Improving OLED performance via semiconductor dilution

Chris Giebink
Electrical Engineering Department
Penn State University

AOPL

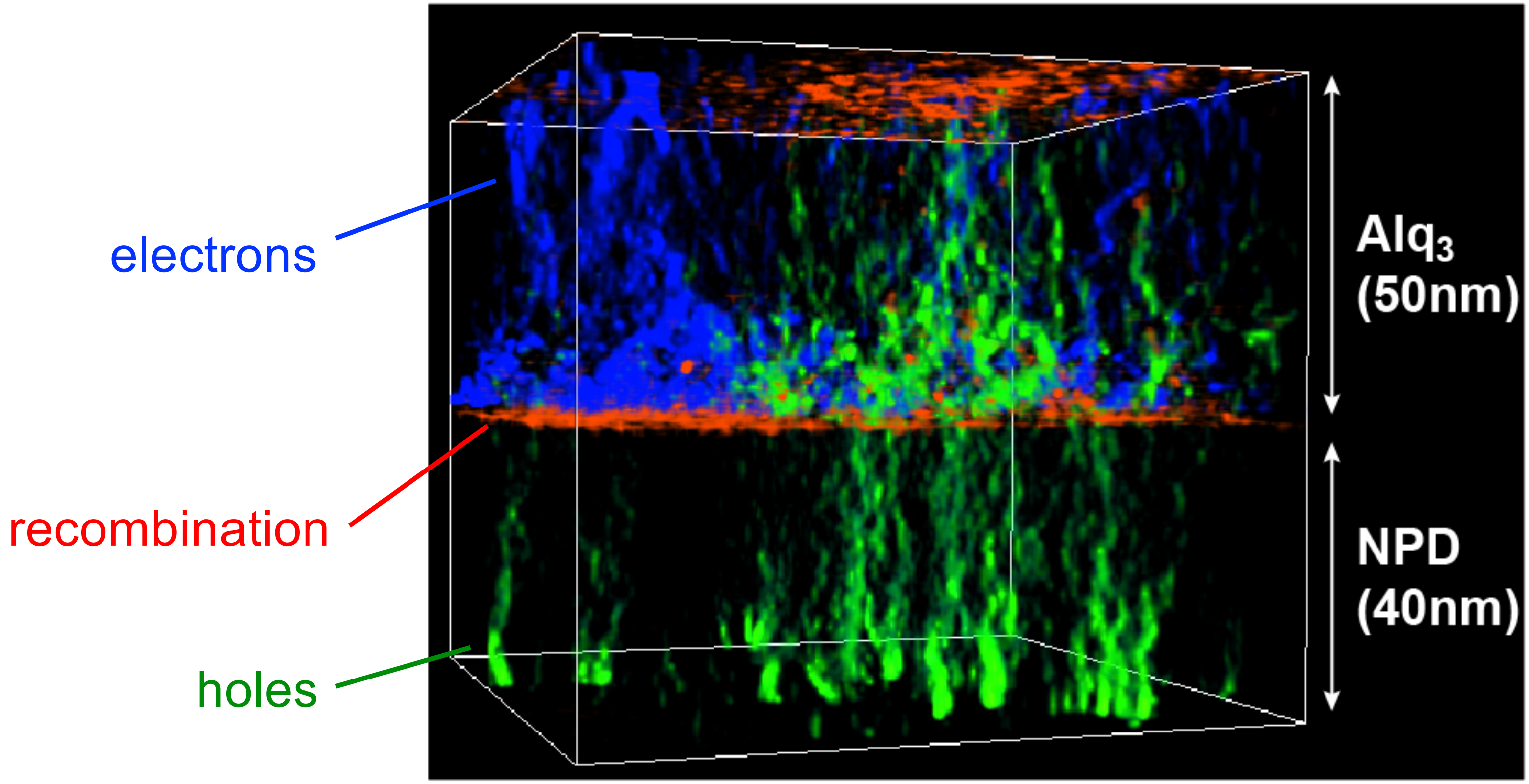
PennState

'Intrinsic' properties of OLED materials

- Refractive index n ~ 1.7
  - Limits optical outcoupling efficiency
- Glass transition temperature T_g ~ 100-120ºC
  - OLED panels operate at elevated temperature
  - Thermal stability closely connected to catastrophic failure
  - Intrinsic OLED lifetime ~ $\exp(-E_A/kT)$

What if we could change properties like these without re-engineering OLED molecules?

