Improving OLED performance via semiconductor dilution

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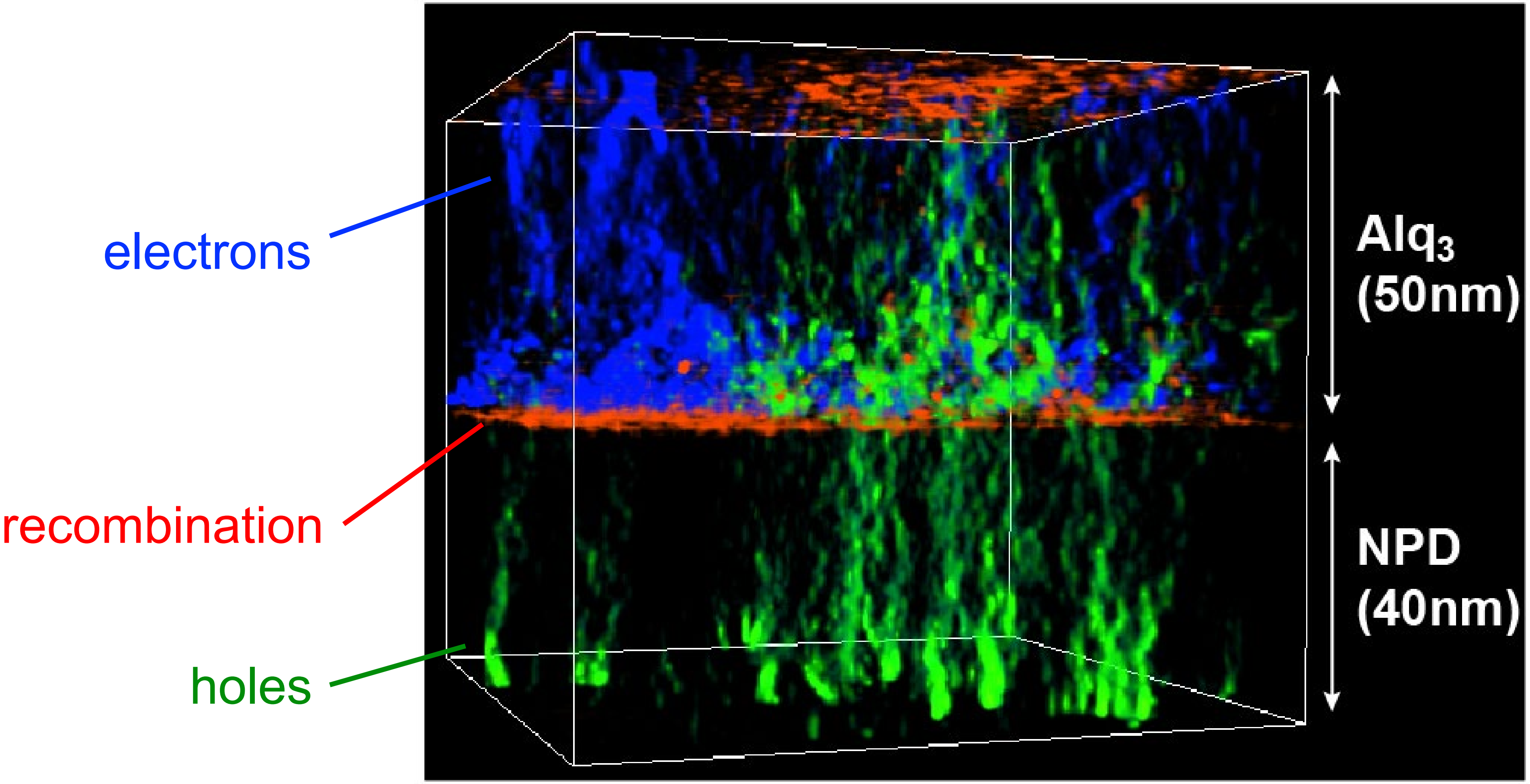
‘Intrinsic’ properties of OLED materials

- 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

Semiconductor dilution

- Blending with insulating molecules can **improve** transport
- …and change optical & morphological properties of the blend

ARTICLES
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nature materials

Elimination of charge carrier trapping in diluted semiconductors

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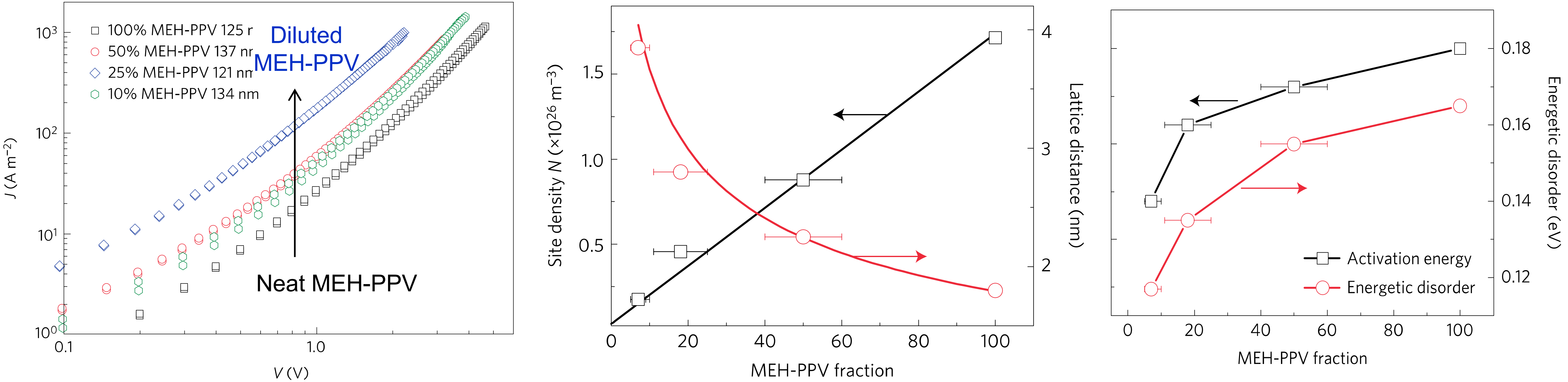
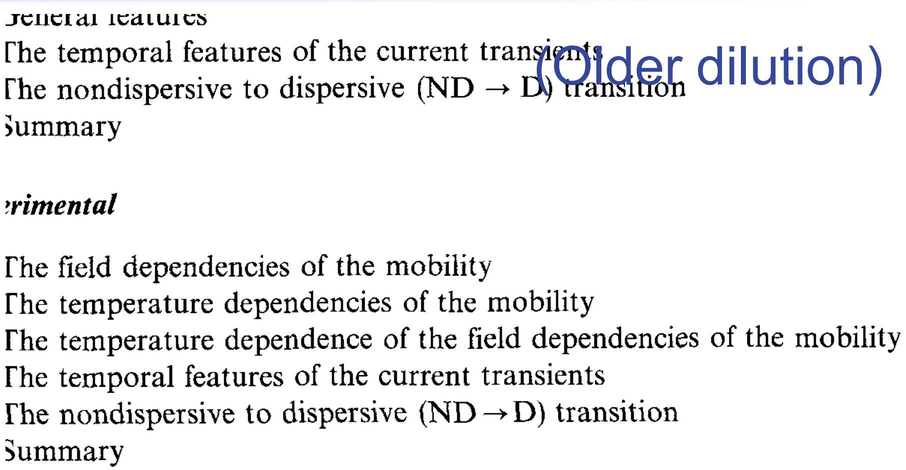


Replace ~half your organic semiconductor w/o sacrificing electrical transport

Semiconductor dilution

- Blending with insulating molecules can **improve** transport
- …and change optical & morphological properties of the blend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The temporal features of the current transients
The nondispersive to dispersive (ND → D) transition
Summary

