Catastrophic OLED failure and pathways to address it

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AOPL

Killer shorts

OLED panels that short catastrophically:

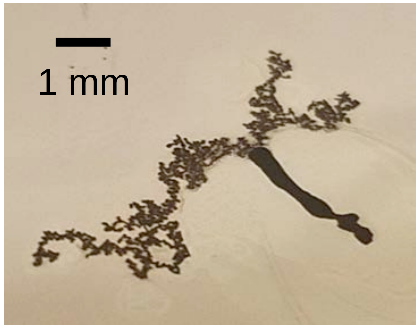
- Decrease manufacturing yield
- Increase warranty expenses
- Decrease customer satisfaction

Highly localized current flow → heating & irreversible damage

Origin of shorts presently unknown

To solve this problem:

- Identify incipient shorts early & determine physical origin
- Model their evolution/growth toward catastrophe
- Predict failure & develop mitigation strategies



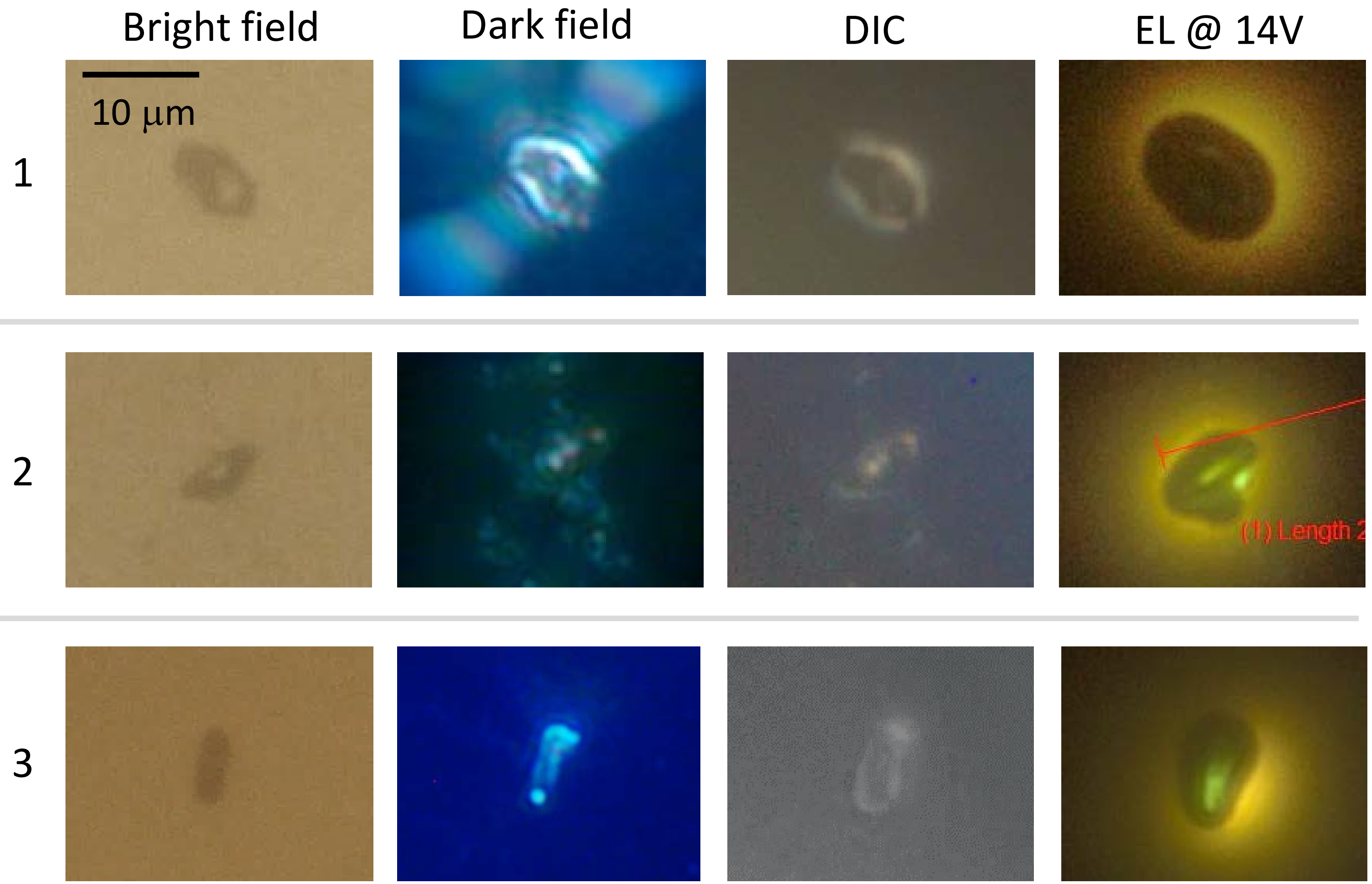
Residue of a short

Hot Spots & Bright Spots

Typic

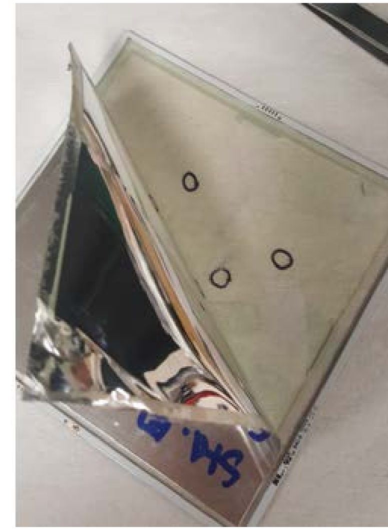
Bright spot microscopy

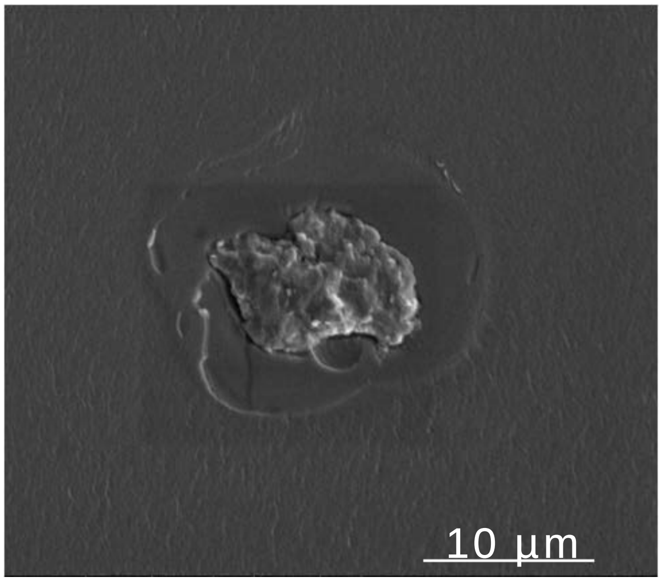
- Bright spots associated with visible inhomogeneities
- Hot spots not easily visible in microscopy



