Multi-scale Electrical Inhomogeneity in OLEDs

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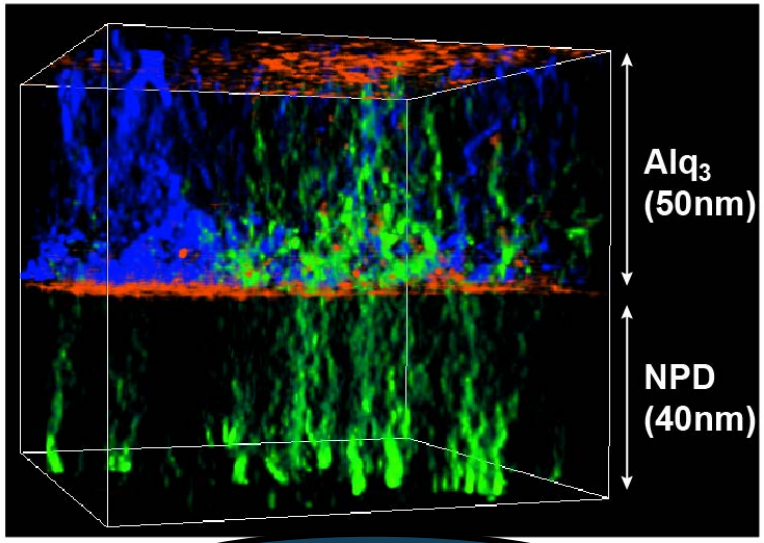

Nanoscale

Macroscale

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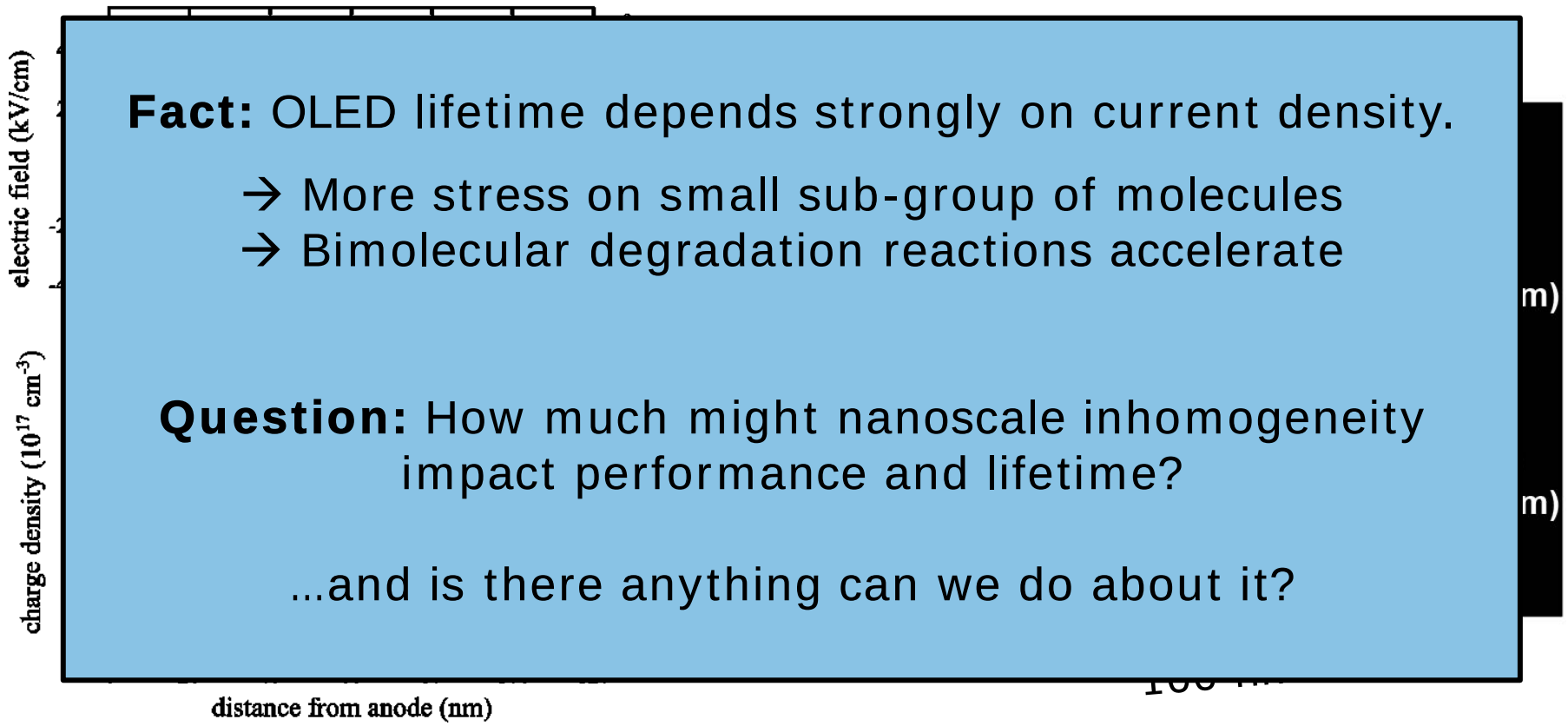
At the nanoscale…