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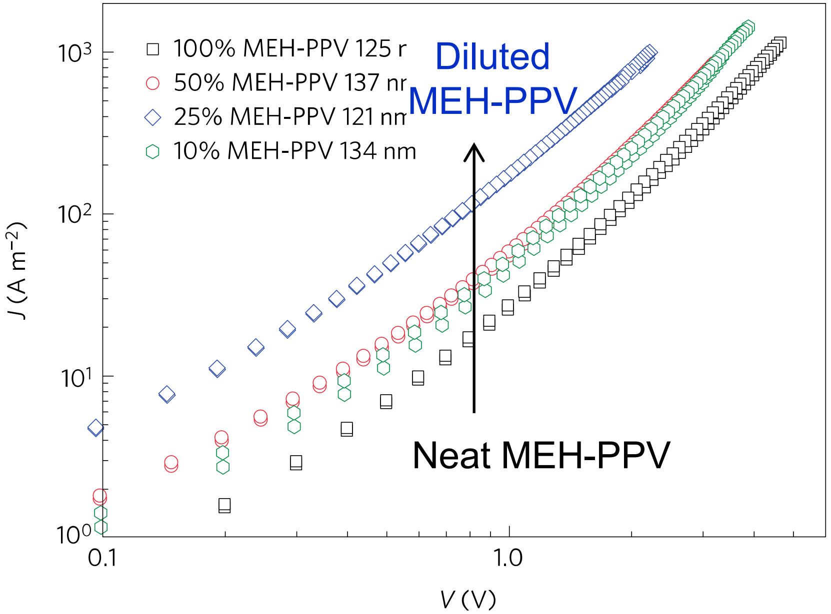
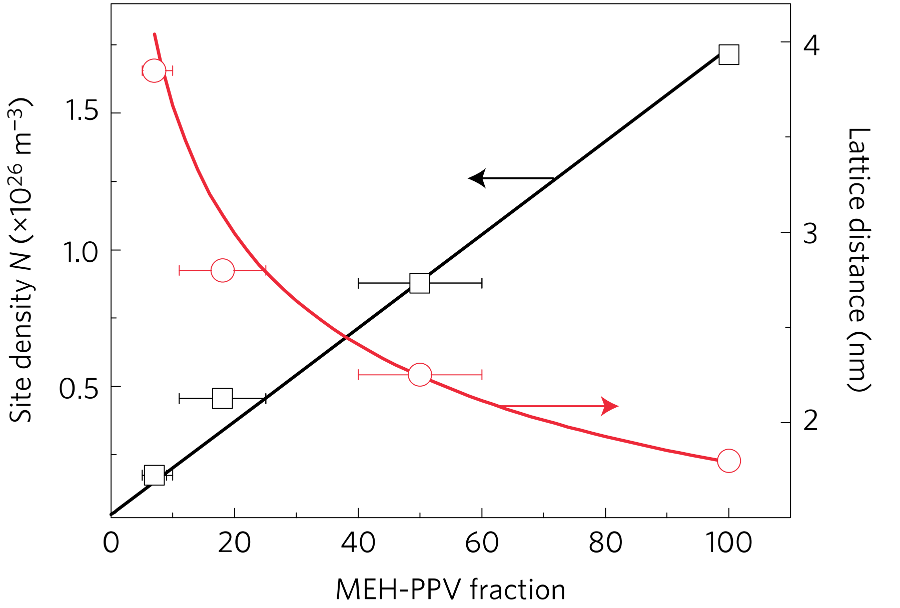
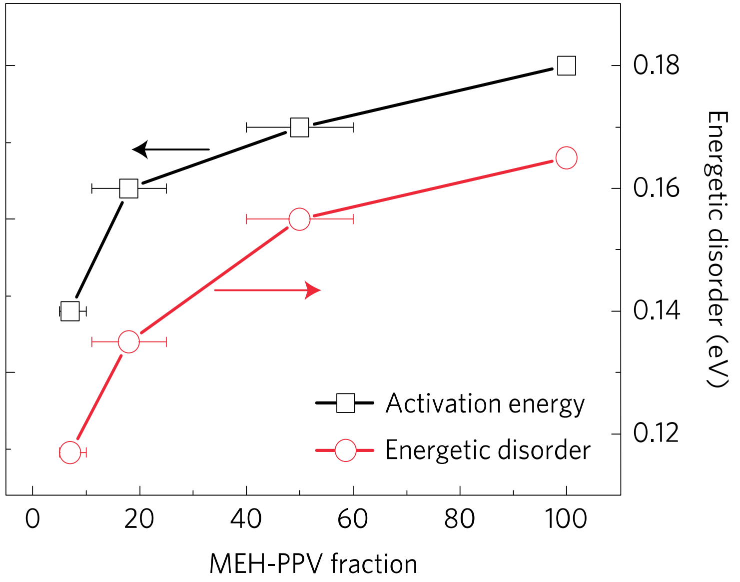
Summary

(Older dilution)



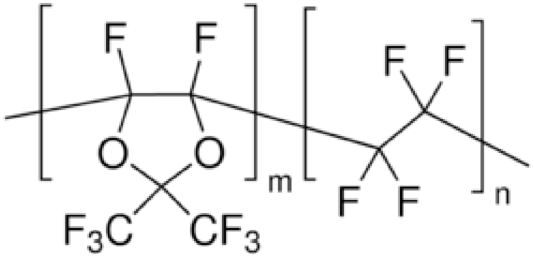




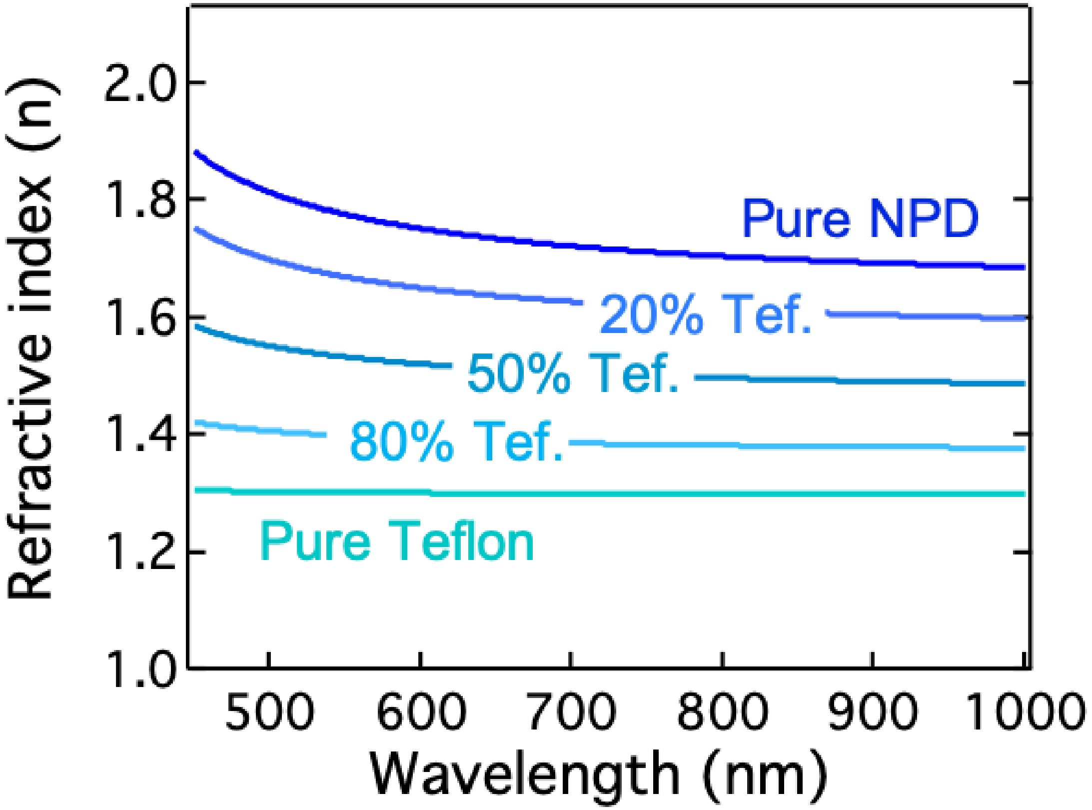
Replace ~half your organic semiconductor w/o sacrificing electrical transport

Changing blend properties with Teflon AF

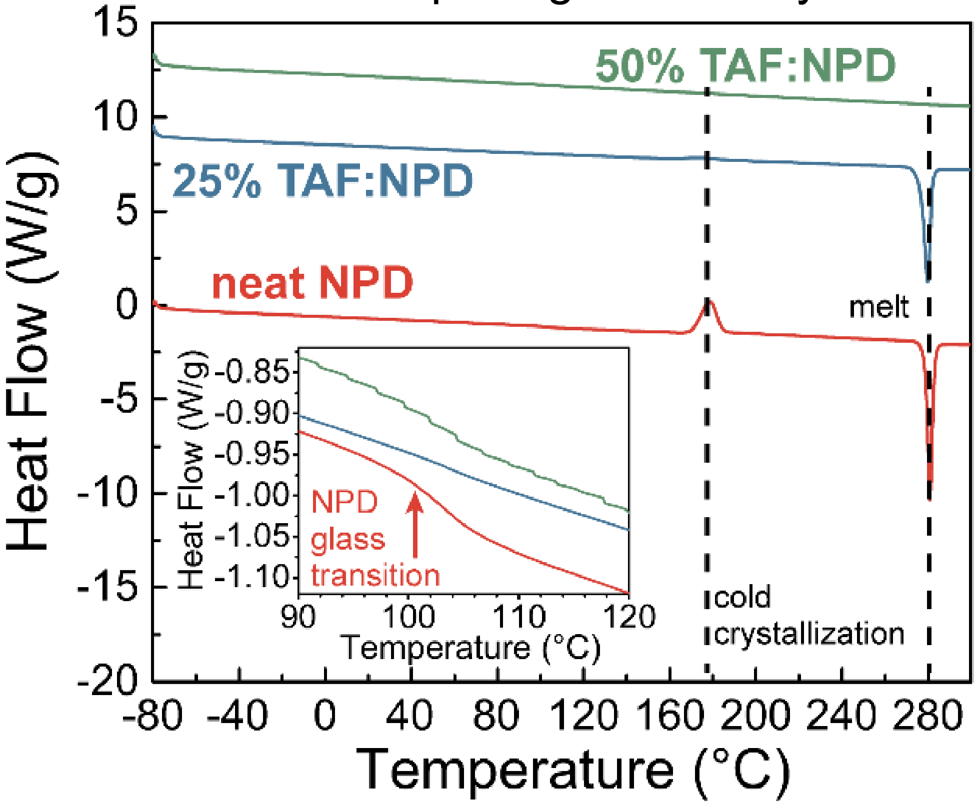
- Co-evaporate Teflon AF w/ small molecules