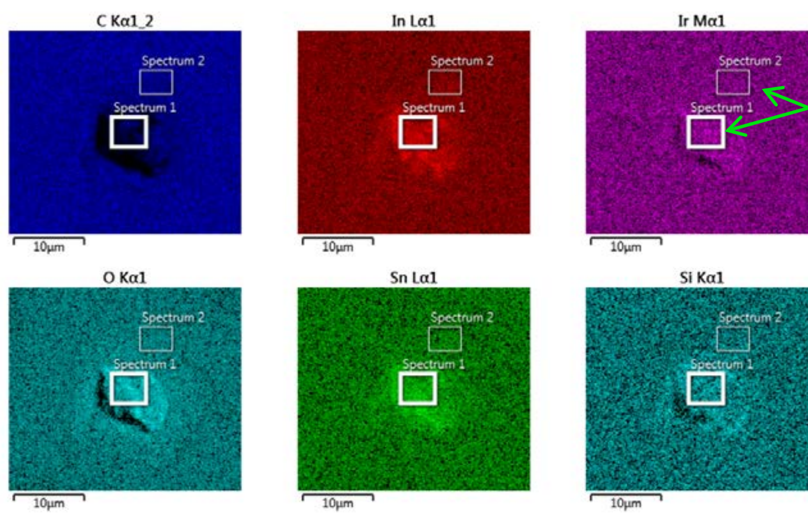
Bright spot origin: ITO agglomerations

- Improved panel deconstruction
  → delamination





SEM image of bright spot



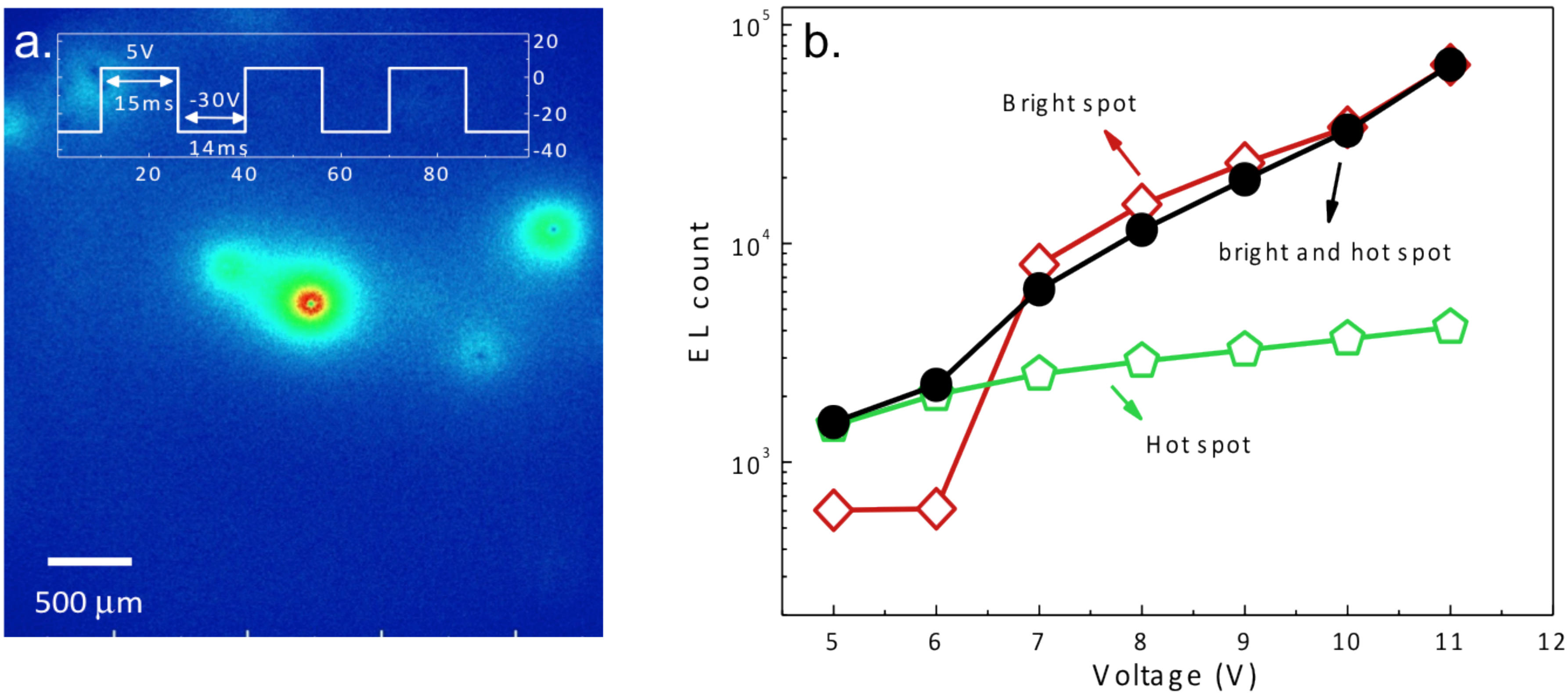
	Spectrum 1 Wt%	σ	Spectrum 2 Wt%	σ
C	42.4	0.7	75.7	0.7
In	35.0	0.7	16.9	0.7
O	15.2	0.5	6.9	0.4
Sn	6.1	0.8		
Si	0.6	0.1	0.5	0.1
Br	0.6	0.2		