Old picture: OLEDs are 1D devices

New picture: OLEDs are highly 3D at nanoscale



Fact: OLED lifetime depends strongly on current density.

→ More stress on small sub-group of molecules
→ Bimolecular degradation reactions accelerate

Question: How much might nanoscale inhomogeneity impact performance and lifetime?

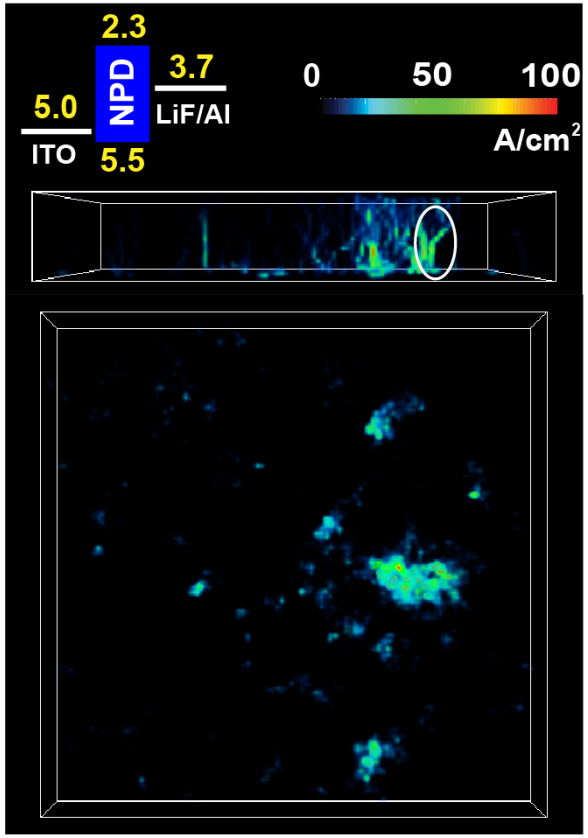
…and is there anything can we do about it?

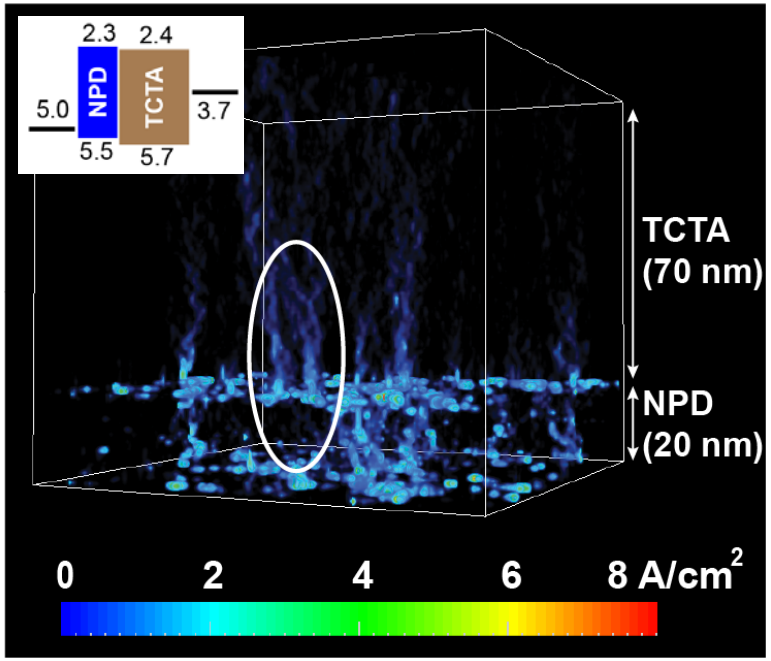
Ruhstaller et. al., JAP, 89, 4575 (2001)

Shen et. al., Phys. Rev. Appl. **4**, 05417 (2015)

Model observations

- Current filaments due to on-site energetic disorder
- Tend to initiate at electrode/organic interfaces