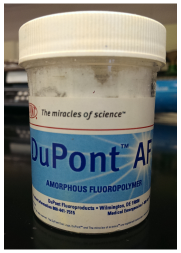
Most of the molecules aren't necessary

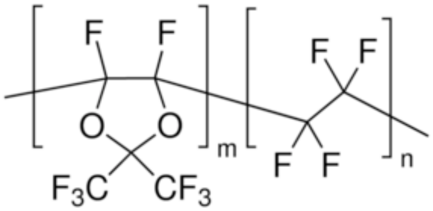


Transport is percolative, involves <5% of all molecules

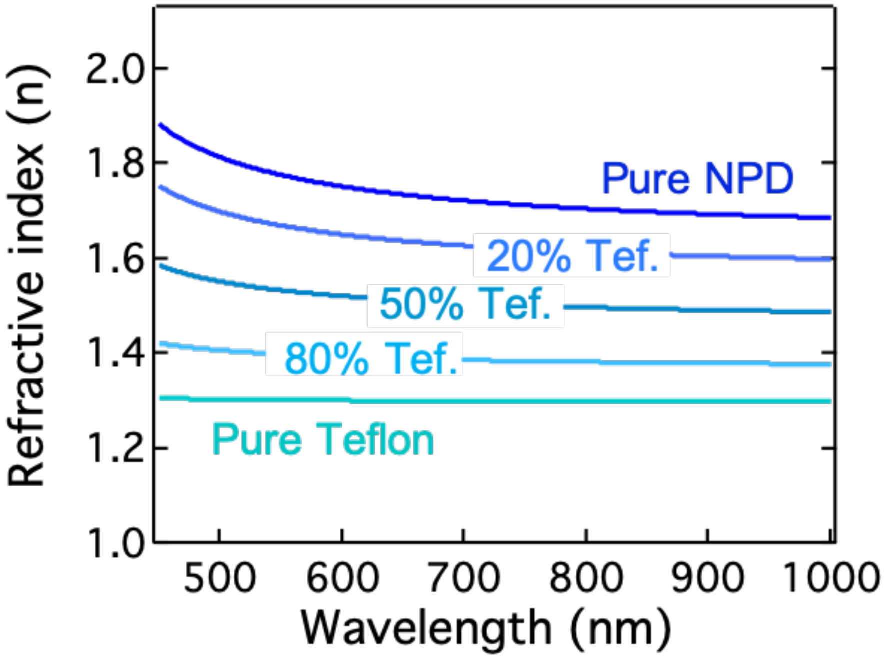
Changing blend properties with Teflon AF