Refractive Index

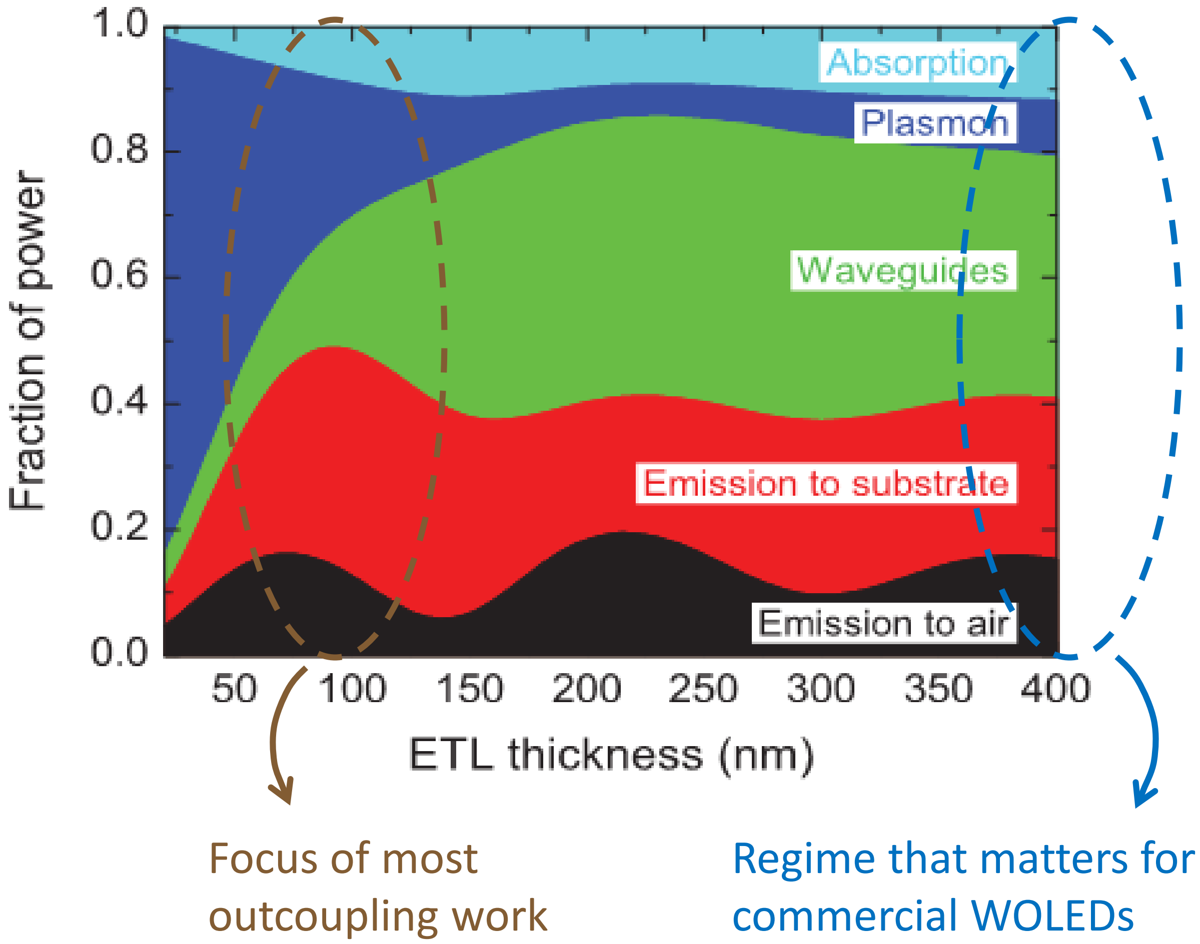


Morphological stability

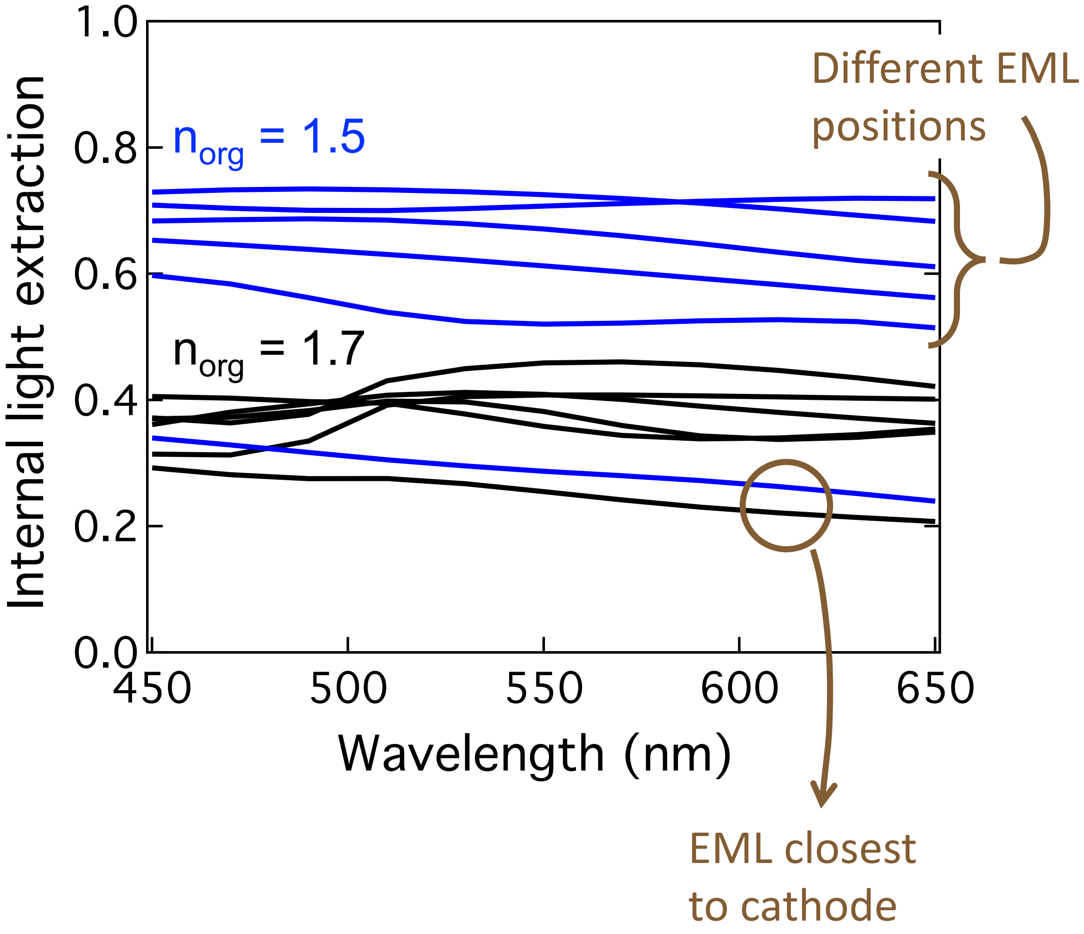


Opportunity for outcoupling

- Guided mode loss dominates in multi-stack WOLEDs

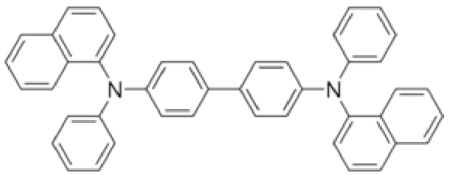


- 6-stack WOLED: Dropping index significantly increases ILE



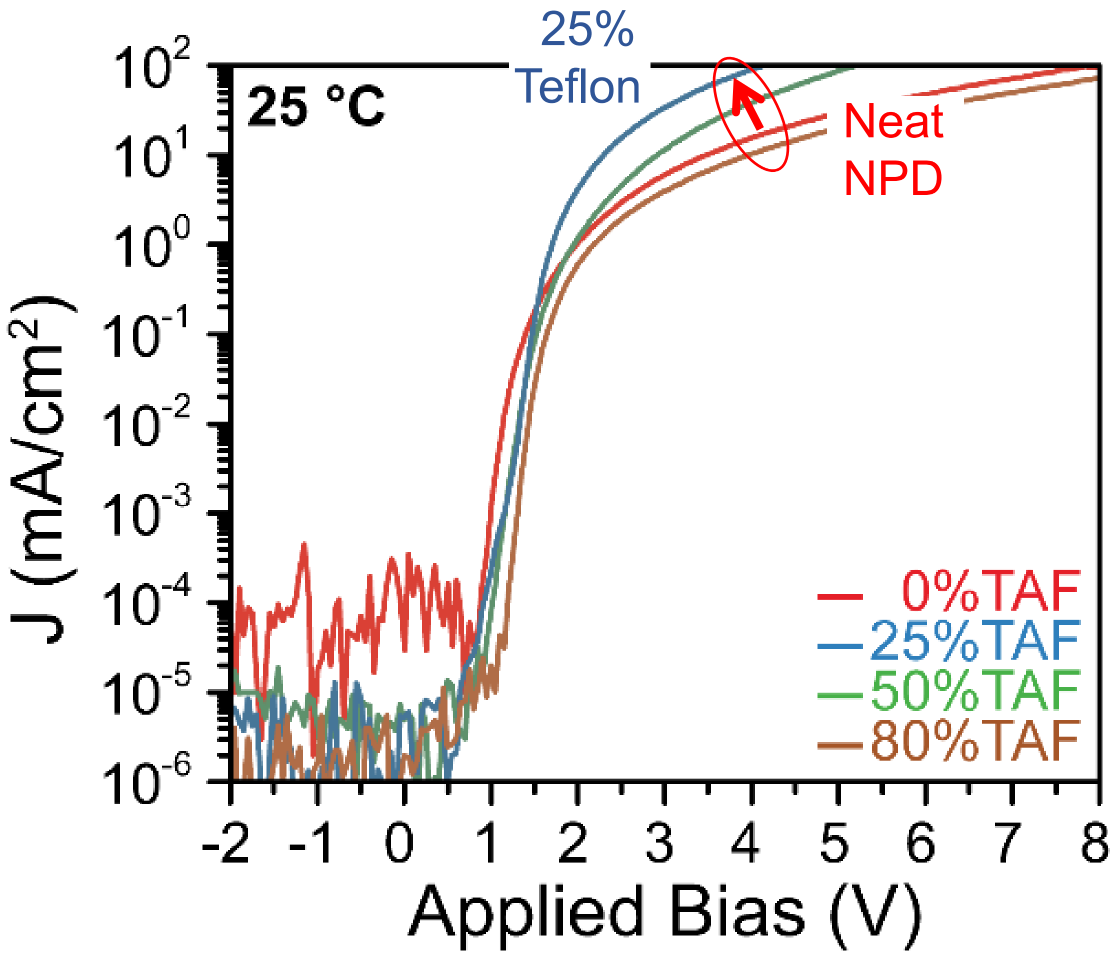
What happens to electrical transport?

- Hole-only devices:



T_g ~ 95ºC

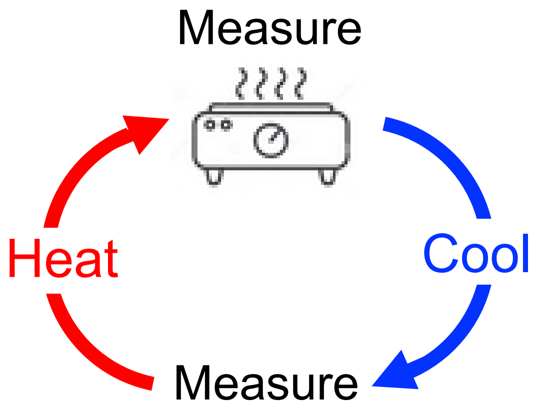
	Drive voltage @ 10 mA/cm²
Neat NPD	3.5±0.1
25% TAF:NPD	2.3±0.1
50% TAF:NPD	2.9±0.1
80% TAF:NPD	4.0±0.1



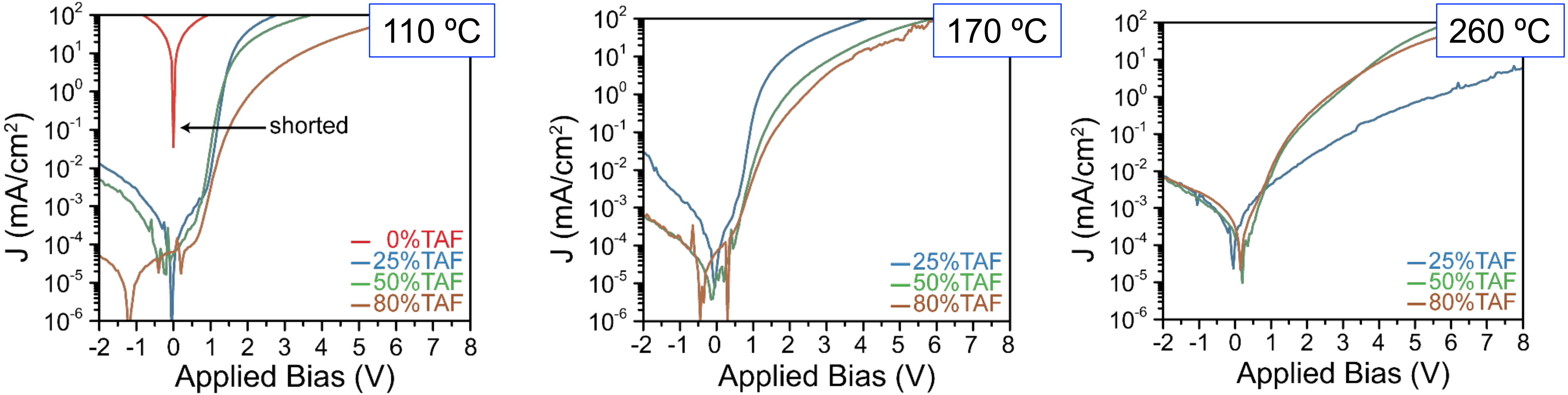
Decreases drive voltage for up to 50% Teflon:NPD

High temperature performance

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



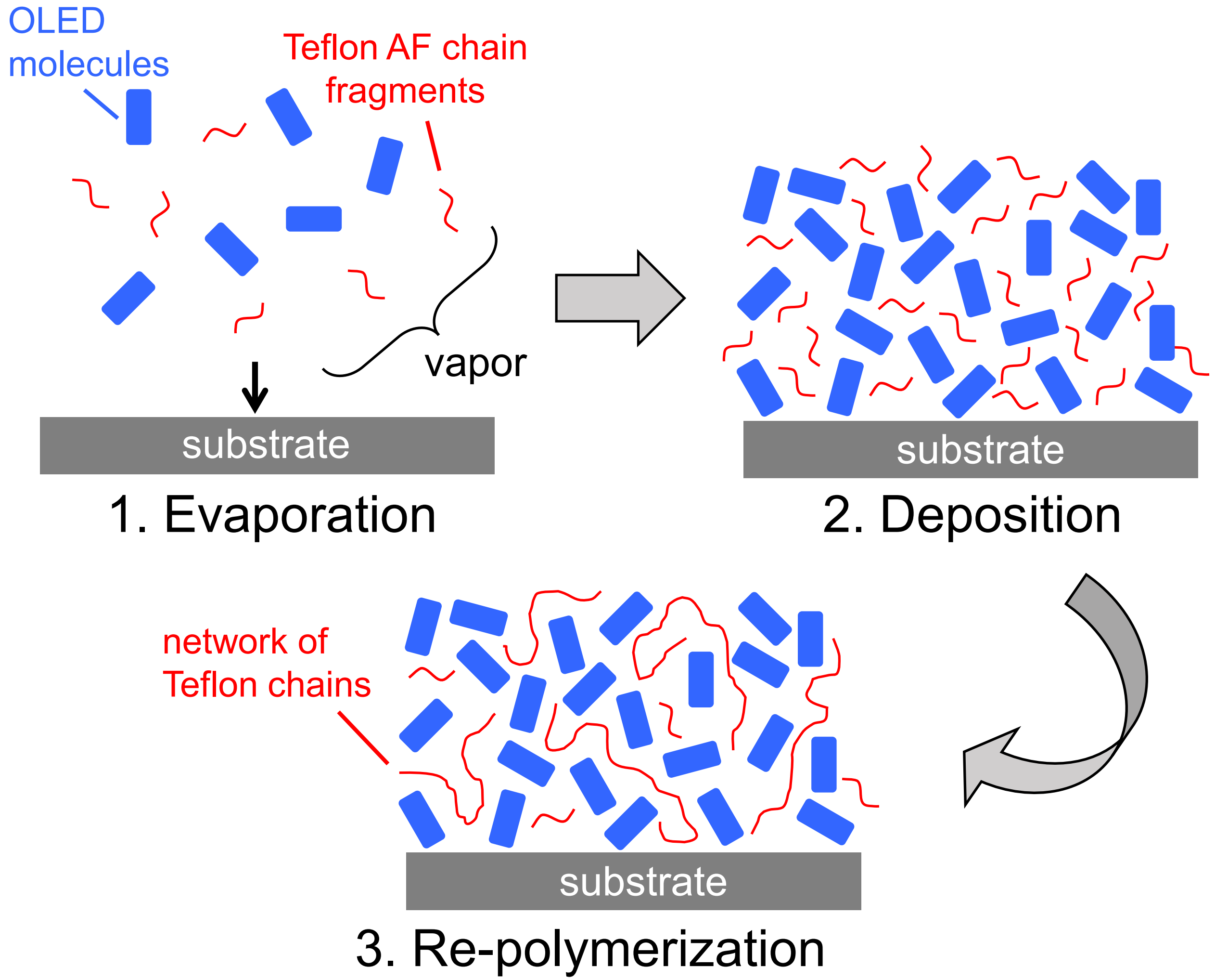
	Catastrophic failure temp.
Neat NPD	110 ºC
25% TAF:NPD	260 ºC
50% TAF:NPD	>260 ºC
80% TAF:NPD	>260 ºC

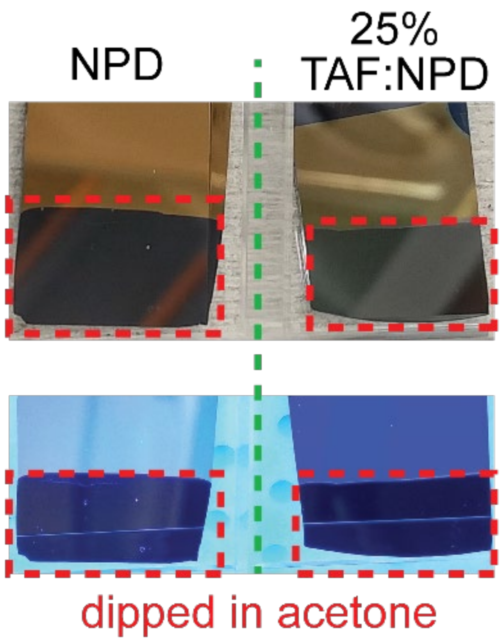


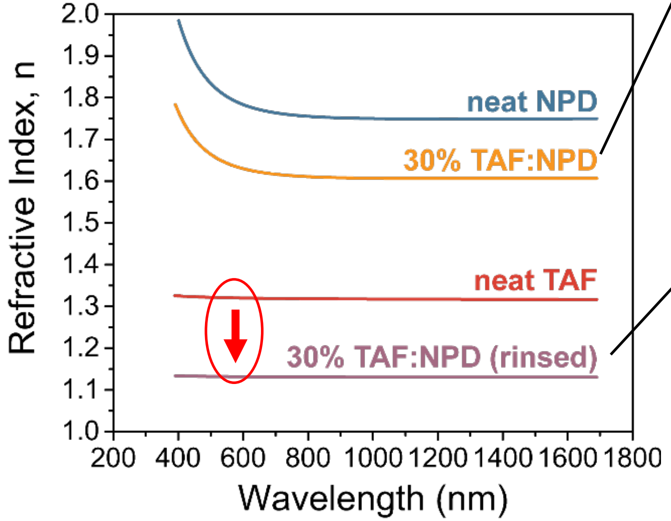
Increases thermal stability of diodes to >250ºC

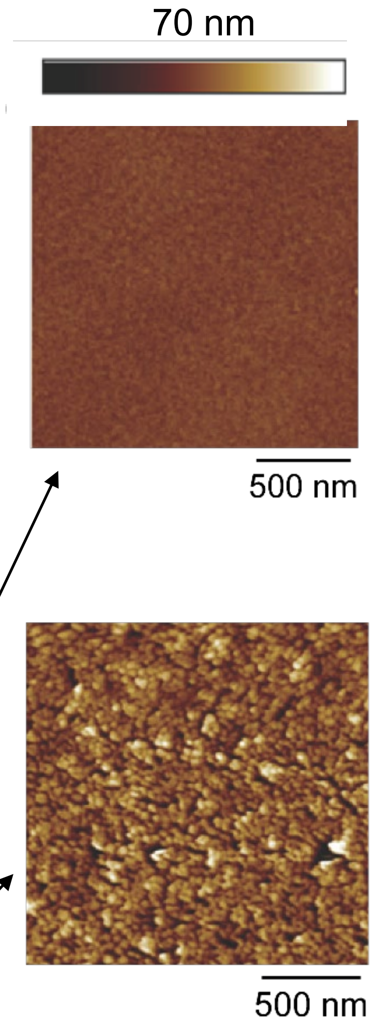
How we think it works

- Analogy to fiberglass:

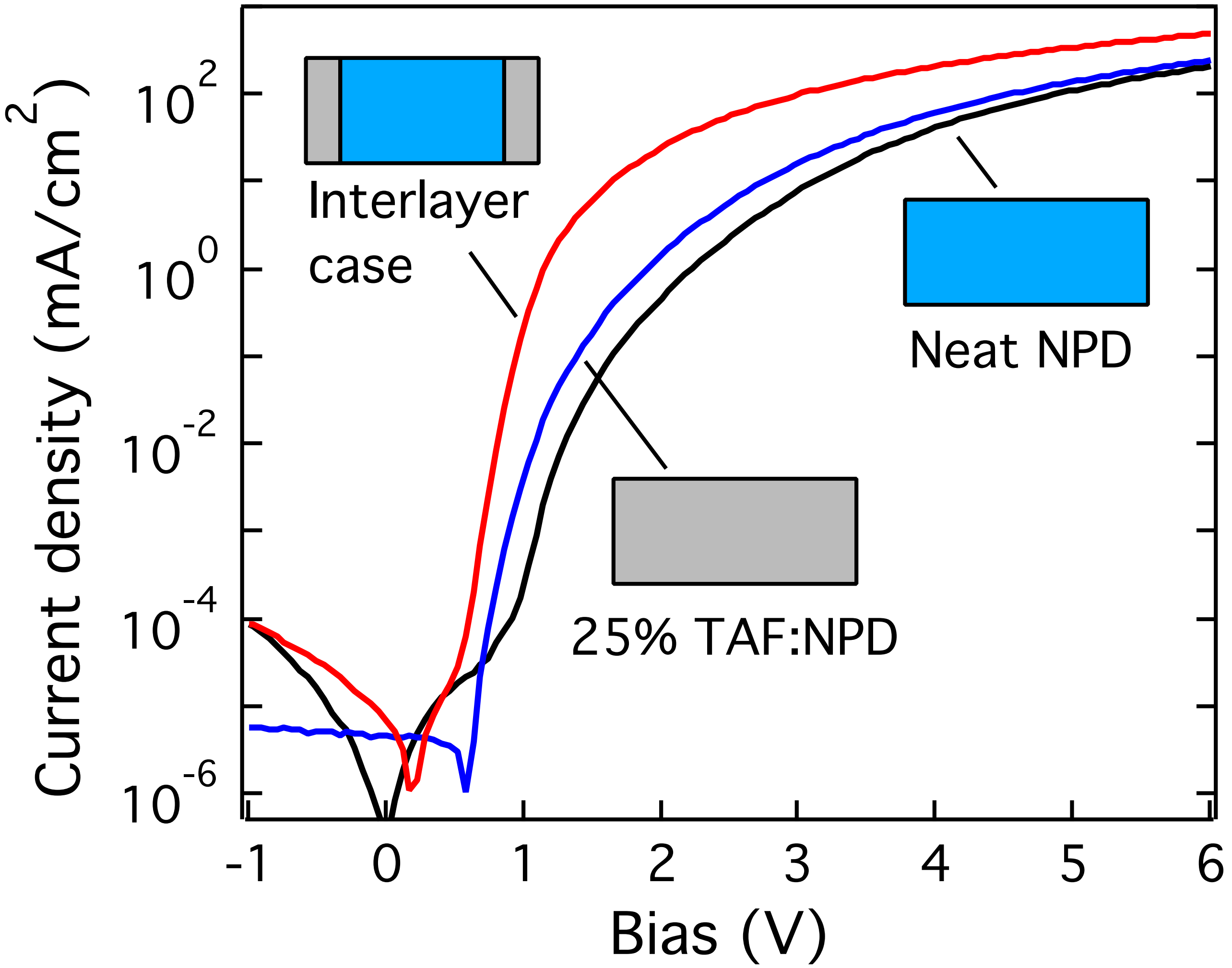








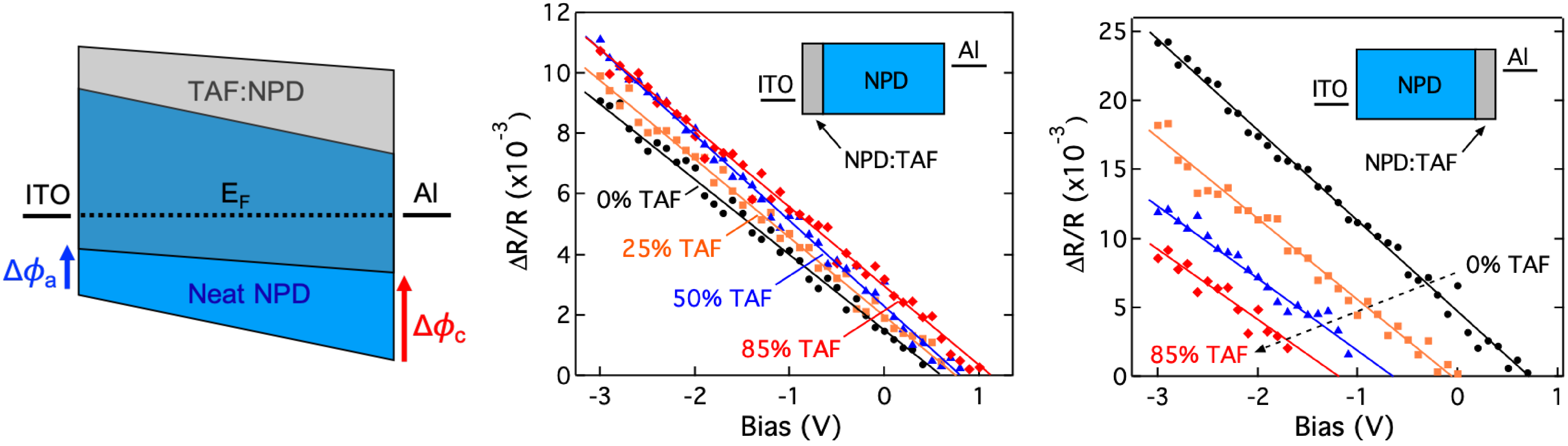
Injection or bulk transport effect?



Injection improves, bulk transport degrades

Interface energetics

- Electroabsorption to measure changes in V_{bi}:



Interface dipoles shift HOMO up at both anode & cathode

Interface energetics

- Electroabsorption to measure changes in V_{bi}:

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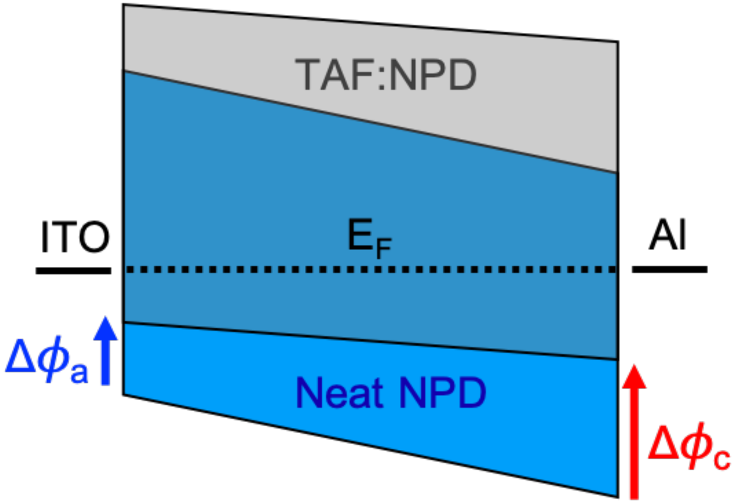
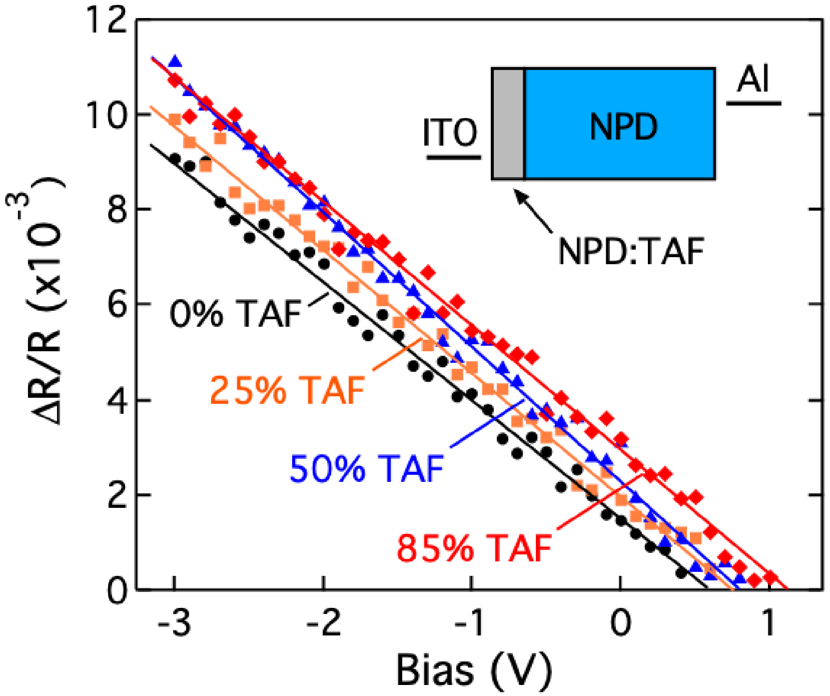
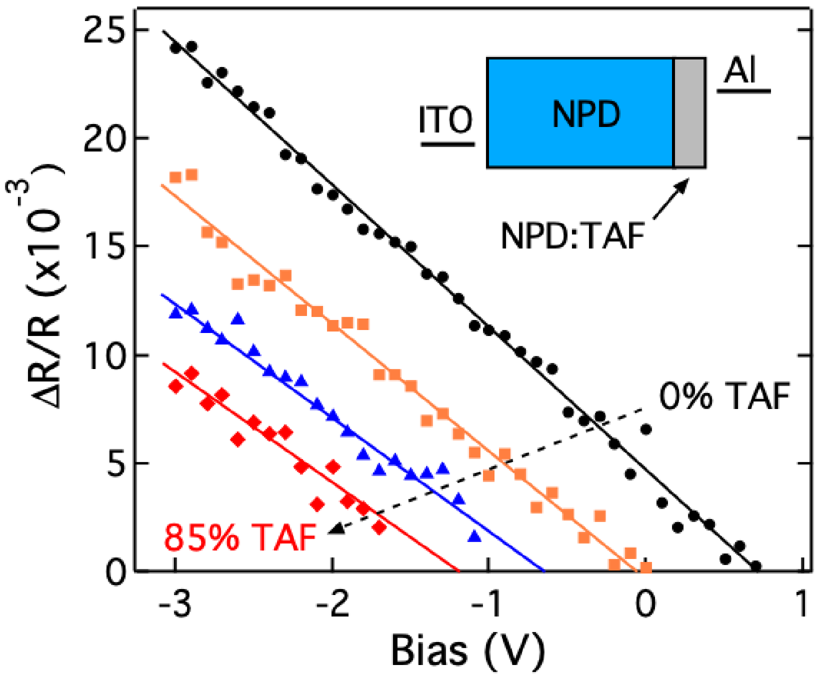
Anode/organic interface modification by plasma polymerized fluorocarbon films

J. X. Tang, Y. Q. Li, L. R. Zheng, and L. S. Hung[a)]
Department of Physics & Materials Science, City University of Hong Kong, Hong Kong, China



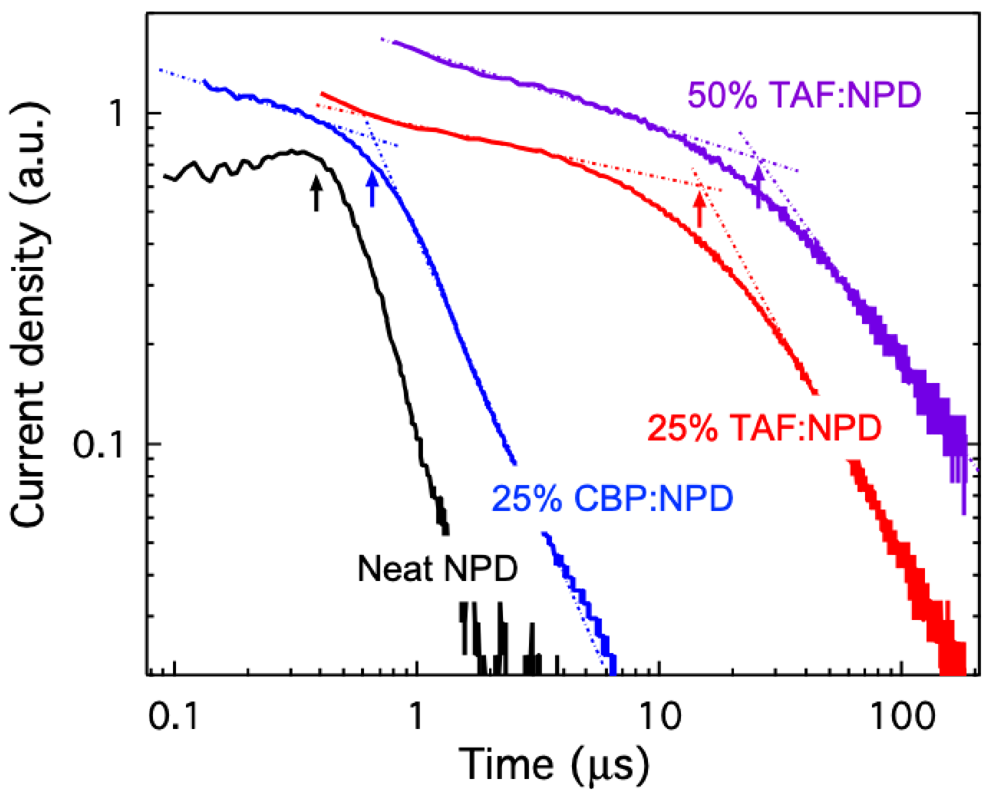


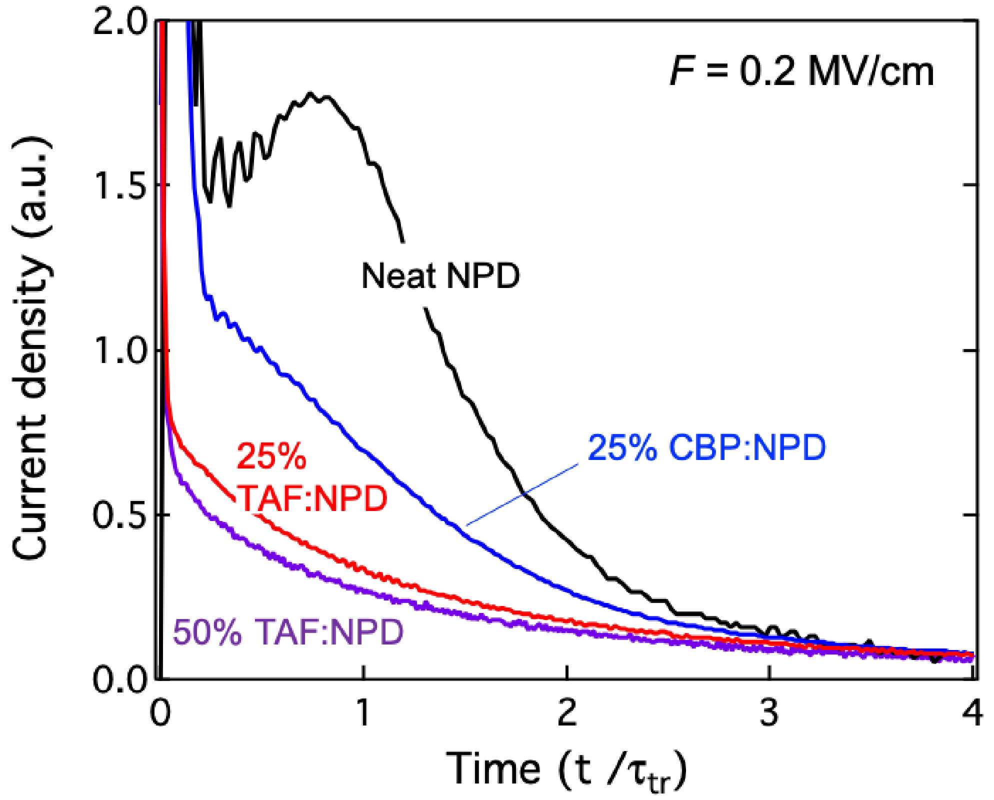


Interface dipoles shift HOMO up at both anode & cathode

Bulk transport?

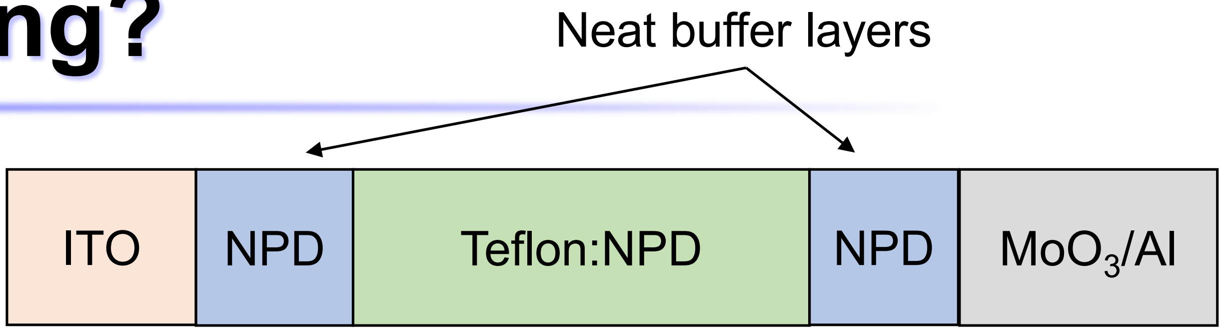
- Time-of-flight mobility:



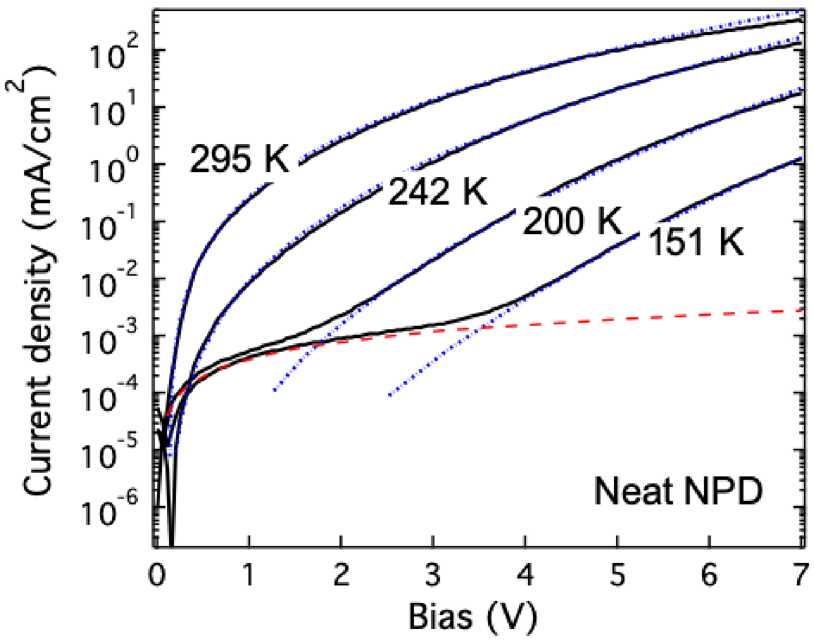


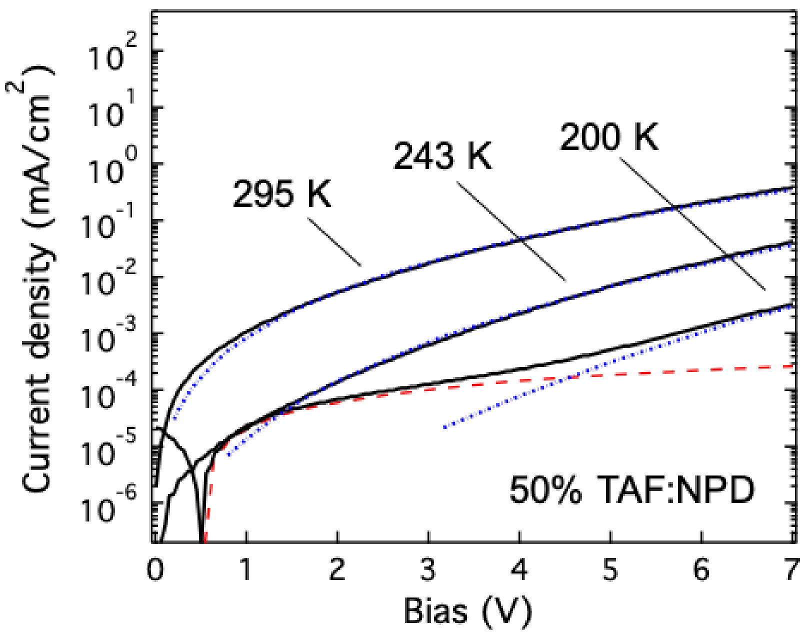
Hole mobility becomes dispersive, decreases ~50-fold

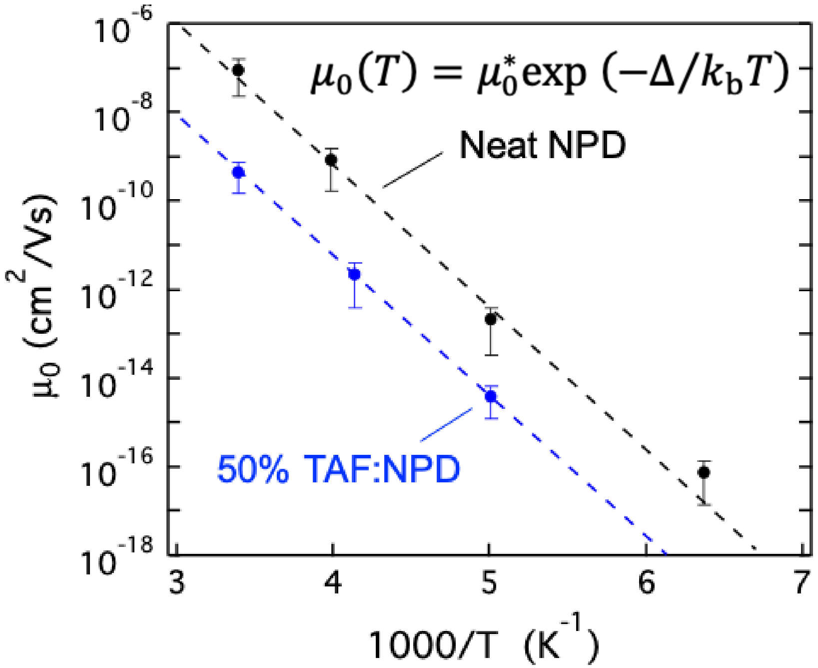
Energetic disorder/trapping?



- Temperature-dependent IVs:



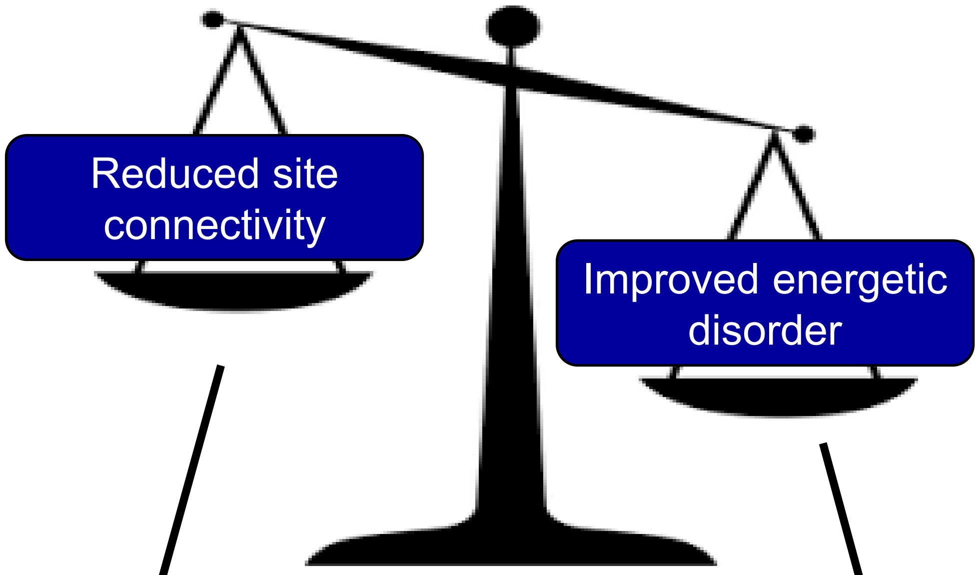


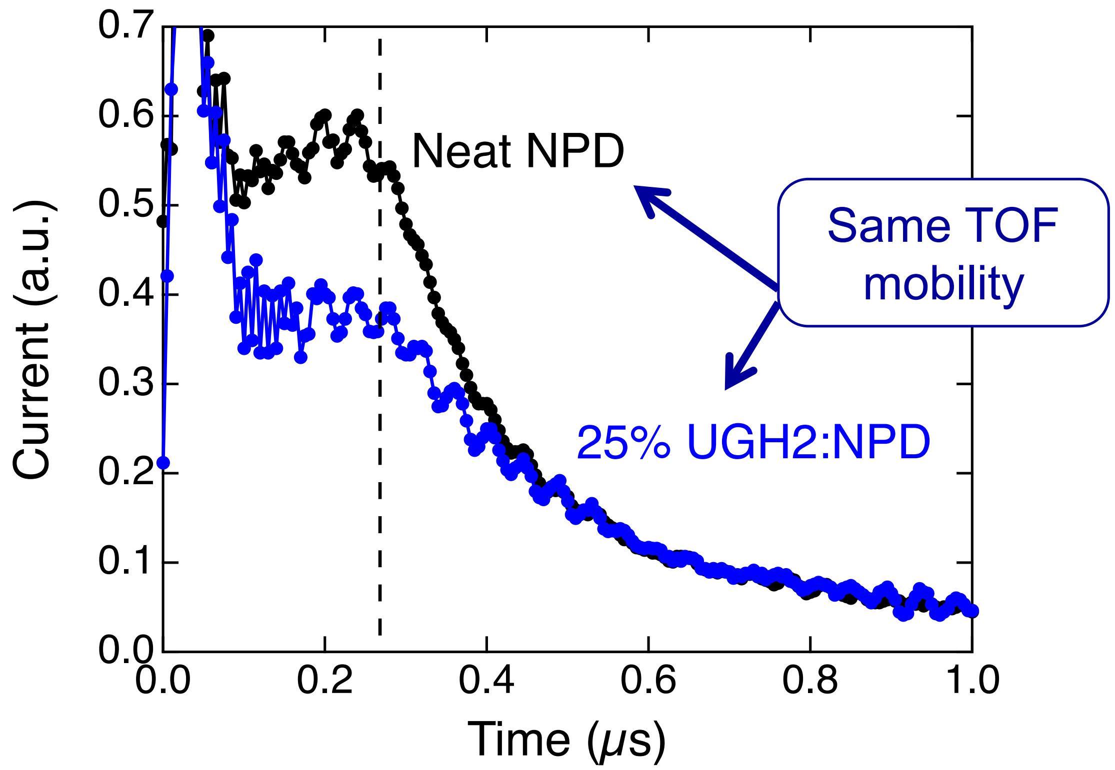


Mobility activation energy is the same → reduced site density/percolation

Prospects for improvement?

- Genuine dilution is non-trivial





- Percolation
- Blend morphology

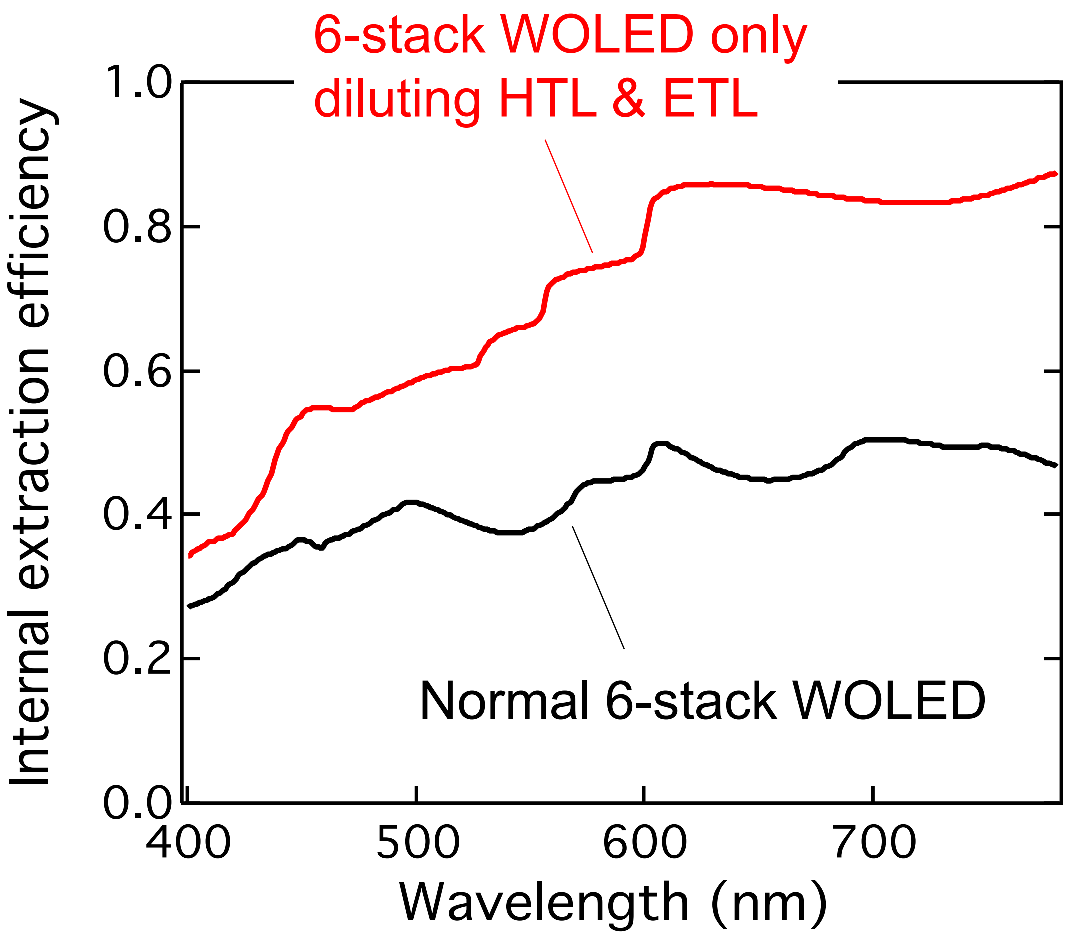
- Relative dipole moments
- Relative polarizabilities

Other considerations

- Optical properties (lower n)
- Thermal properties (higher T_g blends) …

Questions for the community

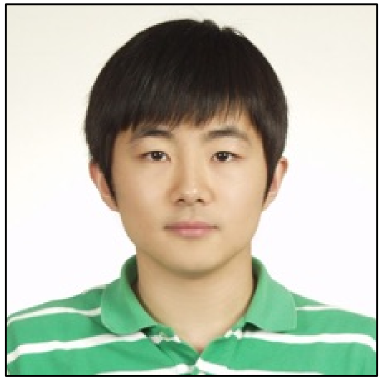
- What if we could tailor μ and n in every transport layer of a WOLED stack?
  - What does the grand electrical & optical optimization look like?
  - What does the magic dilution molecule look like? (We don't want Teflon AF)
  - Is there economic value in displacing the cost of 'expensive' organic semiconductors?



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



- **Collaborators**
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  - Mike Hickner (PSU)
- **Support:** DOE