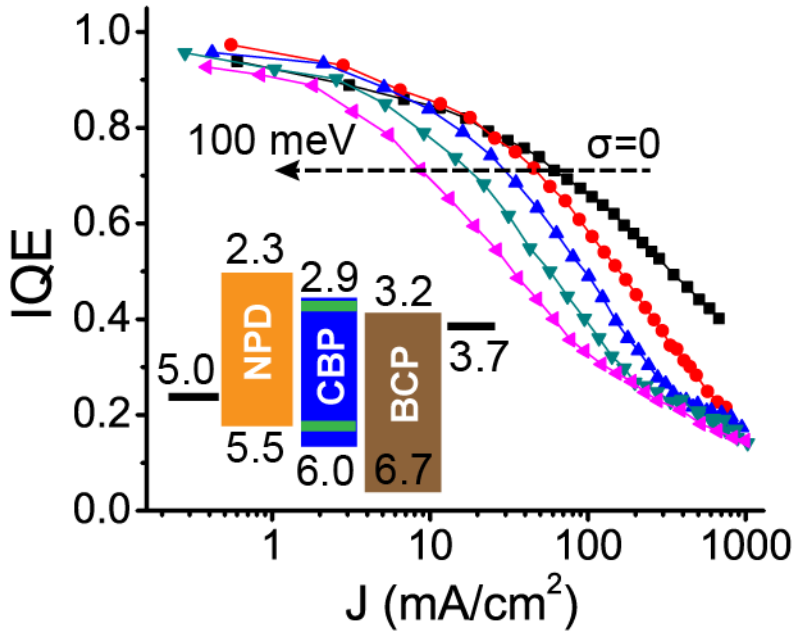


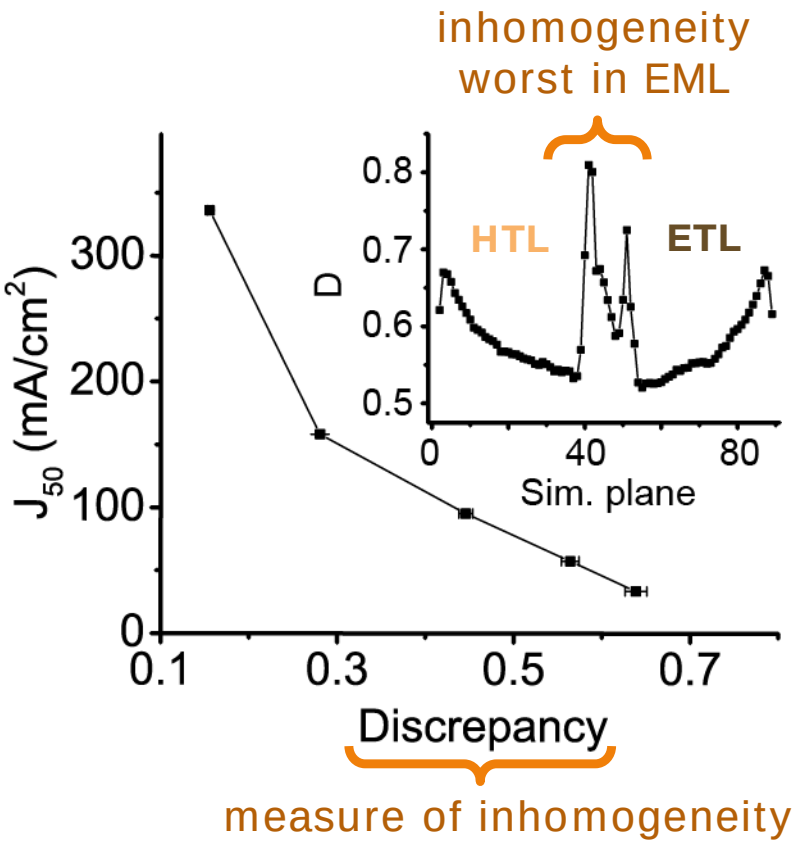


- Can also initiate at organic-organic interfaces

Device implications: Efficiency

Protoypical Ir(ppy)$_3$ PHOLED

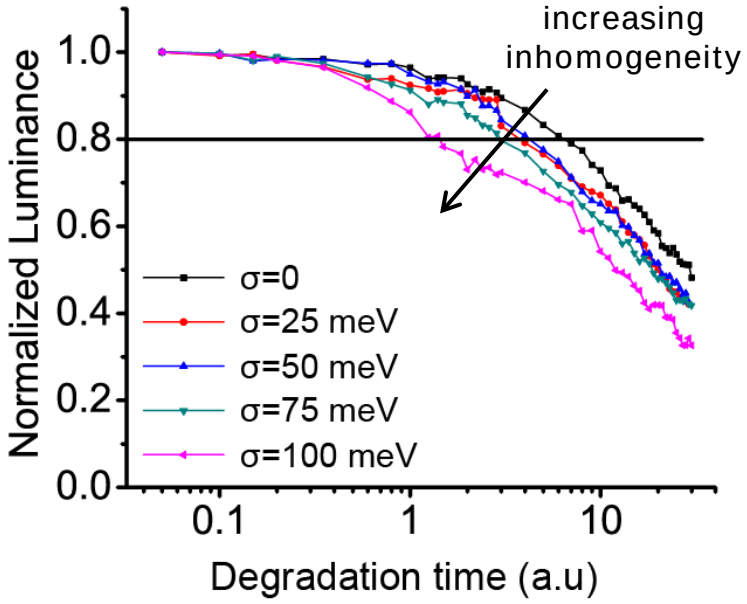


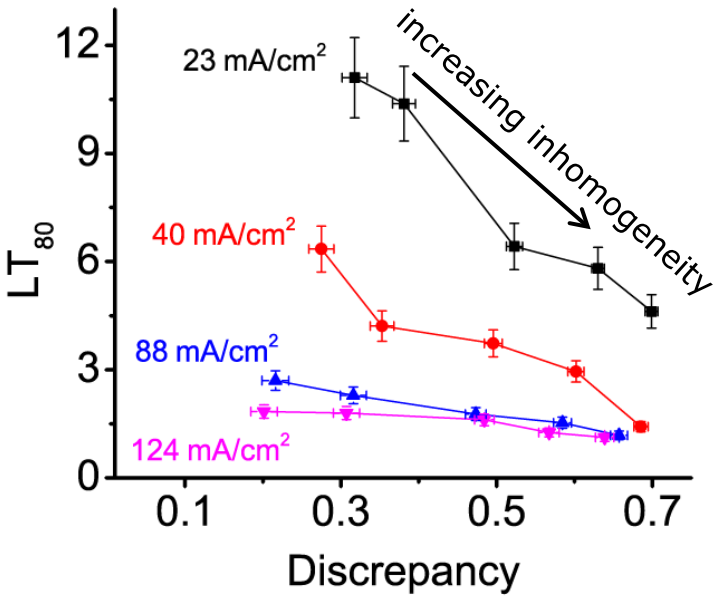


Inhomogeneity leads to 10x increase in exciton-polaron quenching

Device implications: Lifetime

Protoypical $Ir(ppy)_3$ PHOLED





Inhomogeneity leads to ~2x decrease in lifetime at SSL current densities

Inhomogeneity at the macroscale

OLED panels that short catastrophically:

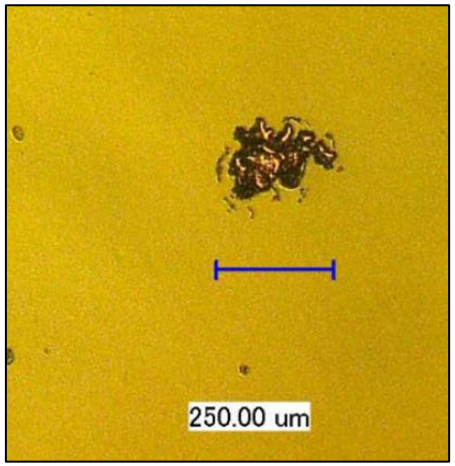
- Decrease manufacturing yield
- Increase warranty expenses
- Decrease customer satisfaction