- Co-evaporate Teflon AF w/ small molecules

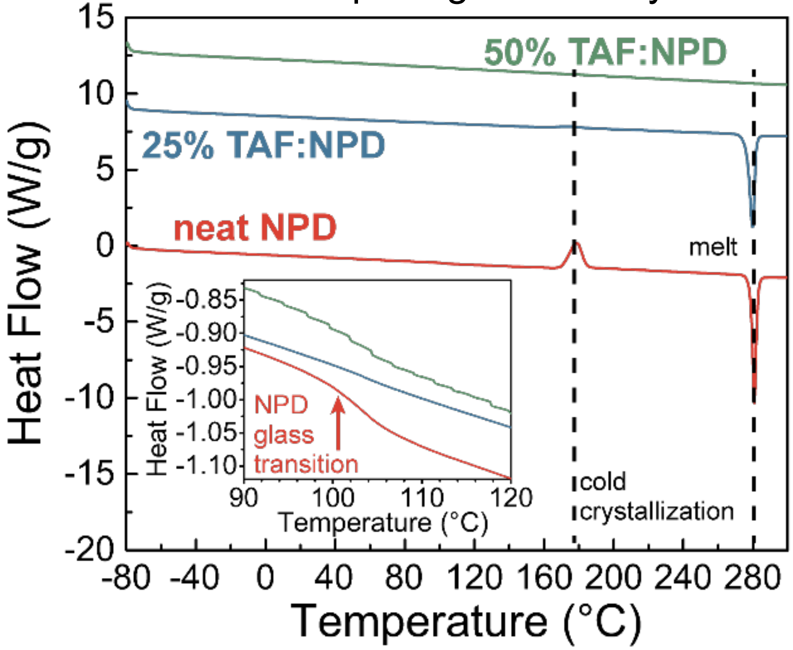




Refractive Index

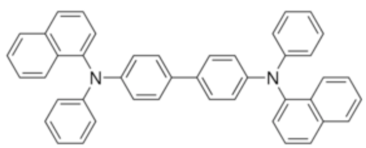


Morphological stability

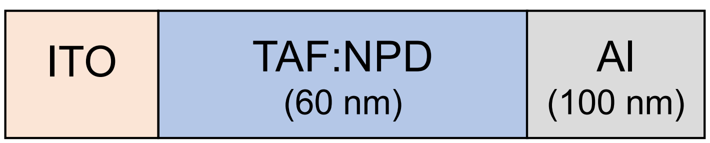


What happens to electrical transport?

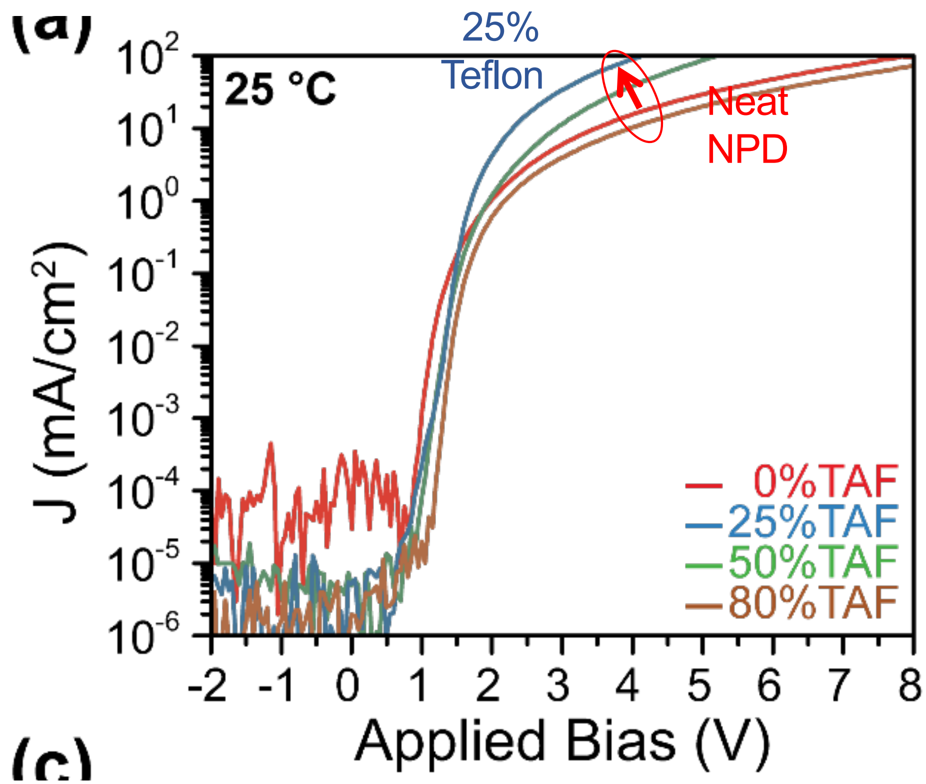
- Hole-only devices:



$T_g \sim 95°C$



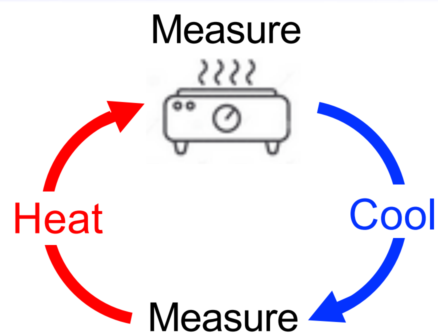
	Drive voltage @ 10 mA/cm^2
Neat NPD	3.5±0.1
25% TAF:NPD	2.3±0.1
50% TAF:NPD	2.9±0.1
80% TAF:NPD	4.0±0.1



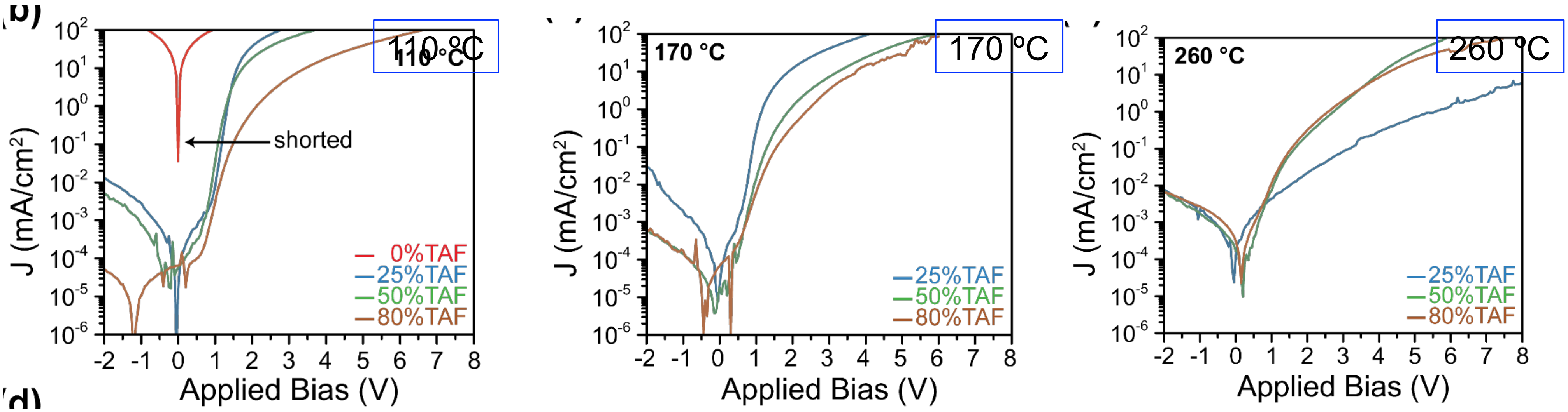
Decreases drive voltage for up to 50% Teflon:NPD