EDS elemental mapping

Bright spots are consistently ITO-rich

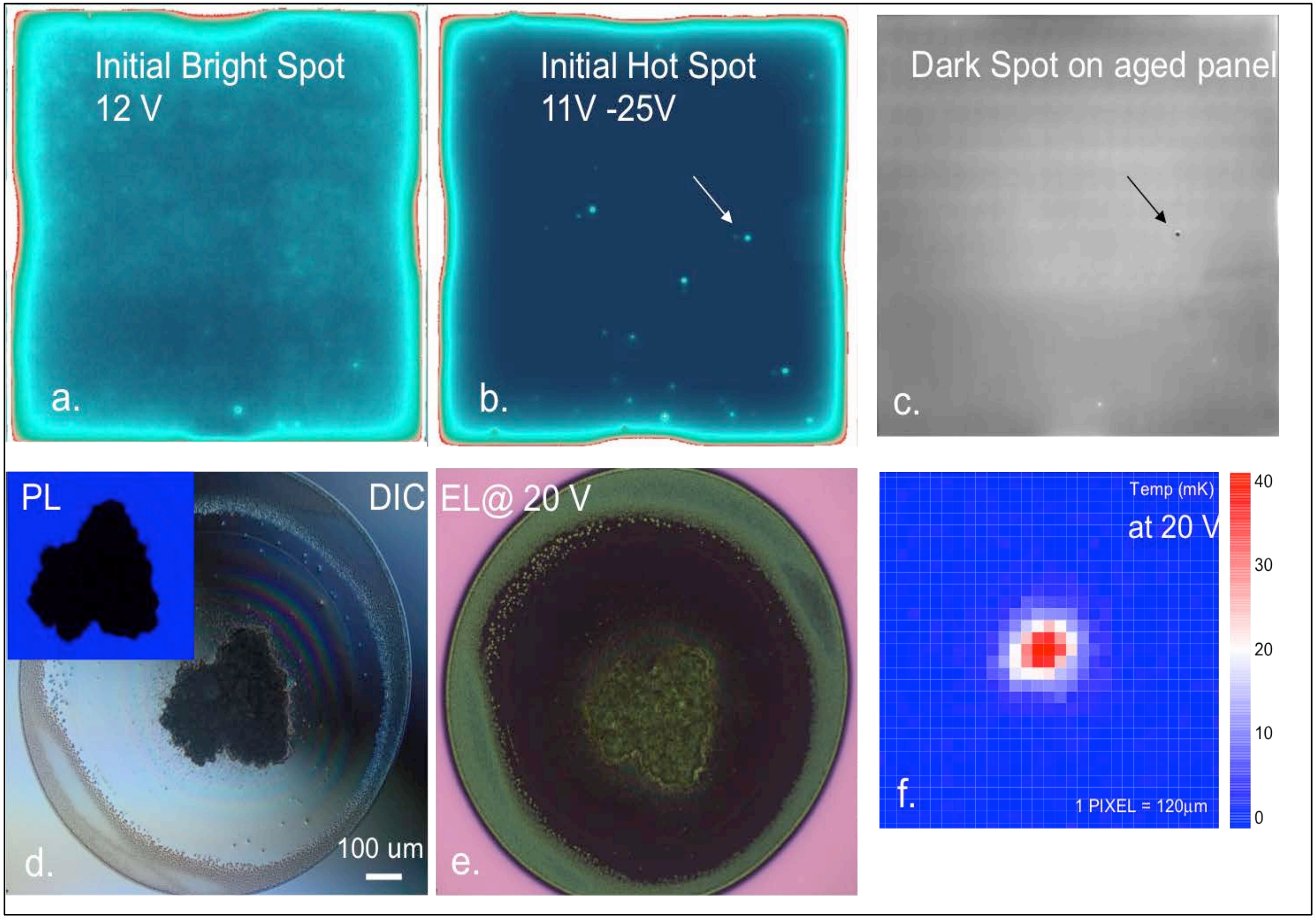
Hot Spot Fine Structure

- Characteristic 'volcano' structure of hot spots
- Hot spots exhibit more Ohmic EL vs. voltage → local shunts
- Hot spots often cluster



