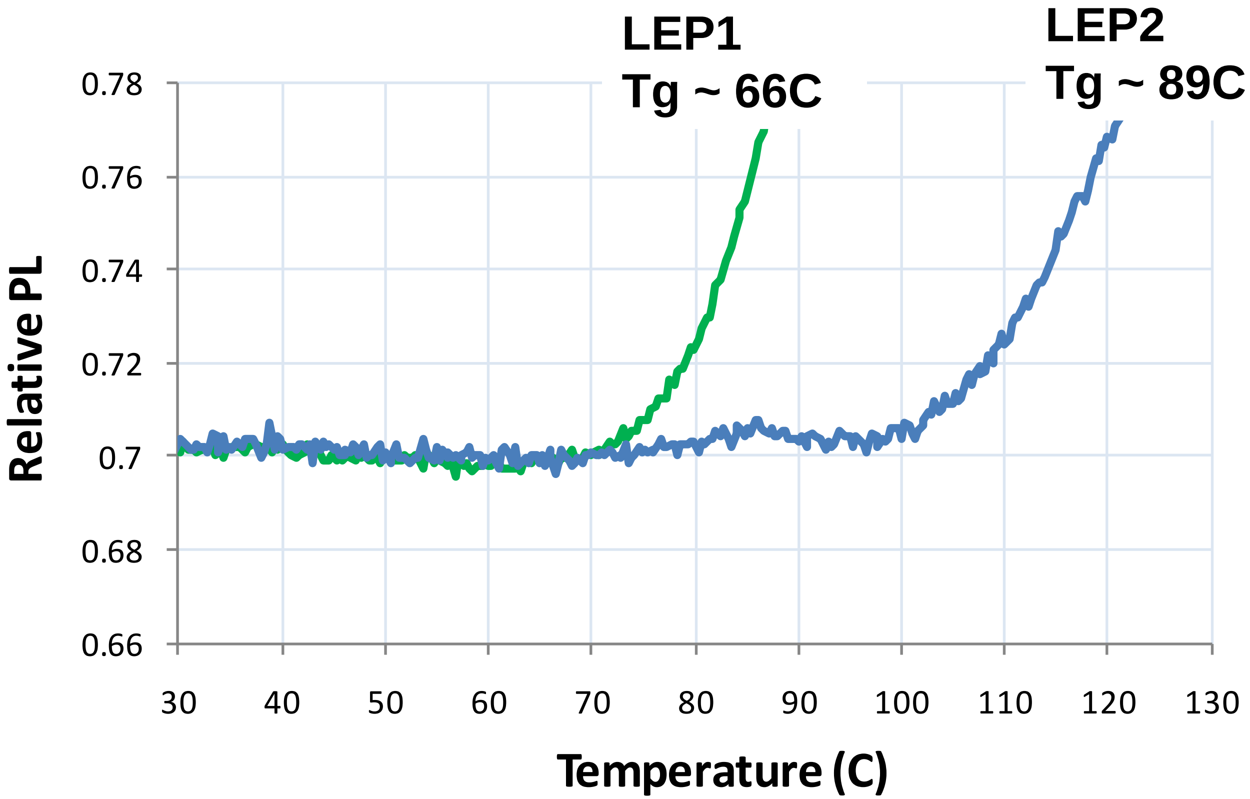






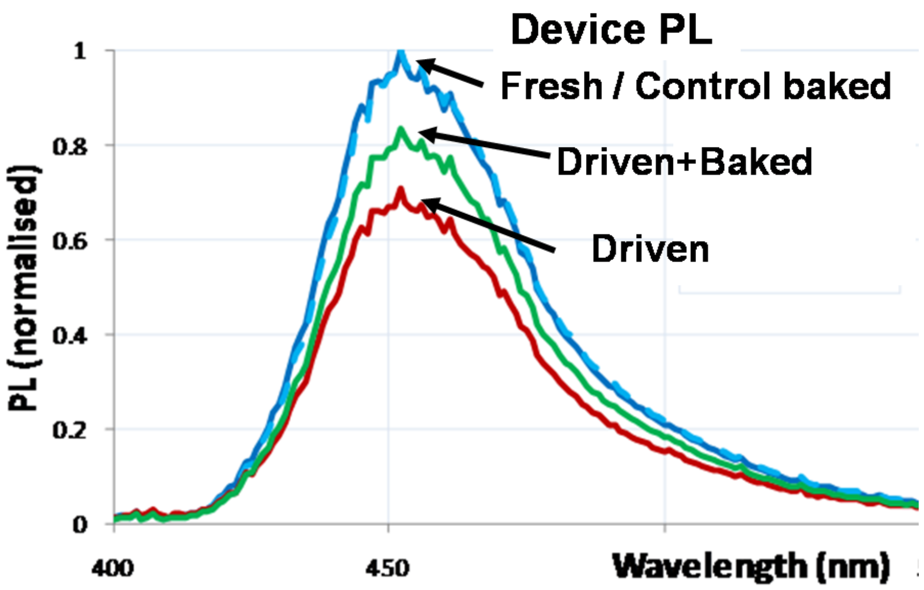
→ Excitons required to generate PL quenching sites