High temperature performance

- Teflon-blended devices don’t short
- Maintain rectification above 250ºC



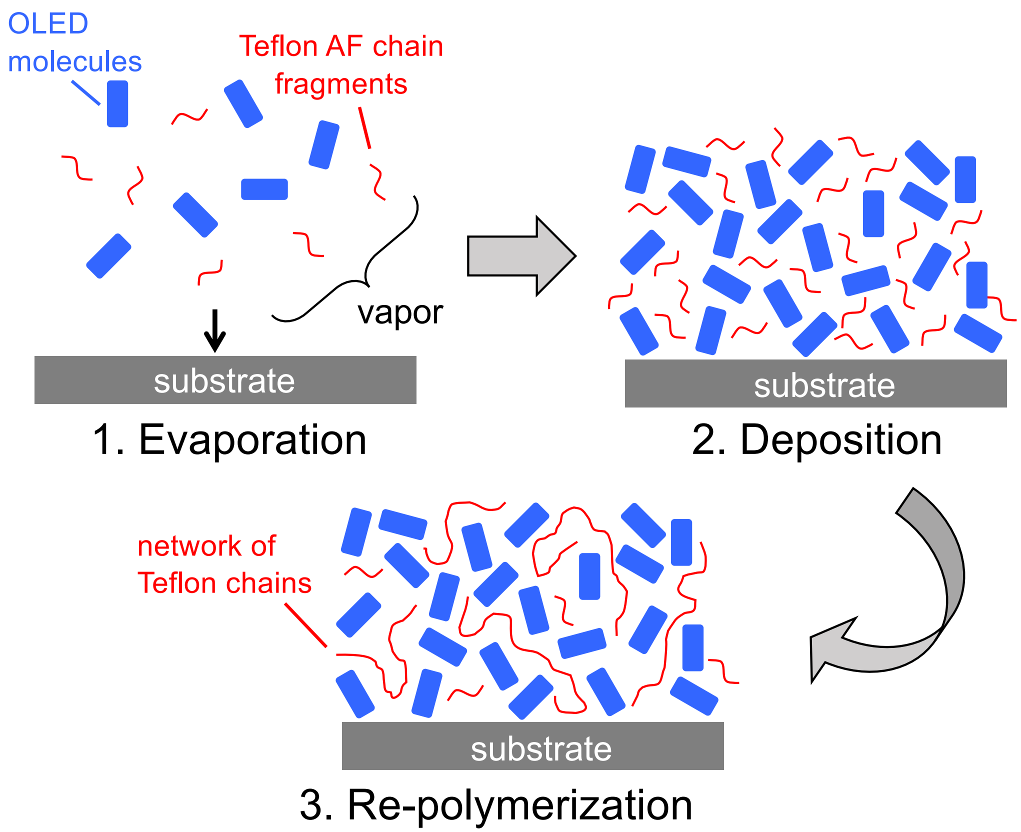
	Catastrophic failure temp.
Neat NPD	110 ºC
25% TAF:NPD	260 ºC
50% TAF:NPD	>260 ºC
80% TAF:NPD	>260 ºC