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

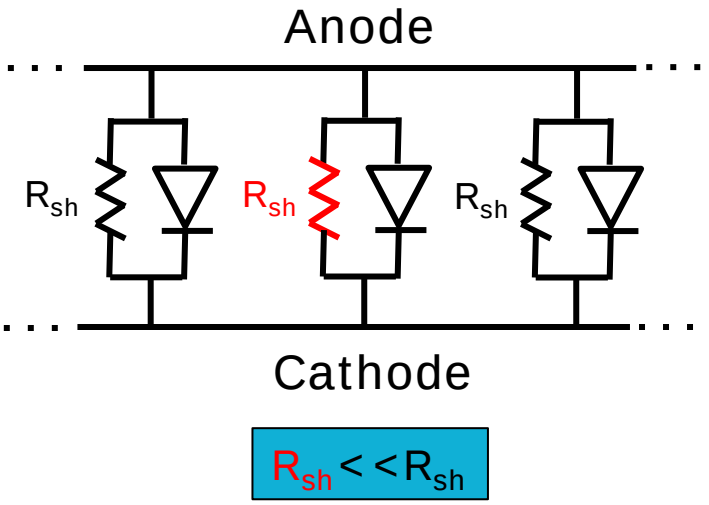


Residue of a short

Locating incipient shorts

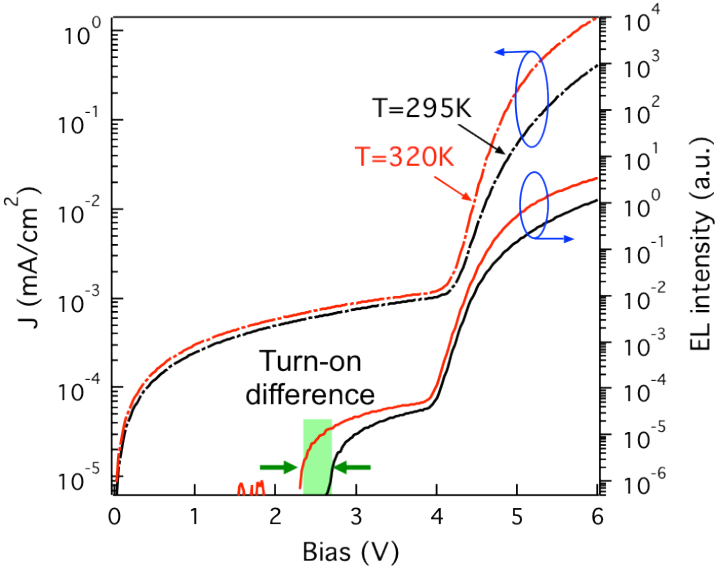
Mapping inhomogeneity:

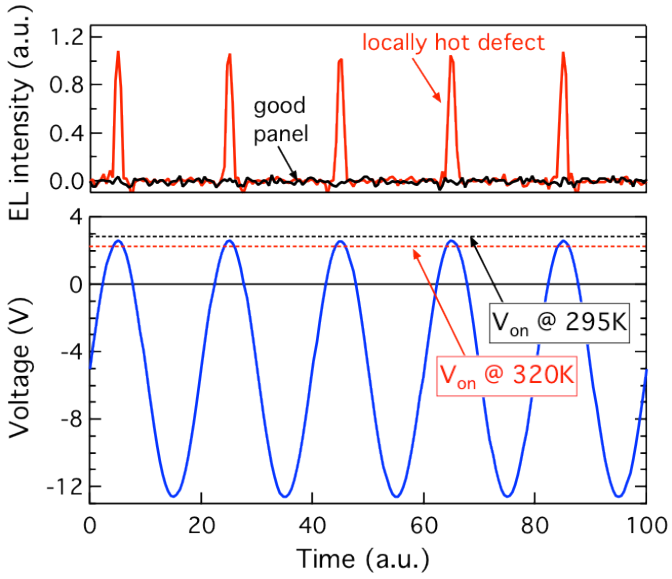
- Electroluminescence (intensity, phase, noise)
- Heat (LIT, temp-selective EL)
- Electric field (reverse bias PL quenching)
- Photocurrent (LBIC)



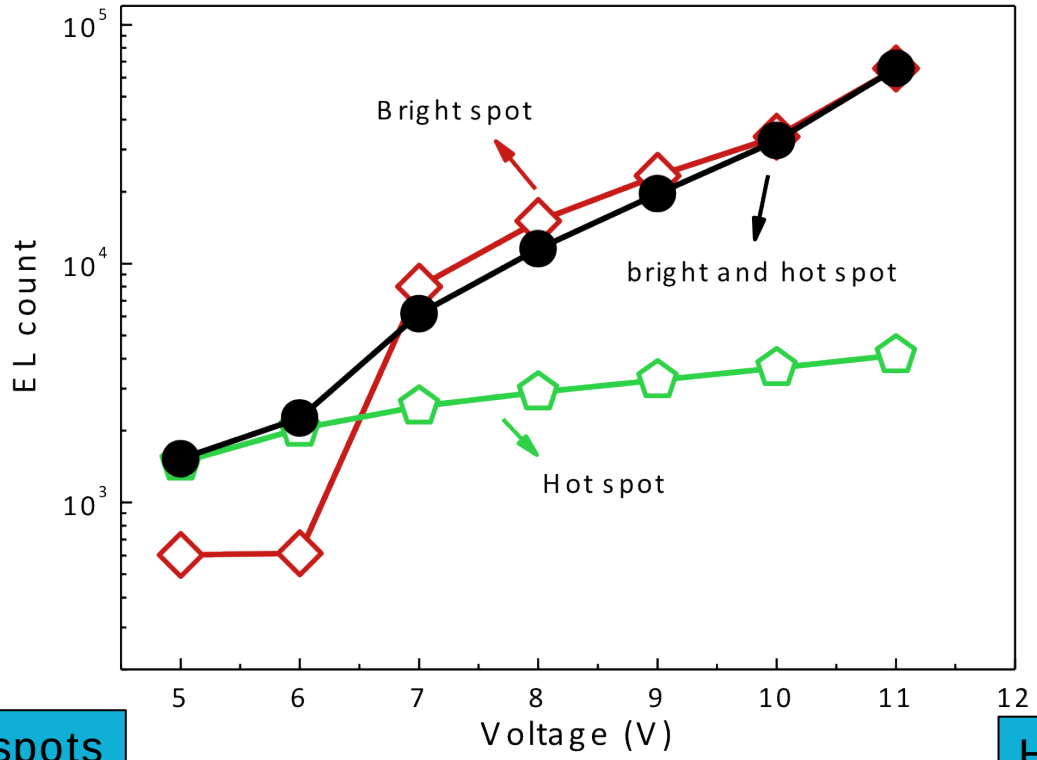
Temperature-selective EL:

- Reverse bias heats local shunt paths
- Decreases V_{on} of surrounding OLED
- Quick forward pulse only lights up areas near shunt

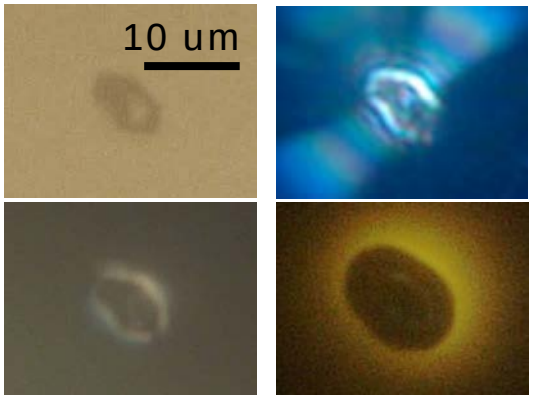




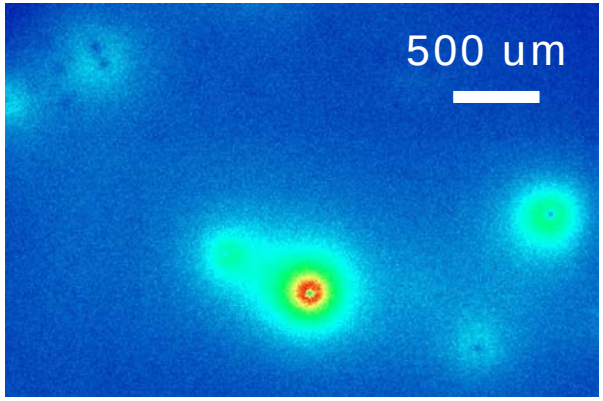
‘Bright’ spots & ‘Hot’ spots



Bright spots

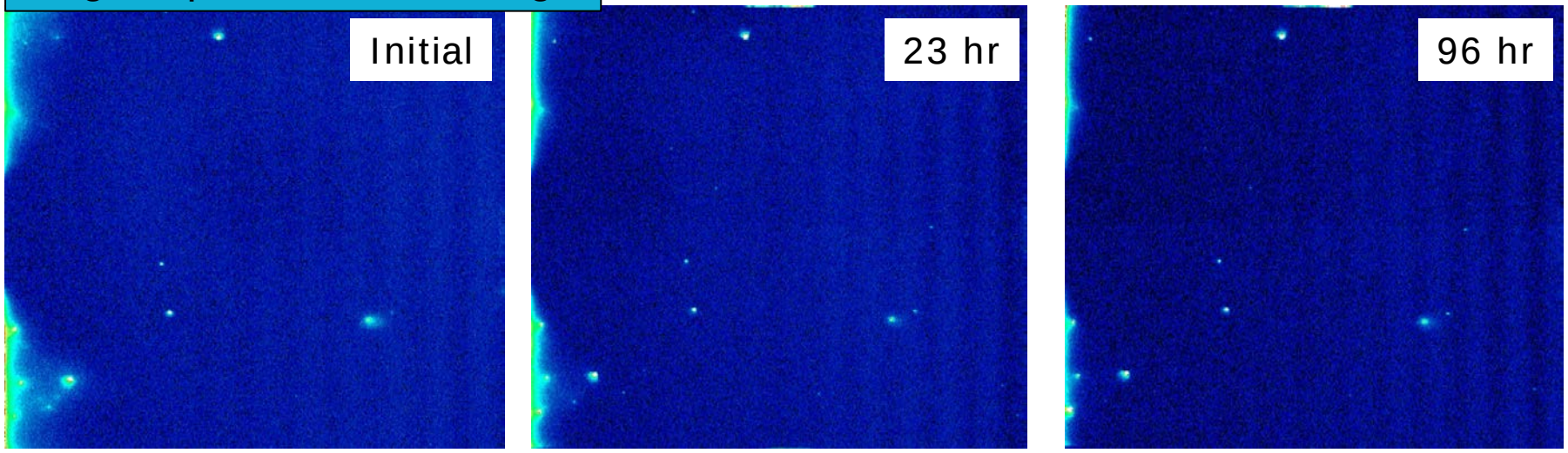


Hot spots

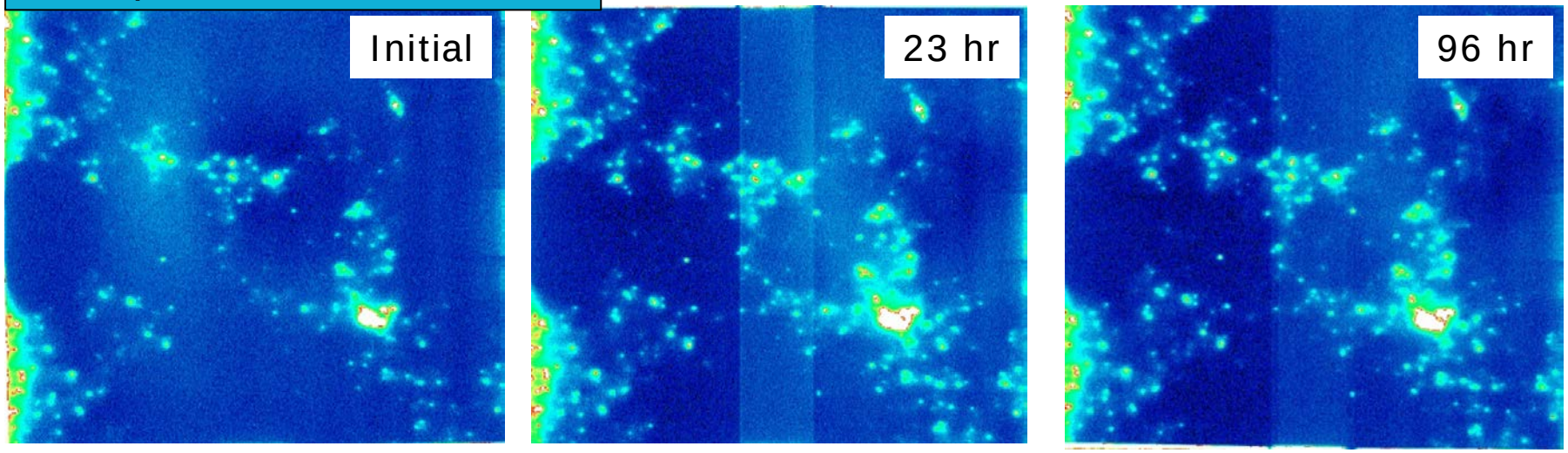


Evolution from accelerated aging