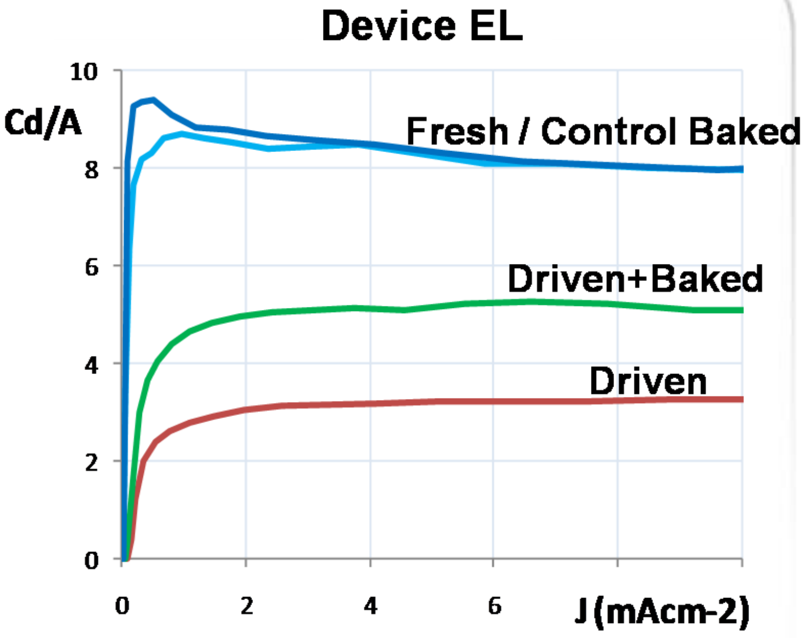
Some of PL recovers with baking!!!