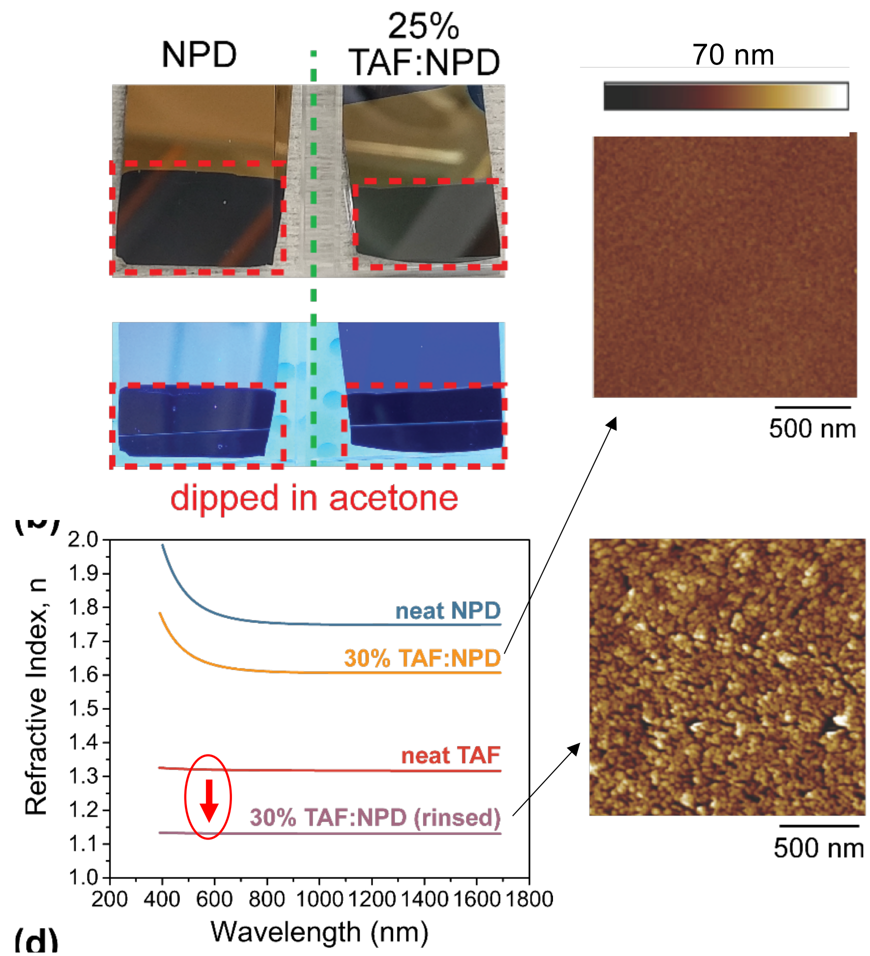


Increases thermal stability of diodes to >250ºC

How we think it works

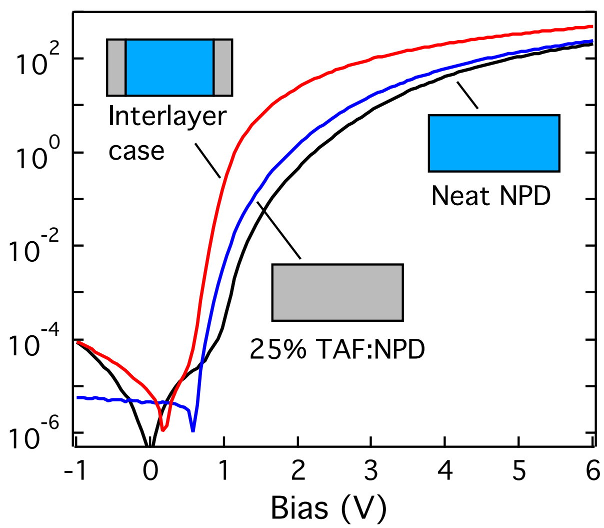
- Analogy to fiberglass:

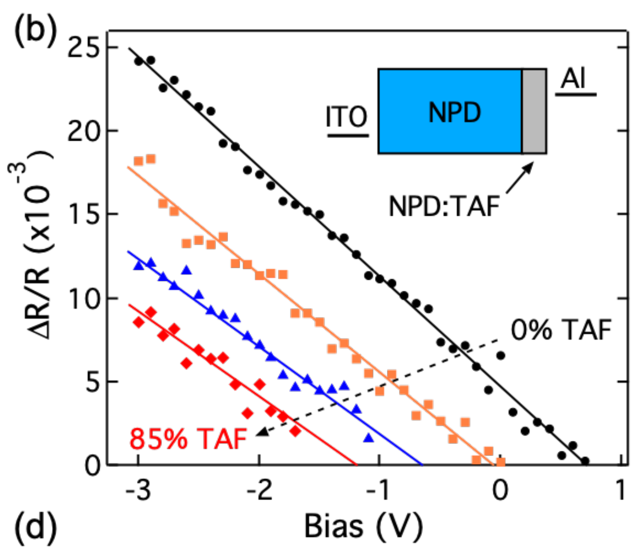


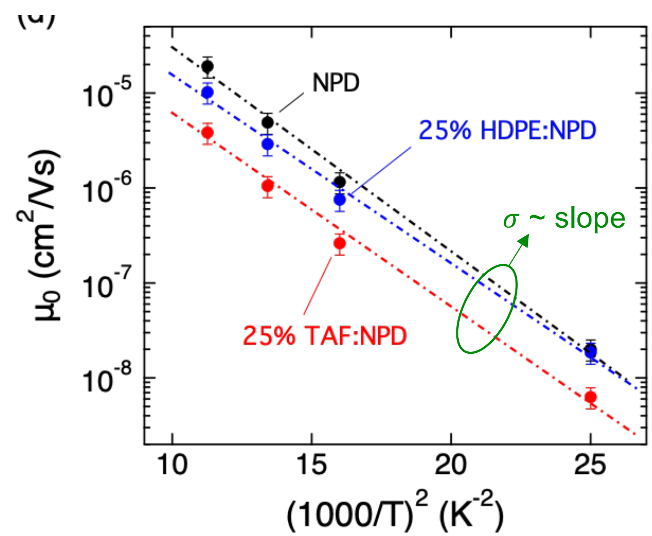


What’s happening electrically?

- NPD hole-only diodes:
  - Suggests improved injection but degraded bulk transport
- Injection improves:
  - Interface dipole reduces hole injection barrier
  - Reduces V_{bi}
- Bulk mobility decreases
  - Reduced disorder
  - Reduced percolation