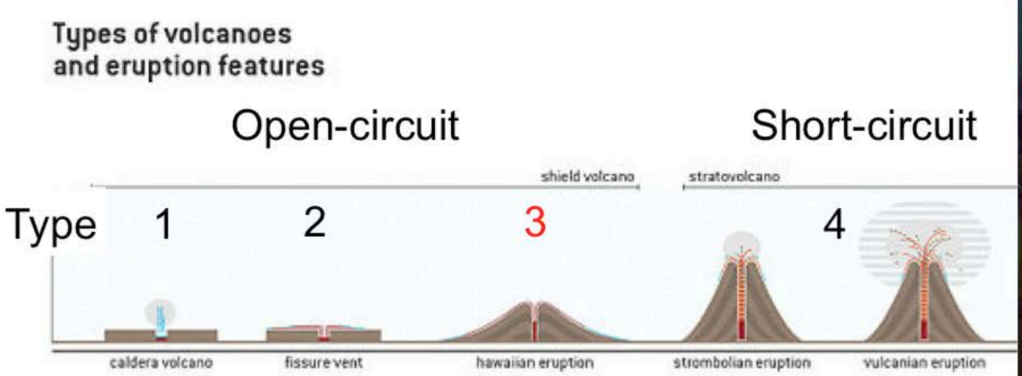
Hot spot link to shorts

- Dark spots emerge from original hot spots

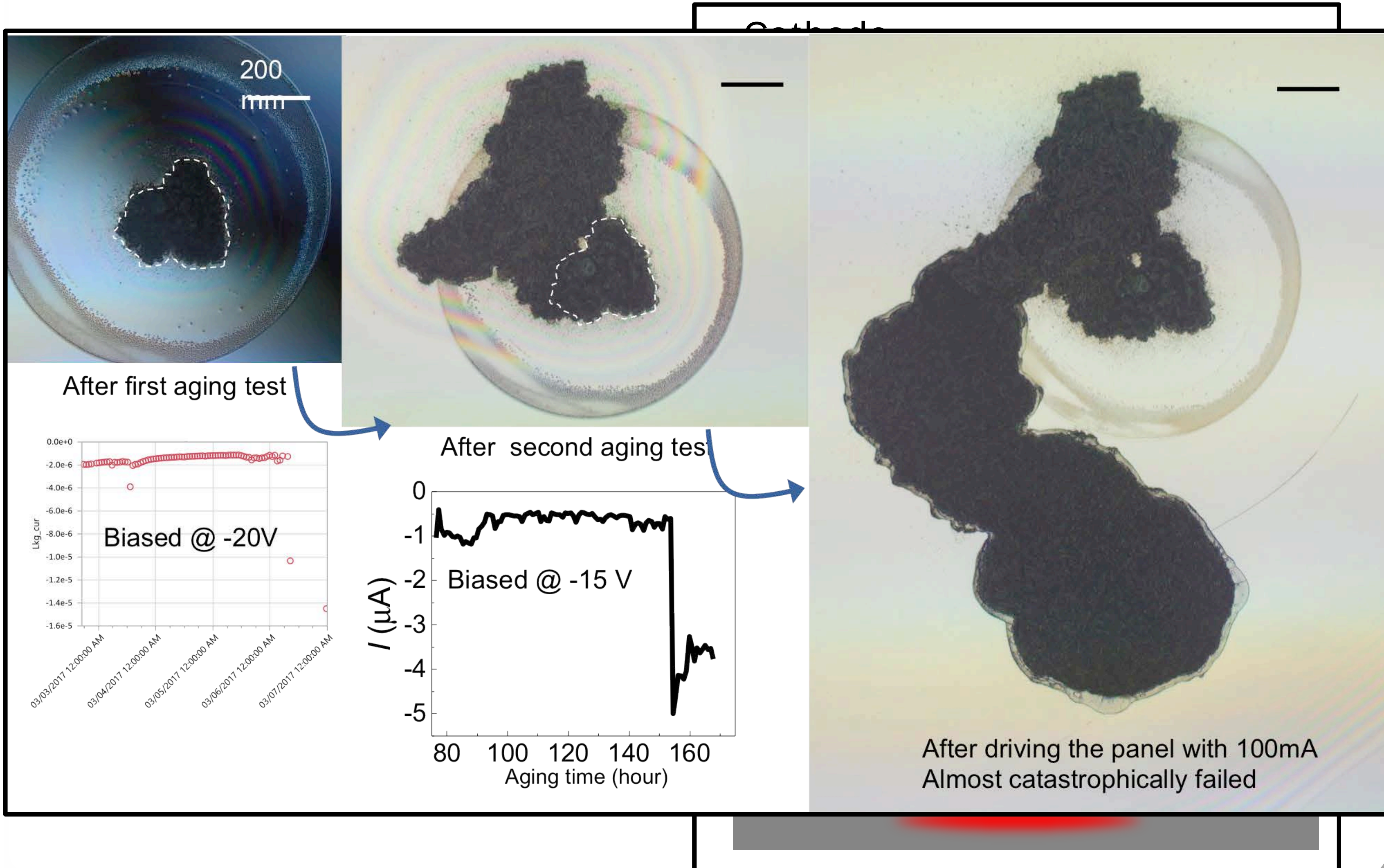


Connecting to catastrophic failure

- Early connection to catastrophic short failure (fractal-like growth of shorts)
- Volcano analog of short growth



Emerging model of short growth



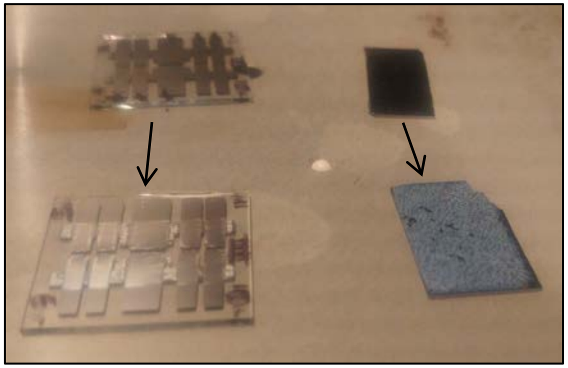
The need for OLED thermal stability

- Automotive applications
  - Hot cars --> 85°C +
- Solid-state lighting
  - Panels operate at elevated temperature
  - Thermal stability closely connected to catastrophic failure
  - Intrinsic OLED lifetime ~ exp($-E_A/kT$)

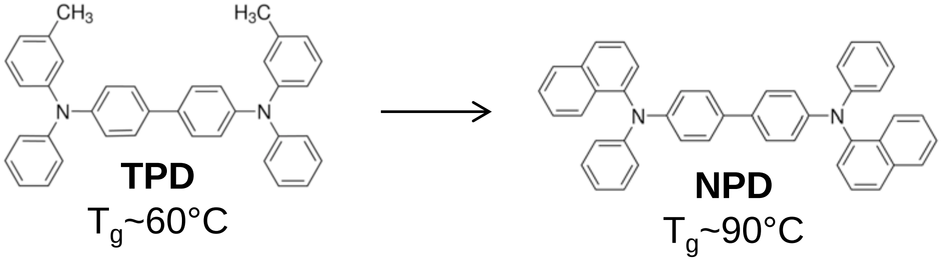
OSRAM

Current status for small molecule OLEDs

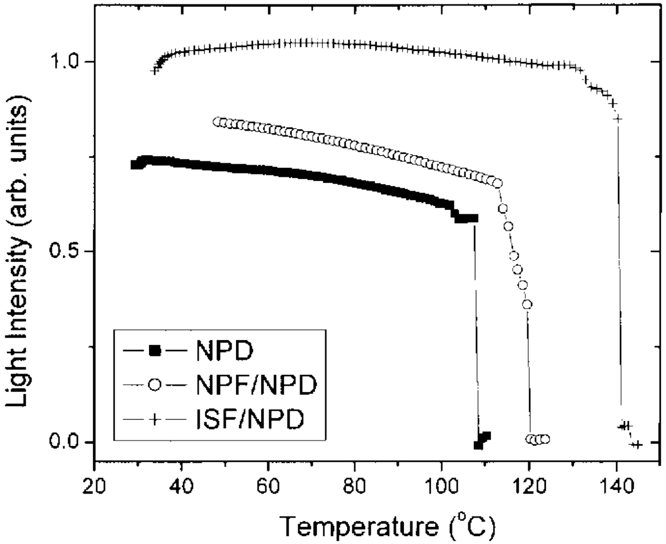
- Elevated temperature causes:
  - Crystallization/morphological changes
  - Expansion
  - Melting and/or vaporization



- Existing strategies to improve thermal stability:
  - New molecules with increased T_g:



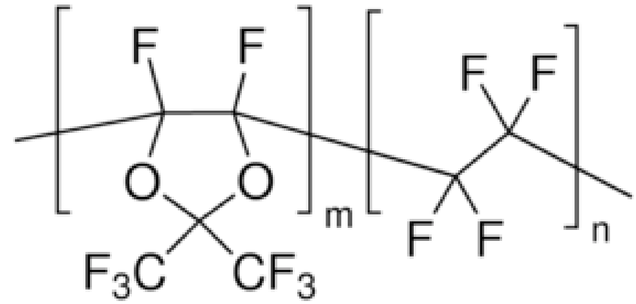
  - Additives:
    - Co-deposition of high T_g small molecules
    - Co-deposition of inorganics (e.g. LiF)



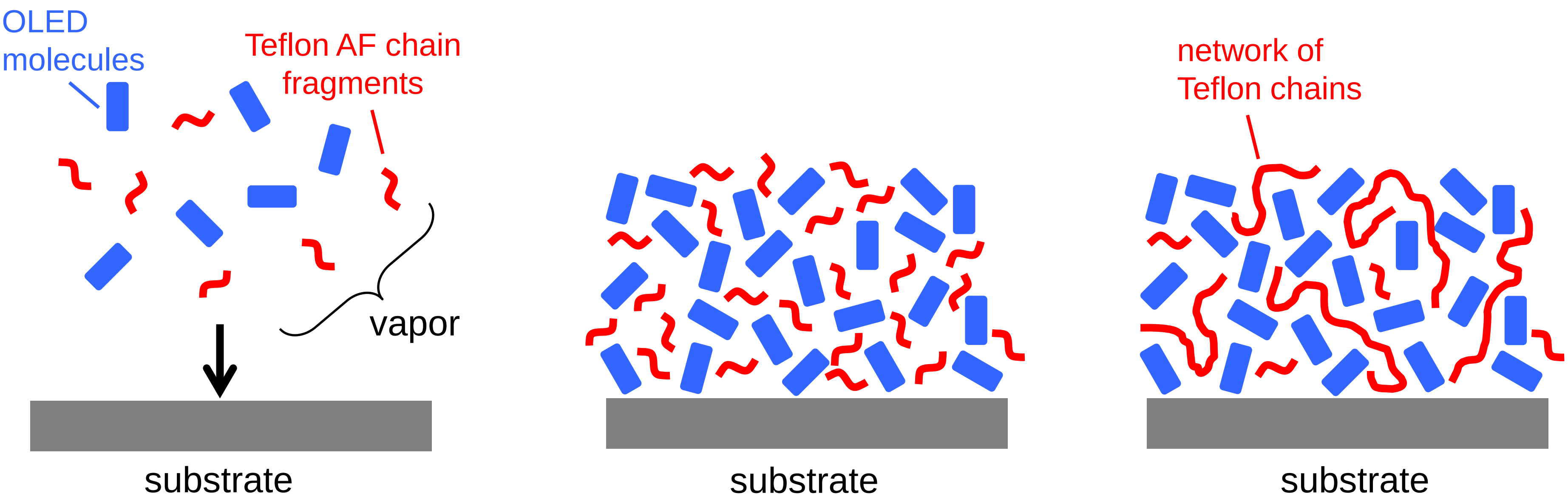
D.E. Loy, *et. al. Adv. Func. Mater*. **12**, 245 (2002)

The additive route: Teflon AF

- Co-evaporate Teflon AF w/ small molecules

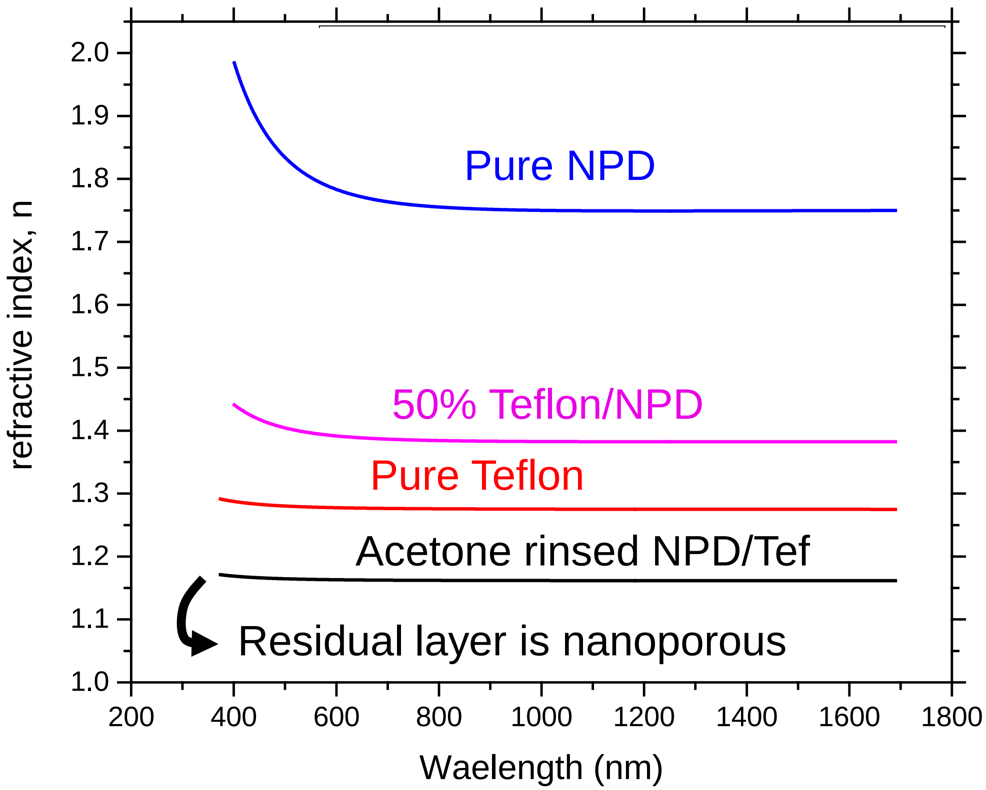


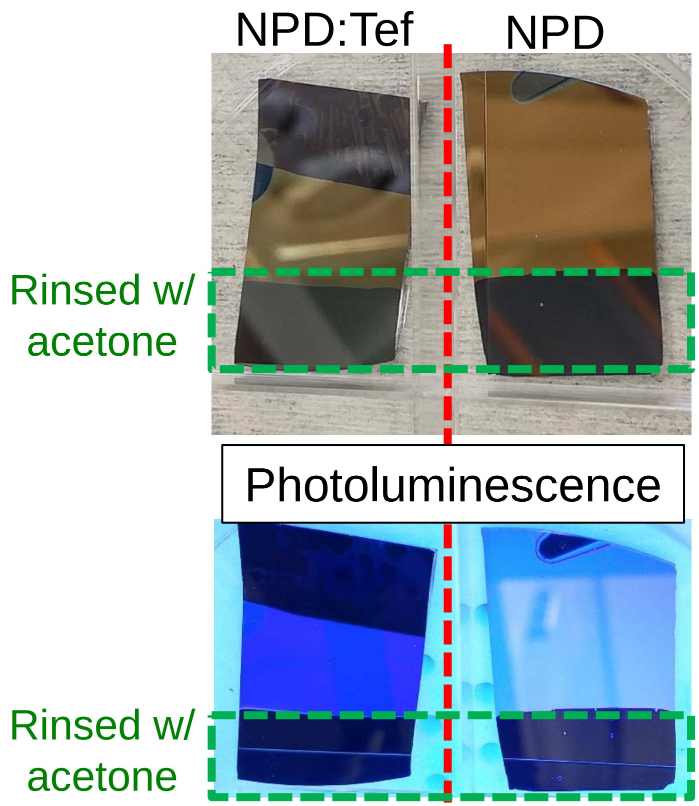
1. Evaporation   2. Deposition   3. Re-polymerization



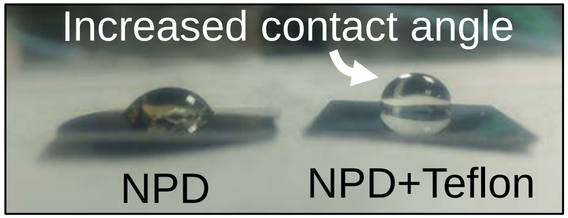
Evidence for polymer network

- Ellipsometry of Teflon/NPD films → Dissolve out NPD



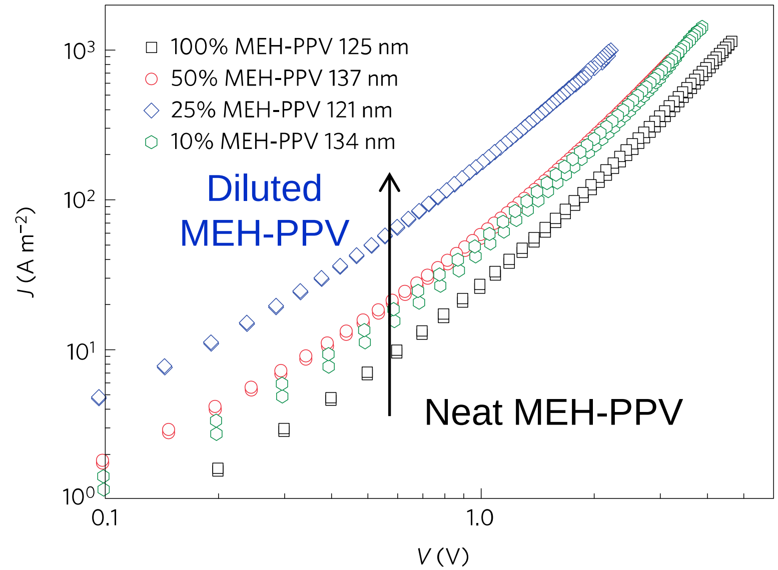


Nanoporous Teflon network must exist

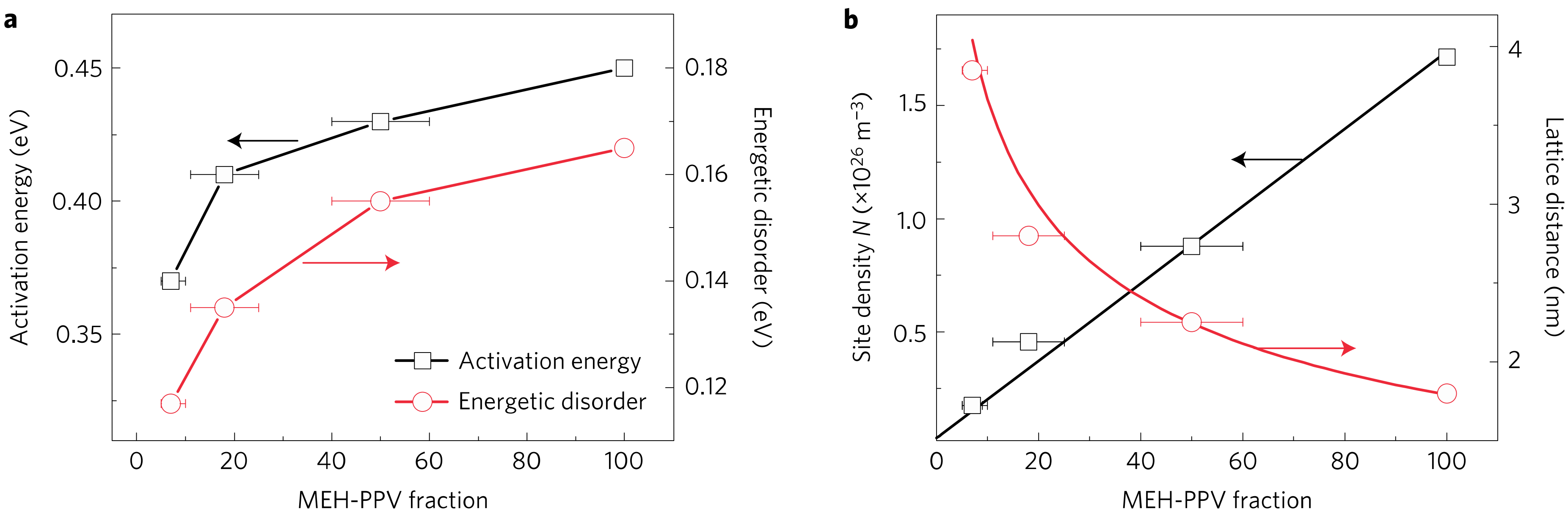


Dilute organic semiconductors

- Dilution in insulating matrix can improve trap-limited transport
  - $J \sim \left(\frac{N}{N_t}\right)^m$
  - Example: hole-only MEH-PPV / PVK

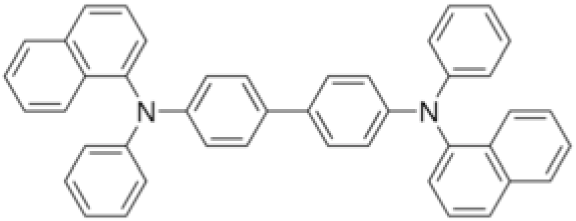


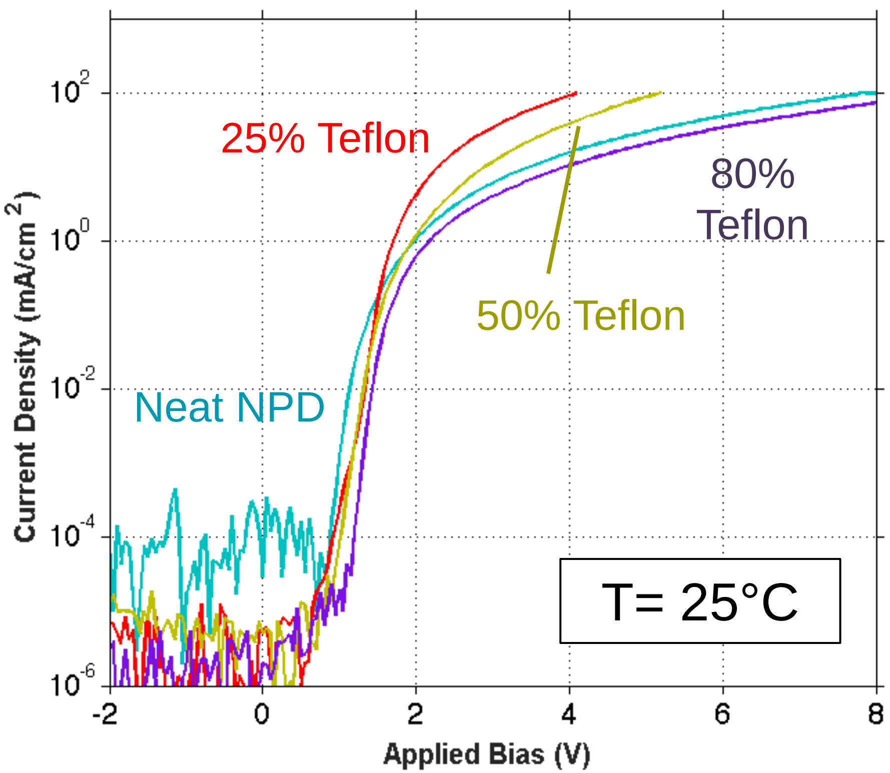
D. Abbaszadeh, *et. al*. *Nat. Mater*. **15**, 628 (2016)

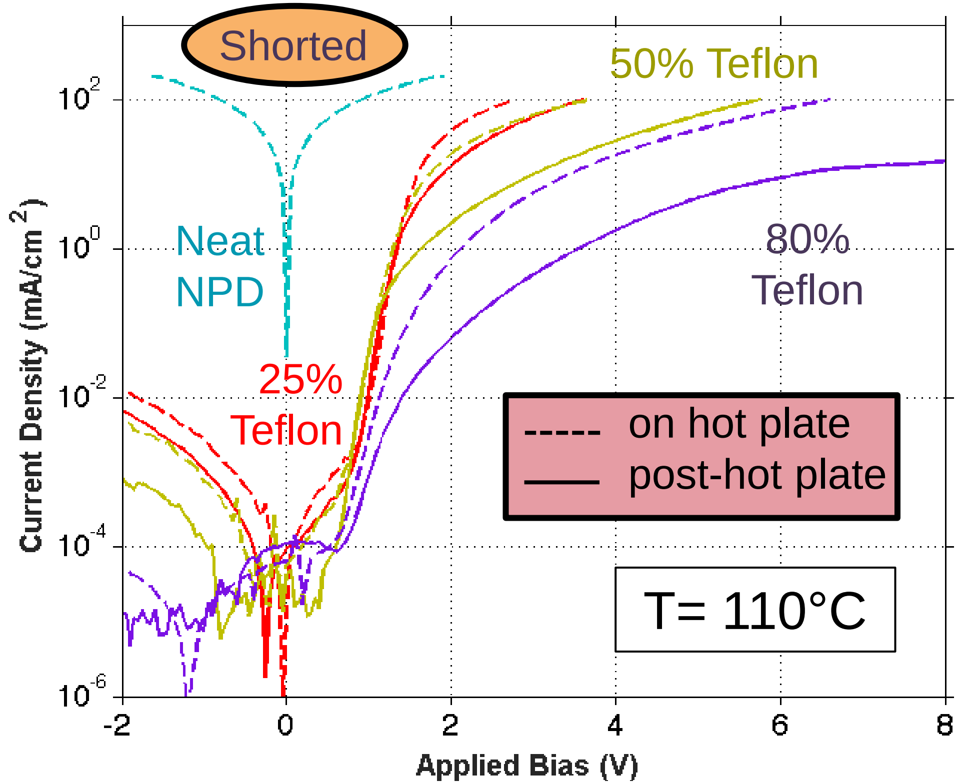


NPD + Teflon AF

- Hole-only devices: ITO/NPD (60 nm)/Al
  - $T_g \sim 95°C$
- Measured **on** and **post**-hot plate







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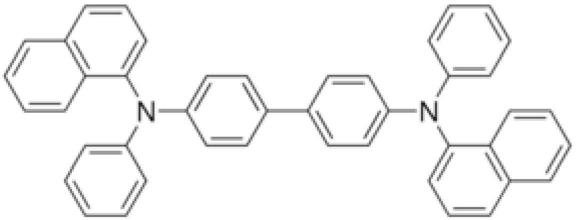

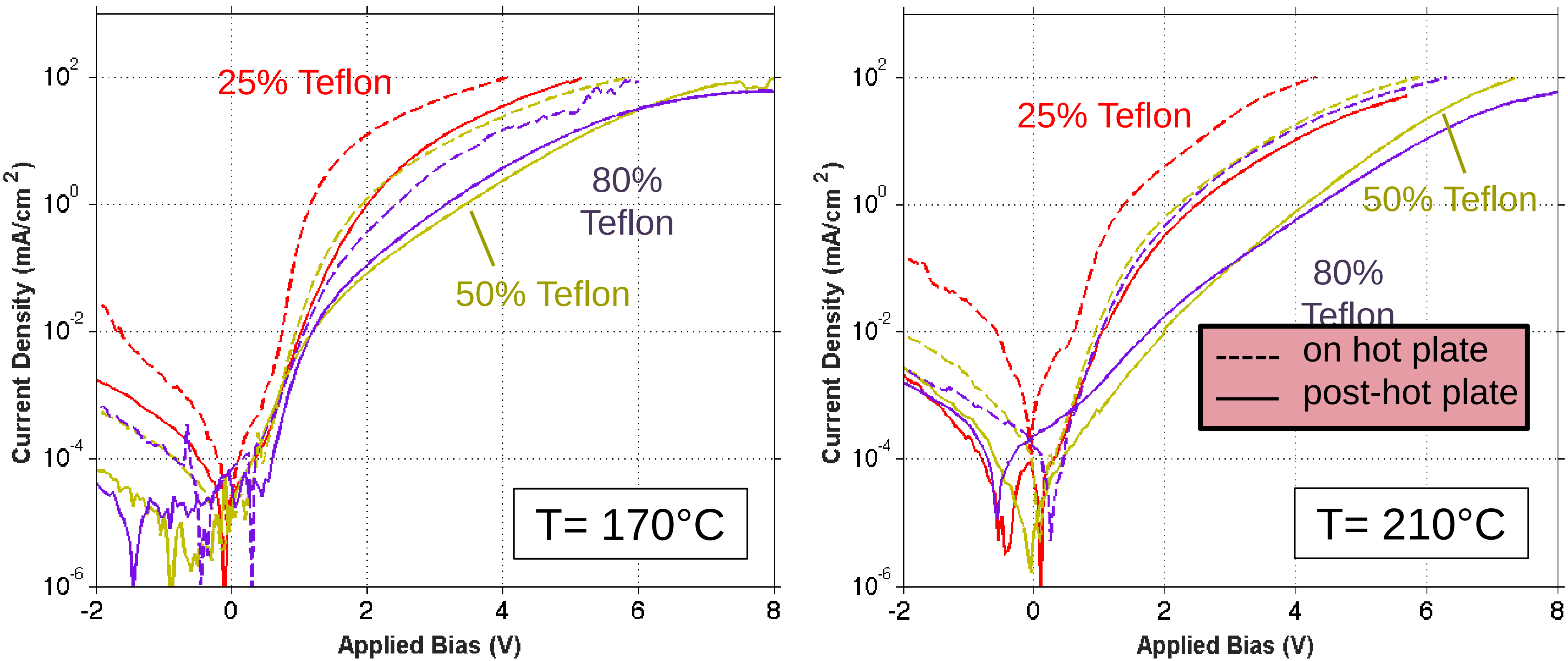

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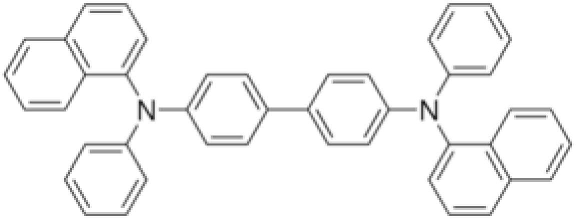
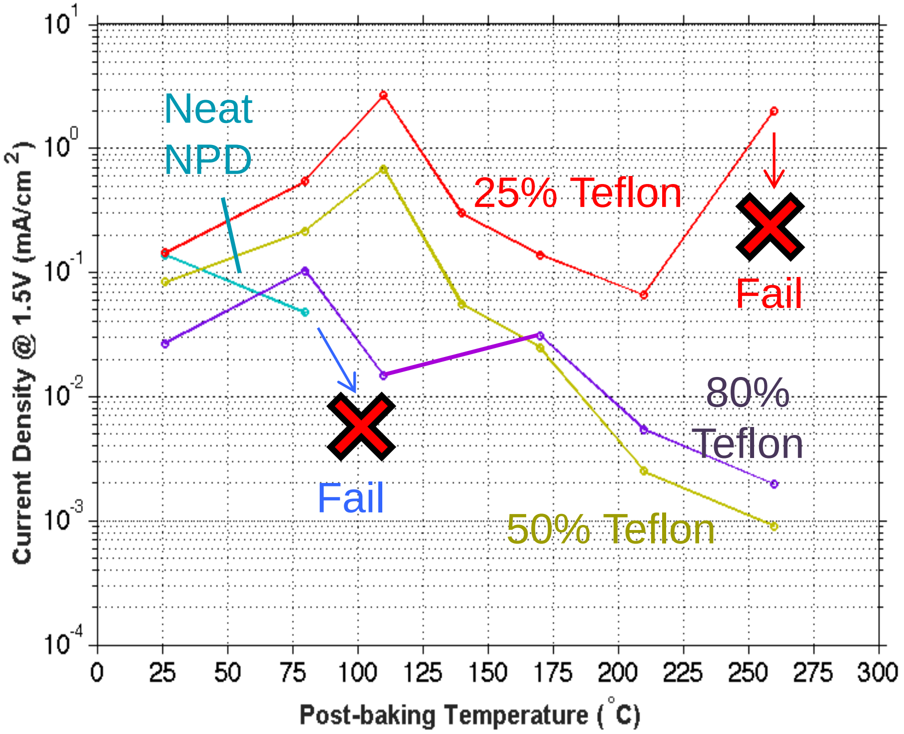
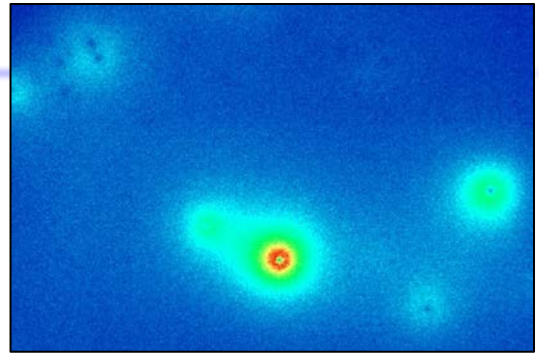


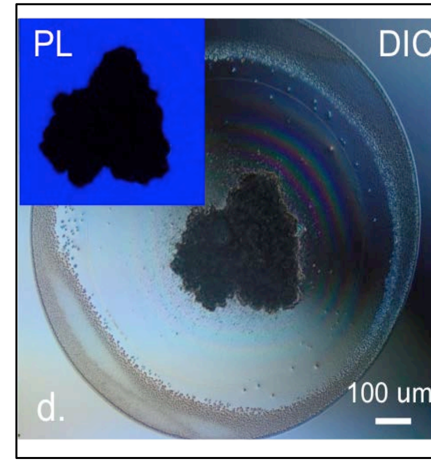


Summary

Hole-only device (50 nm)	Voltage at 10 mA/cm² (25°C)	"Shorted" Temp
Neat NPD	3.4 V	110°C
25% NPD/Teflon	2.2 V	250°C
50% NPD/Teflon	2.7 V	>260°C
80% NPD/Teflon	4.0 V	>260°C

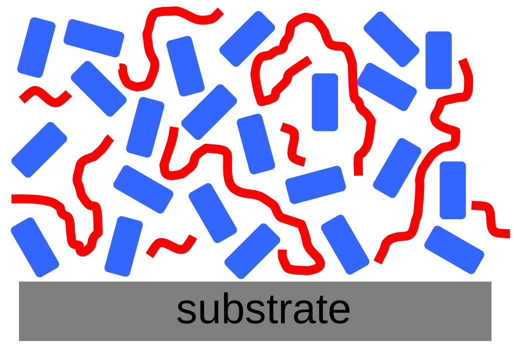
Conclusions





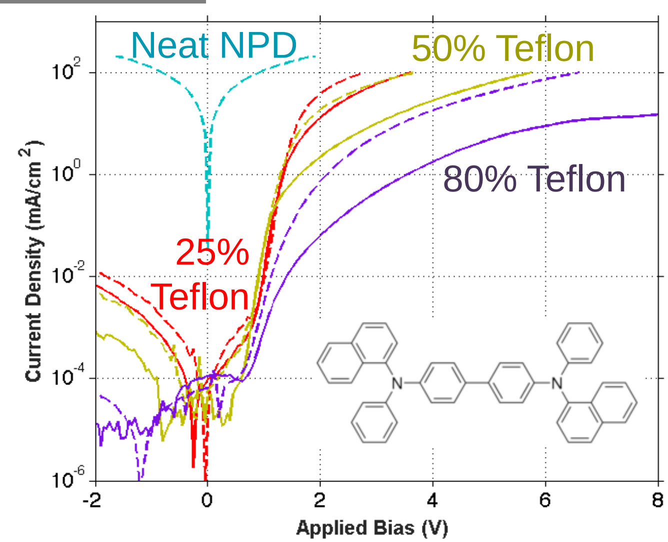
OLED panel failure

- Bright spots & Hot spots
- Temp. selective EL imaging
- Hot spots >> short precursors
- Nano >> Micro >> Macroshort



Thermal stability via Teflon

- Co-evap w/ HTLs
- Repolym to nanoscale Teflon network
- Improves injection & bulk transport
- >100°C thermal stability increase



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