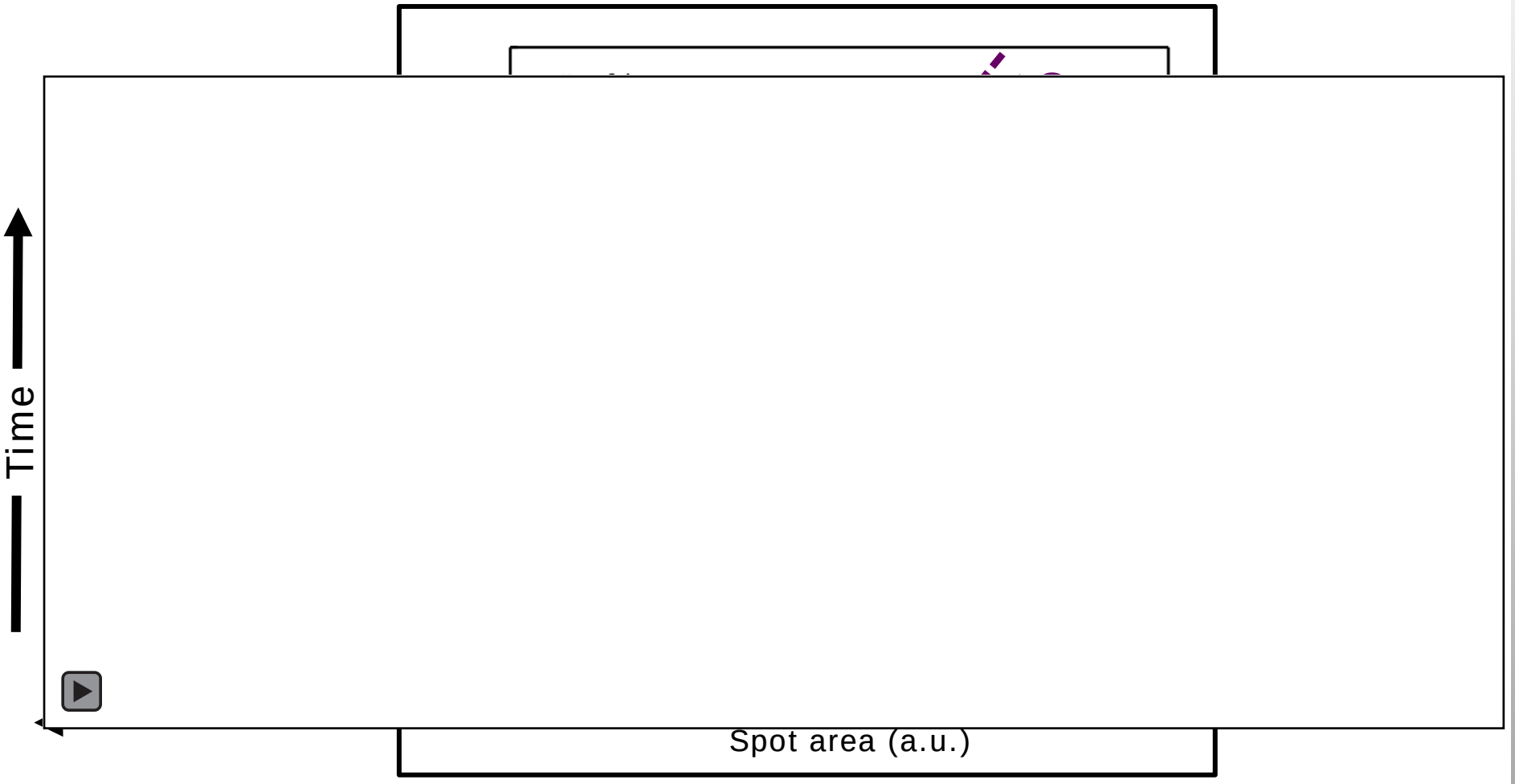
Bright spots: Little change



Hot spots: Growth



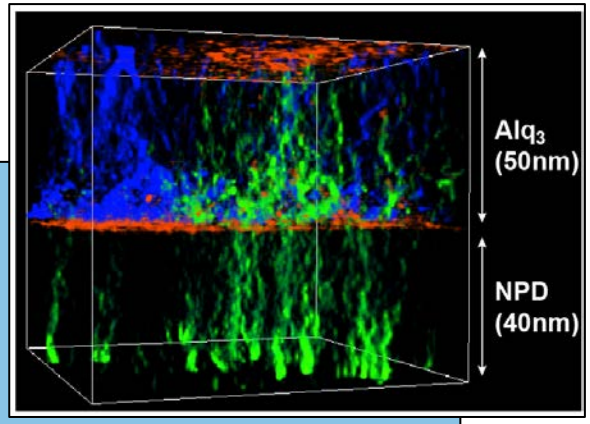
Visualizing hot spot evolution



- Hot spots can grow and extinguish over time
- Different classes of hot spots: benign vs. dangerous?

Questions for the community

Nanoscale inhomogeneity



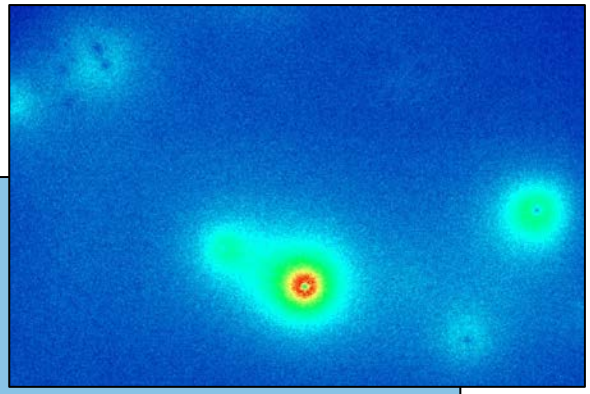
1. **Is this real?**

   -Experimental evidence?

2. **Is there anything we can do about it?**

   -Control over energetic disorder in the bulk and at interfaces.

Macroscale inhomogeneity



1. **Clear link between hot spots and shorts?**
2. **Physical origin of hot spots?**
3. **How do we avoid or arrest hot spot growth?**

Acknowledgements

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