→ Threshold / activation temperature for PL recovery is the LEP Tg

PL recovery matched by EL recovery

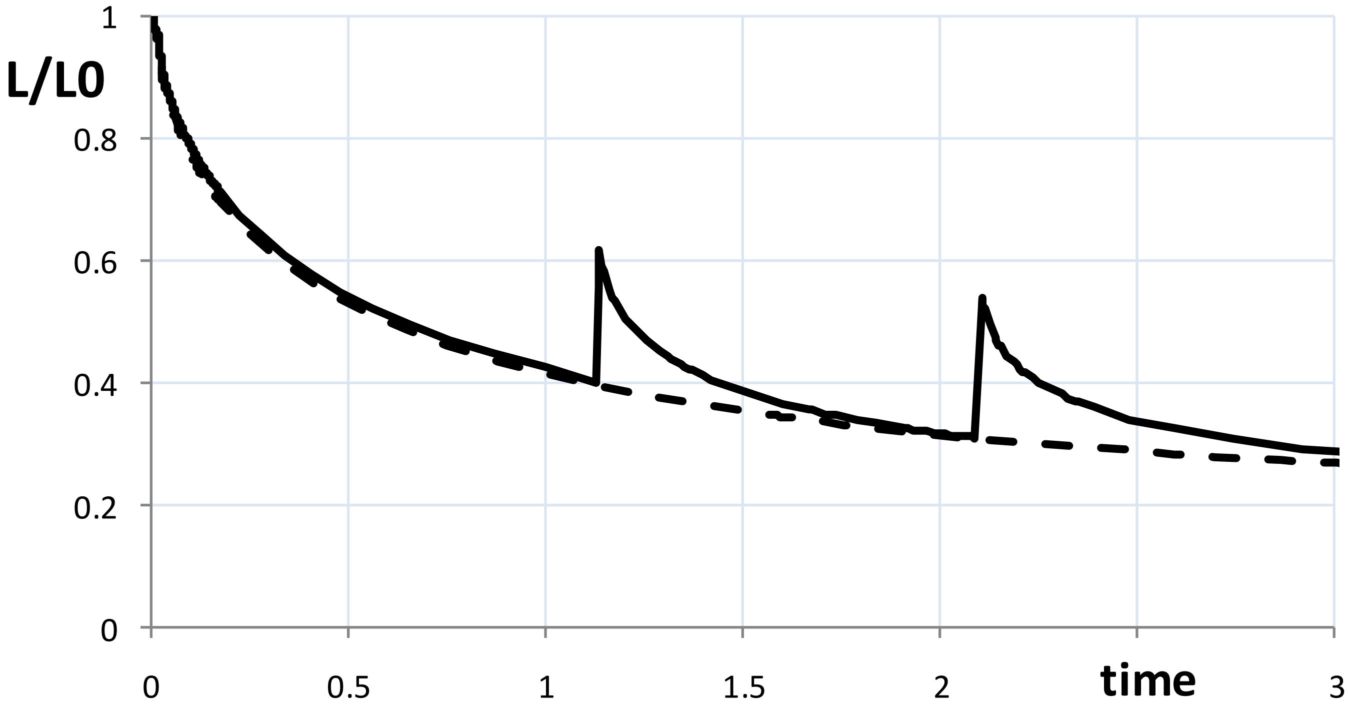




Bake: 120C 30mins

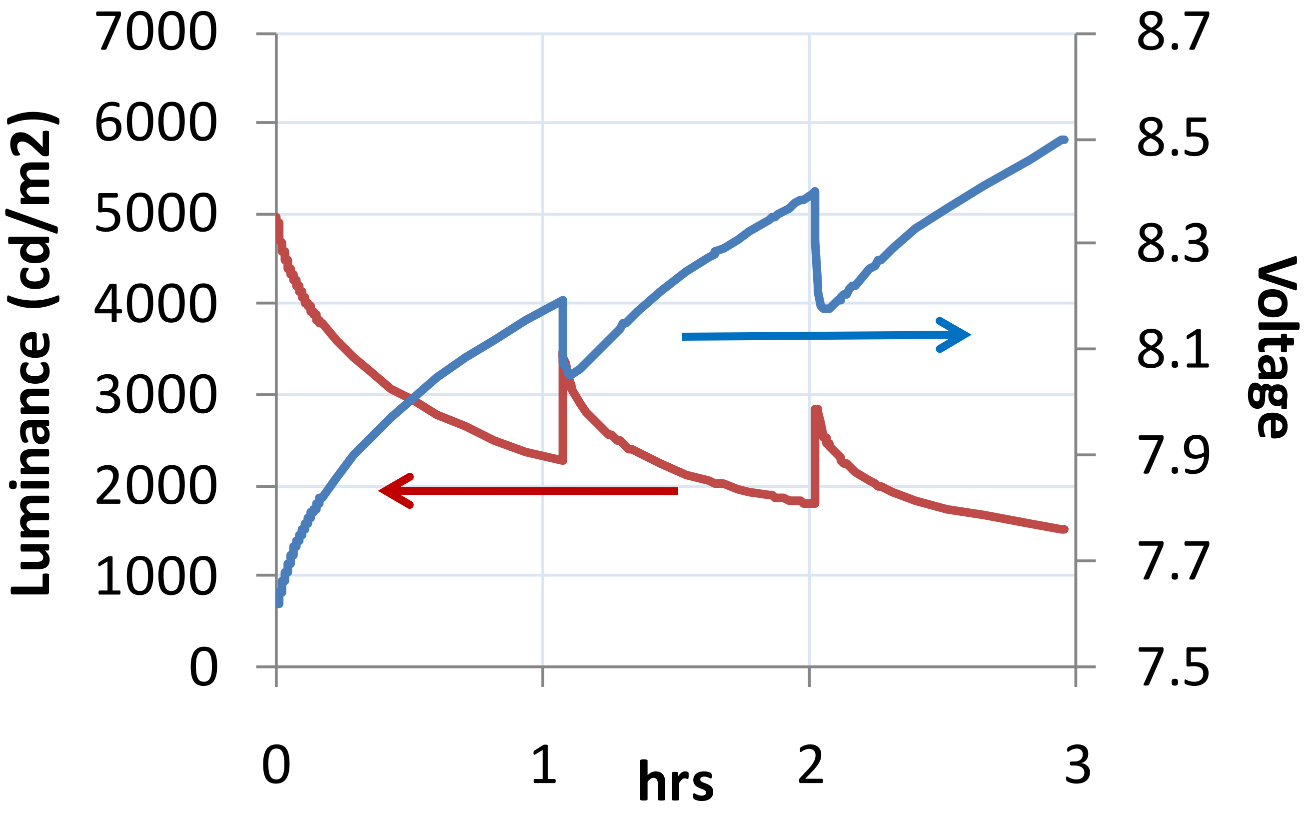
→ PL decay can be split into 'permanent' and 'recoverable' components
→ 40-50% of EL and PL decay at T50 can be recovered by baking!!

Reversible portion of degradation



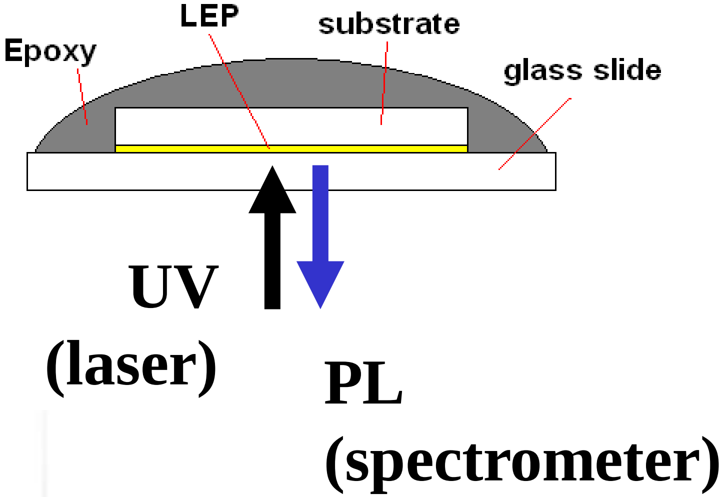
→ Recoverable component of decay can be cycled many times

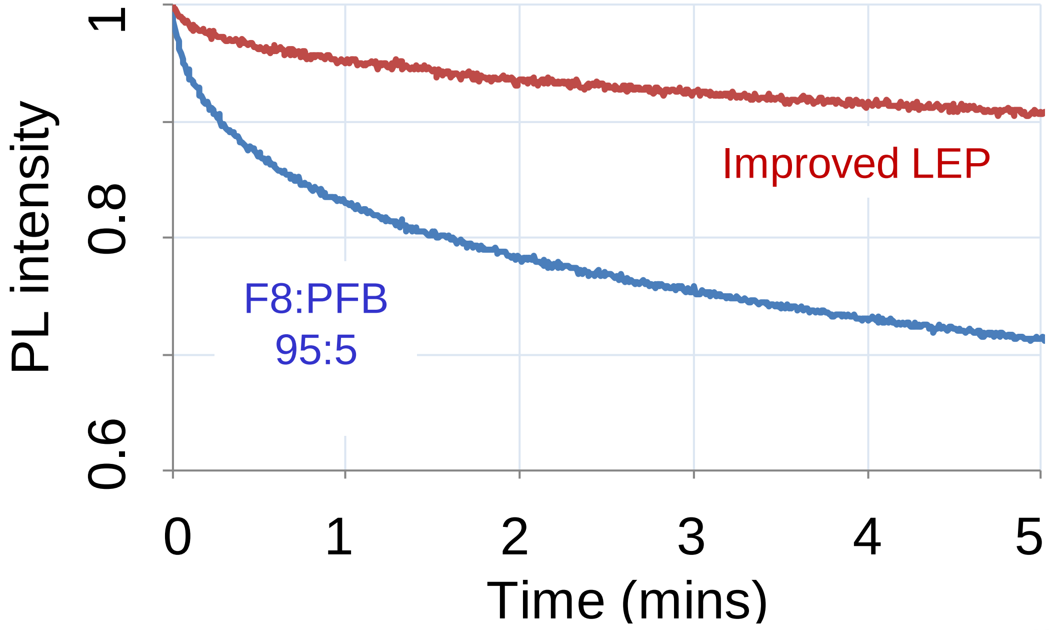
Reversibility of optical and electrical

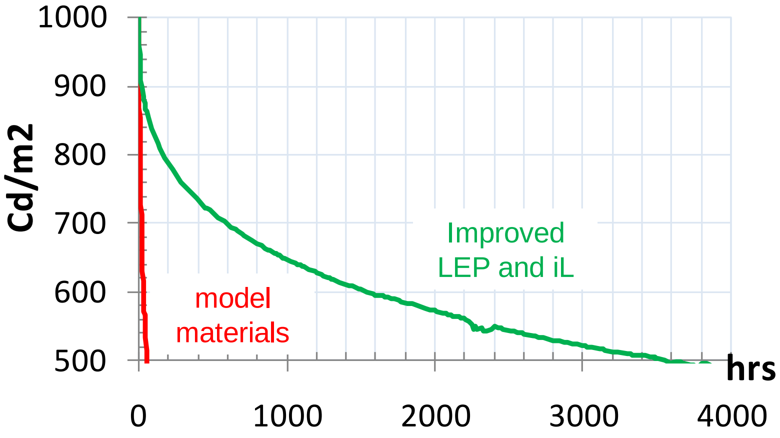


→ Reversible portion of PL degradation and ΔV have common cause

Model vs improved materials





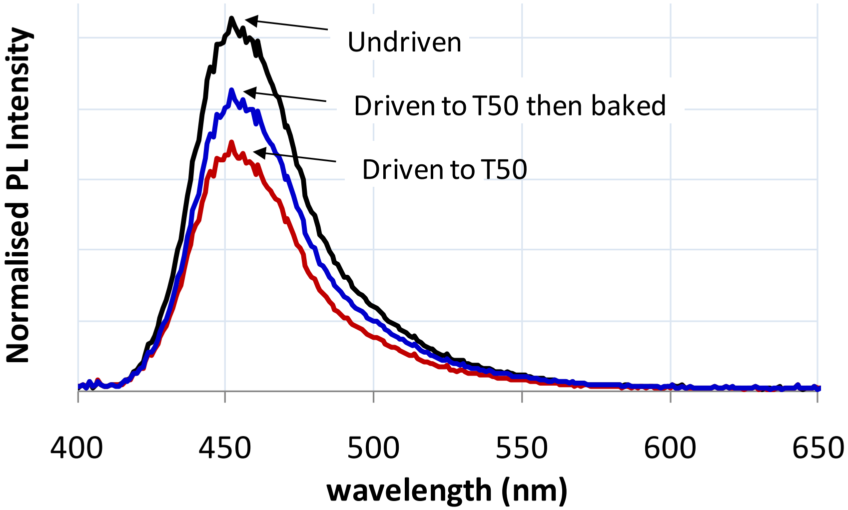


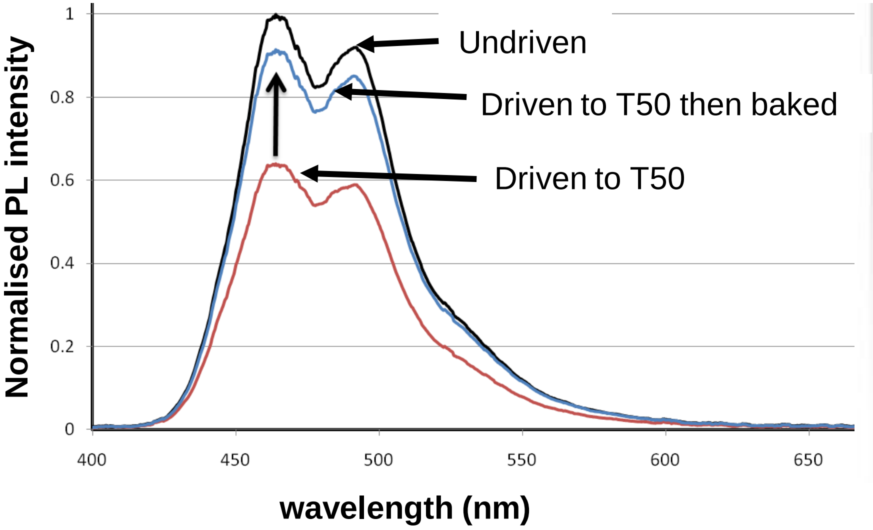
→ Improved LEP materials are more stable to excitons

Recoverable PL dominates in improved materials set

iL:LEP = model materials

iL:LEP = improved materials





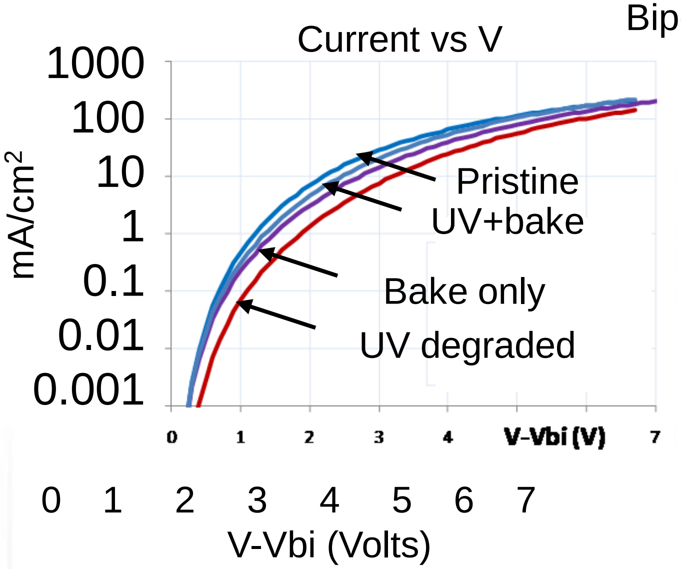
40-50% PL recovery

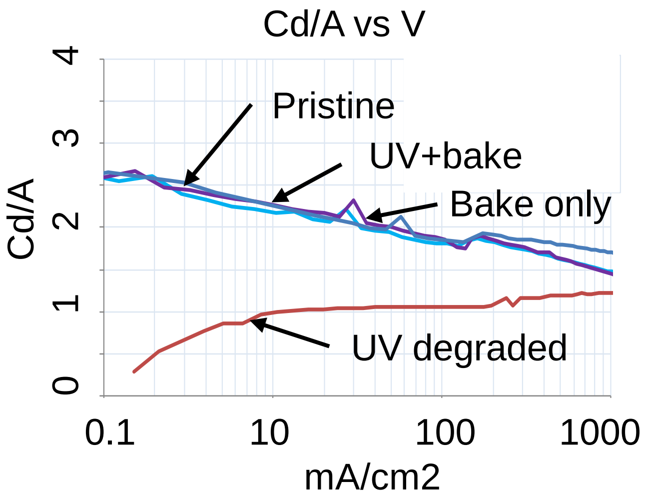
>95% PL recovery

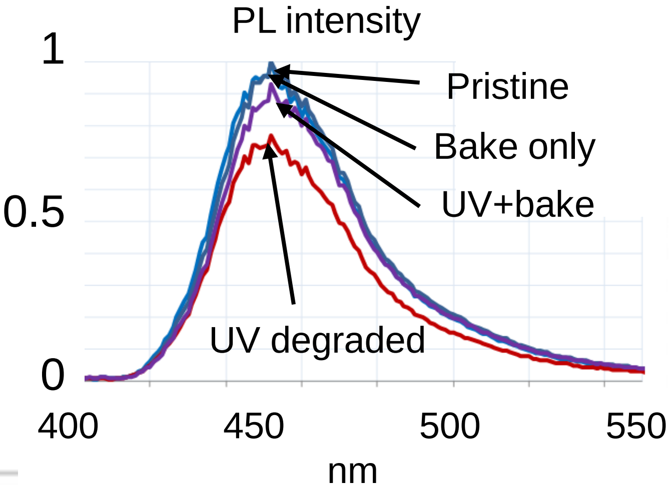
→ Tackling the recoverable PL quenching sites is the key to P-OLED stability

UV exposure as model degradation

Bipolar device – LEP only







→ Reversible PL, EL and ΔV can be induced by optical excitation alone

Summary

Simulation	• Simple models give design rules
Reality	• Good agreement with simulations
Degradation	• Reversible degradation sites caused by excitons