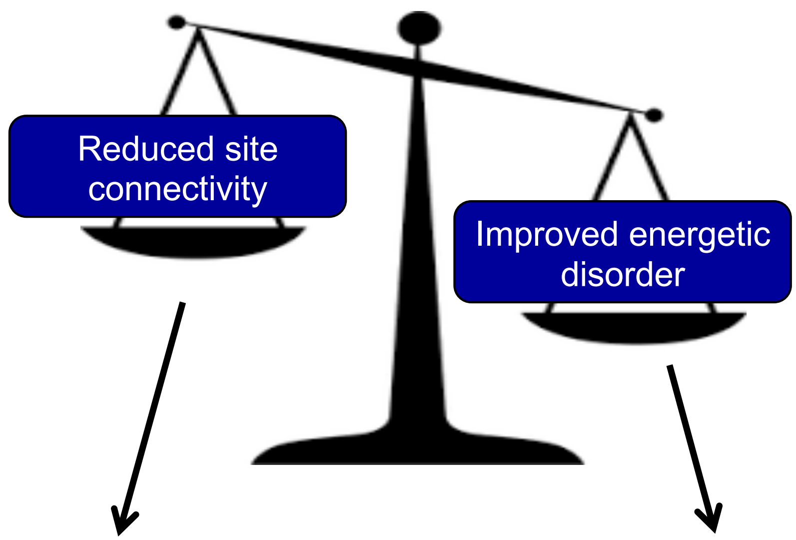


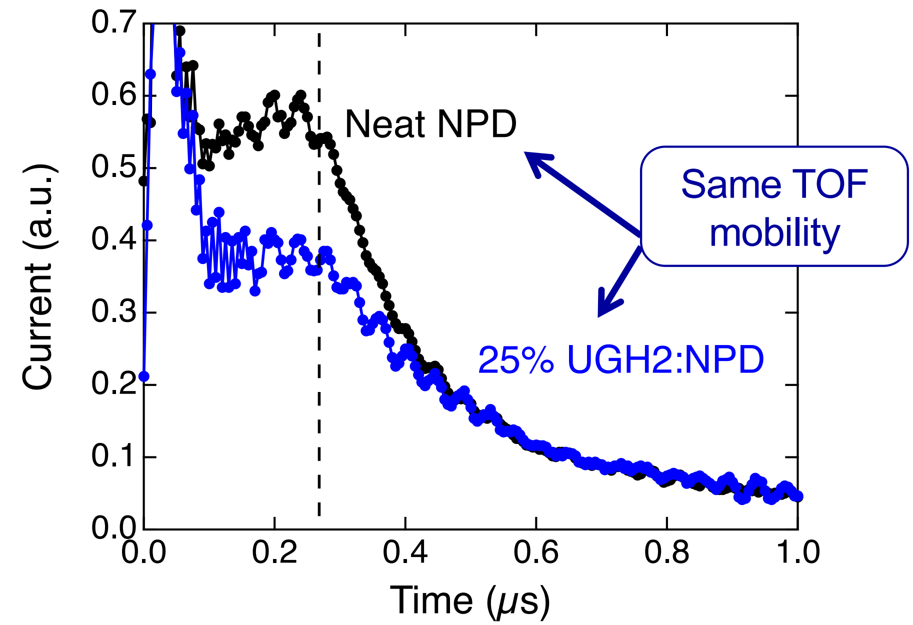




Prospects for improvement?

- Genuine dilution is non-trivial





- Percolation
- Blend morphology

- Relative dipole moments
- Relative polarizabilities

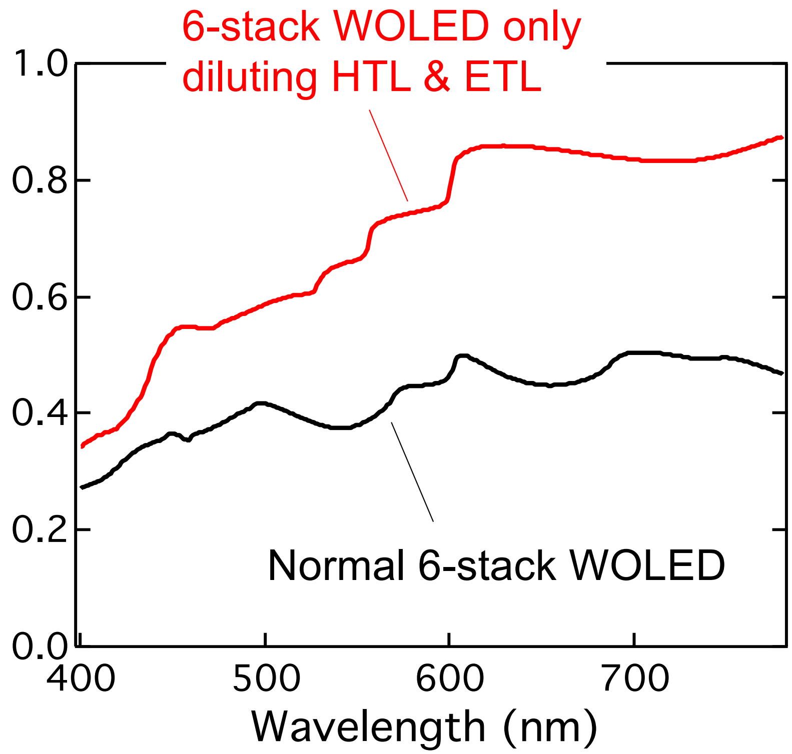
Other considerations

- Optical properties (lower n)
- Thermal properties (higher T_g blends) …
- Spont. orient. polarization

Questions for the community

- What if we could tailor μ and n in every transport layer of a WOLED stack?
  - What does the grand electrical & optical optimization look like?
  - What does the magic dilution molecule look like? (We don't want Teflon AF)
  - Is there economic value in displacing the cost of 'expensive' organic semiconductors?

Should dilution molecules become another standard ingredient for OLEDs?
(like emitters, HTMs, ETMs, HBLs, EBLs, etc)



Acknowledgements

- **Students**
  - Jared Price
  - Taehwan Kim
  - Christian Ruud
  - Emmanuel Afolayan
  - Rijul Dhanker
- **Collaborators**
  - Michael Boroson (OLEDWorks)
  - Sukrit Mukhopadhyay (DOW)
  - Mike Hickner (PSU)
- **Support:** U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy