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# Effect of Nanorod Morphology on ZnO Nanorod-Polymer Photovoltaic Device Performance

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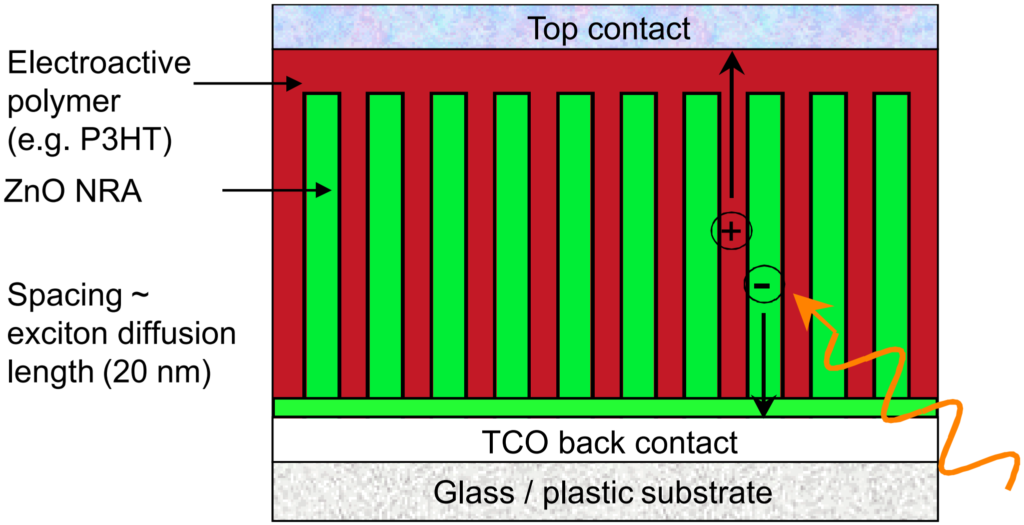
# Polymer-ZnO NRA PV Device



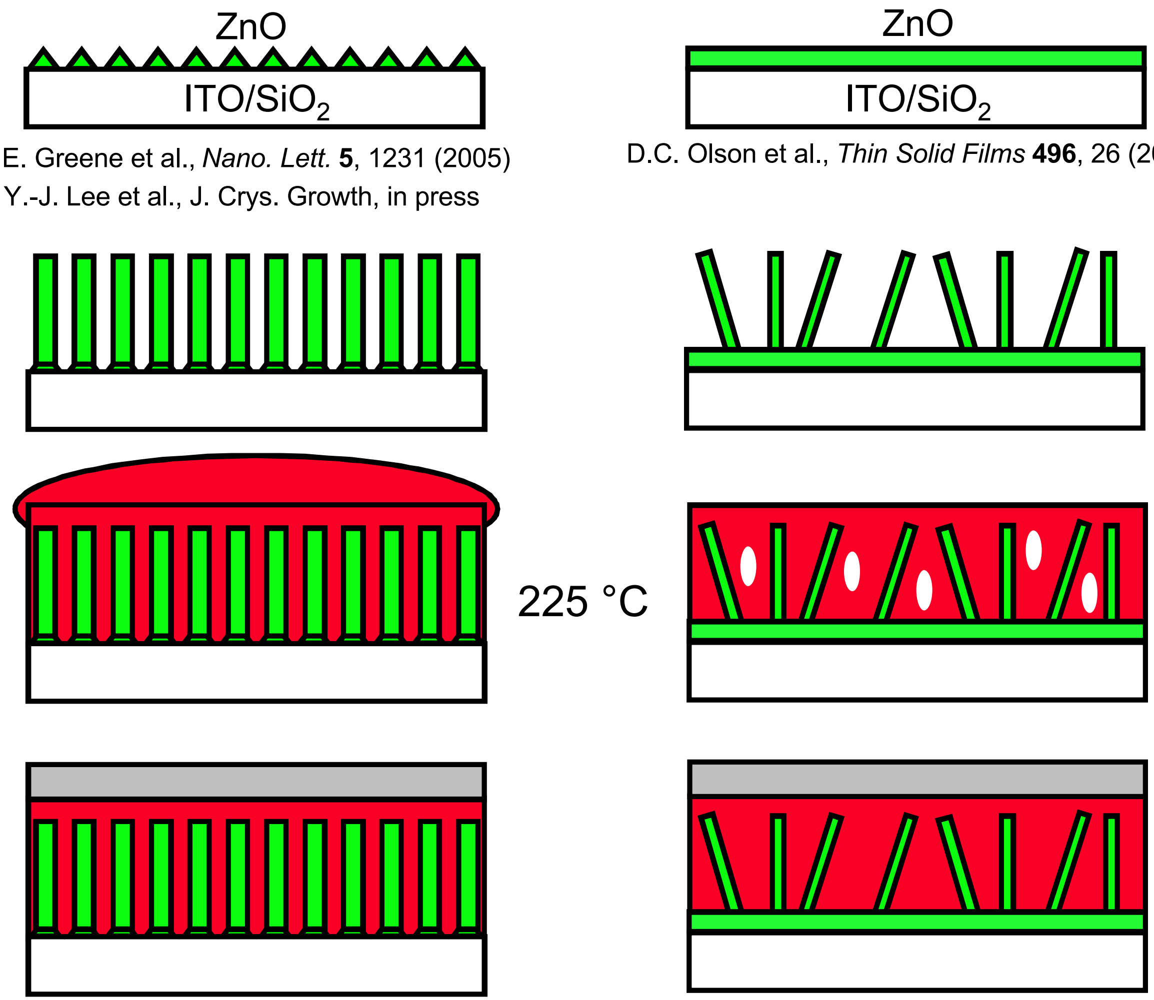

Proposed "ideal structure"

## Motivations for ZnO NRA electron transport layer

- High interfacial area
- Good electrical contact to bottom electrode
- High electron mobility (up to 10 $cm^2$ / V s)
- Potential to improve carrier collection by changing:
  - NRA alignment (interfacial area)
  - Nanorod spacing (polymer infiltration)
  - Nanorod length (interfacial area vs. carrier transport)

# PV Device Fabrication

1. Seed substrate
2. Deposit NRA
3. Deposit/anneal P3HT
4. Deposit Ag electrode



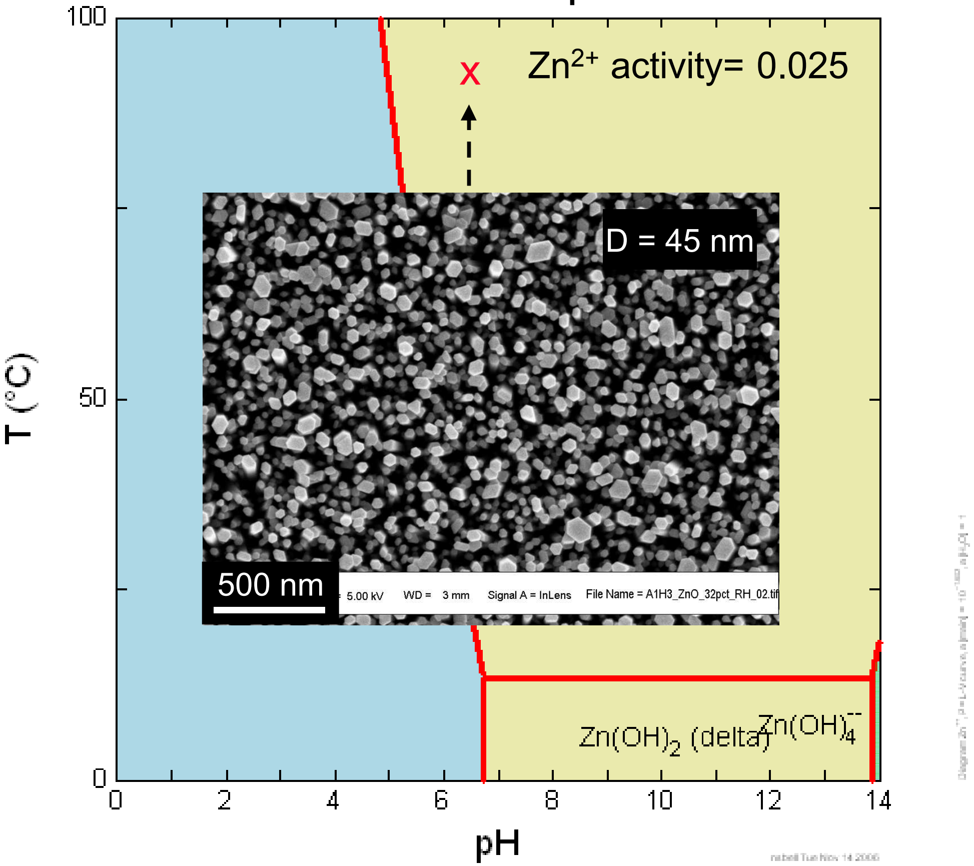

L. E. Greene et al., *Nano. Lett.* **5**, 1231 (2005)
Y.-J. Lee et al., J. Crys. Growth, in press

D.C. Olson et al., *Thin Solid Films* **496**, 26 (2006)

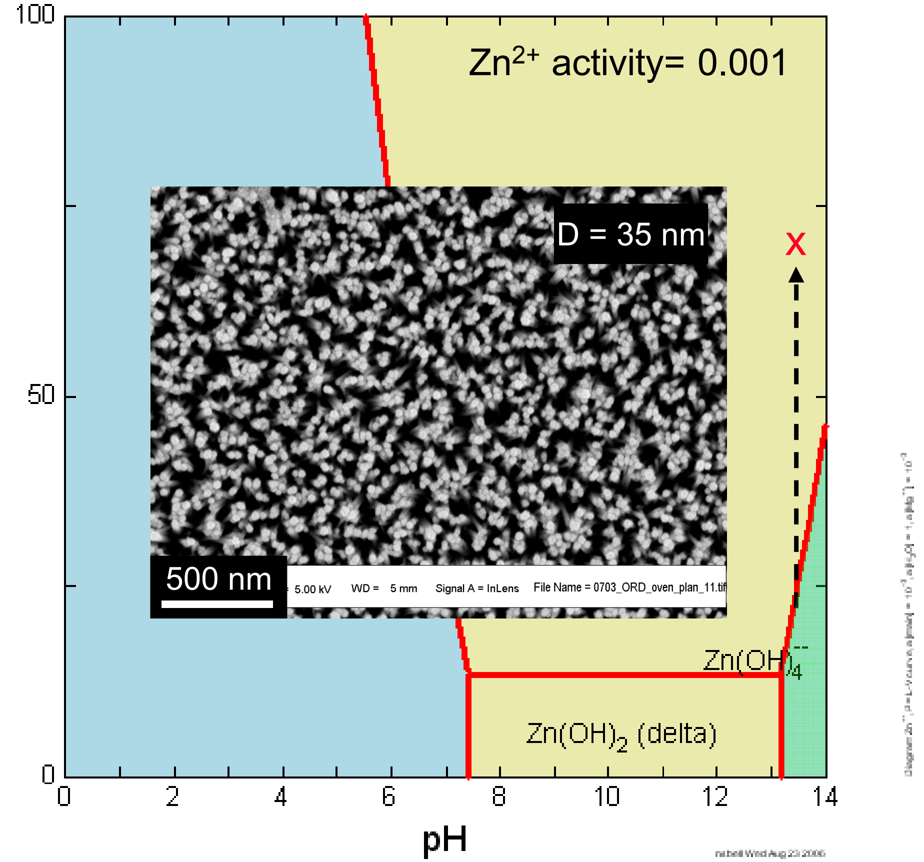
How does NRA morphology affect PV device performance?

# Zn Speciation Diagram

HMT recipe




NaOH recipe




- ZnO deposition caused by decreased solubility at high temperatures
- Soluble Zn species depends on solution pH
- ZnO NRAs with different average diameter, spacing, and possibly surface chemistry



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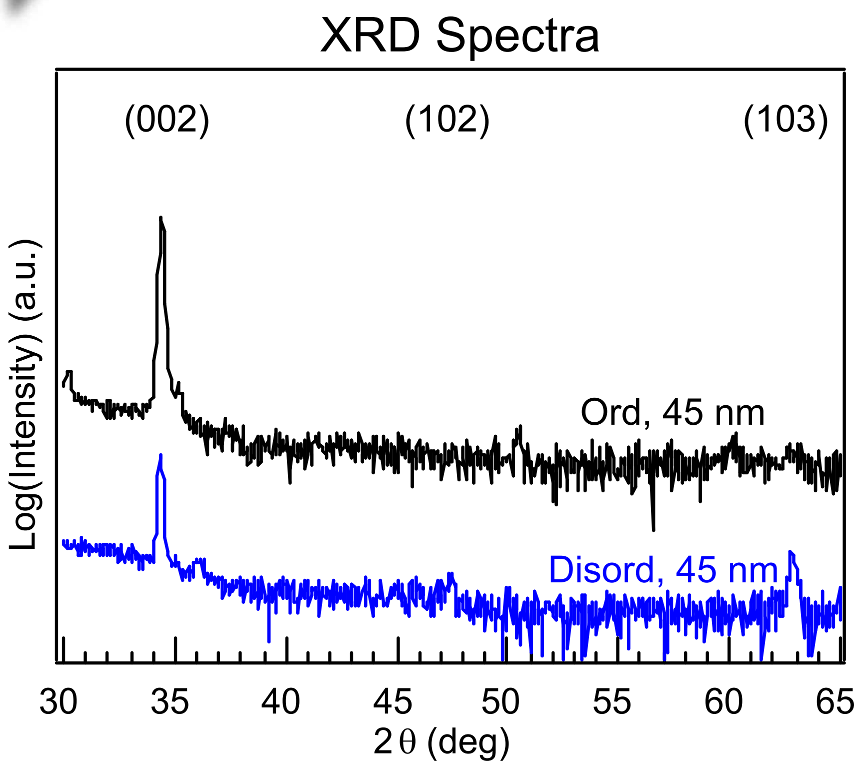
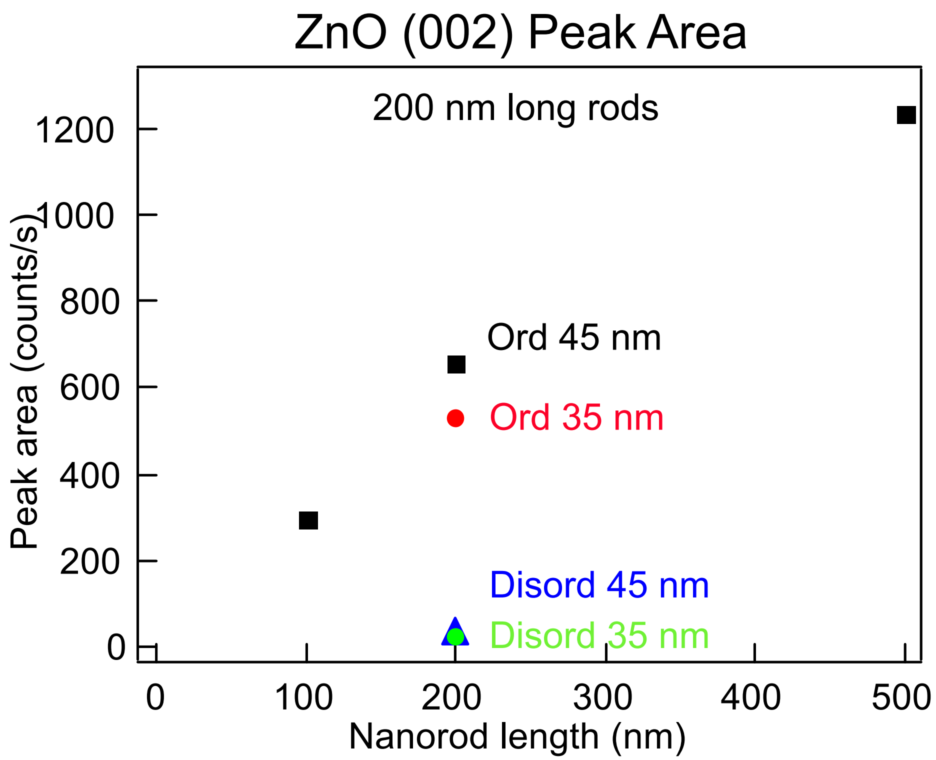
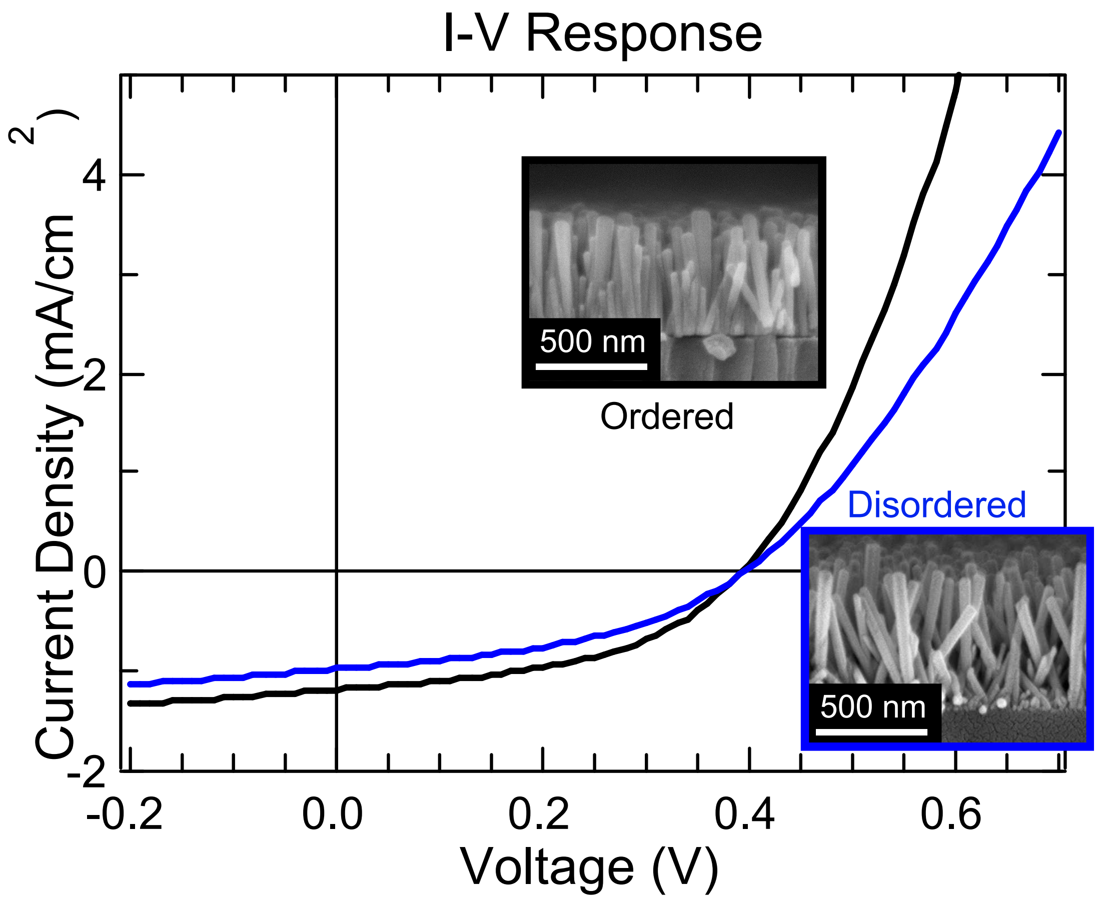
# XRD of ZnO Nanorod Arrays




- Weak (002) peak for disordered NRAs
- (103)/(002) ~ 6% for disordered NRAs
- Lower (002) peak area for NaOH vs HMT NRAs
- Diameter from FWHM agrees with SEM data
- (002) peak area linearly proportional to nanorod length

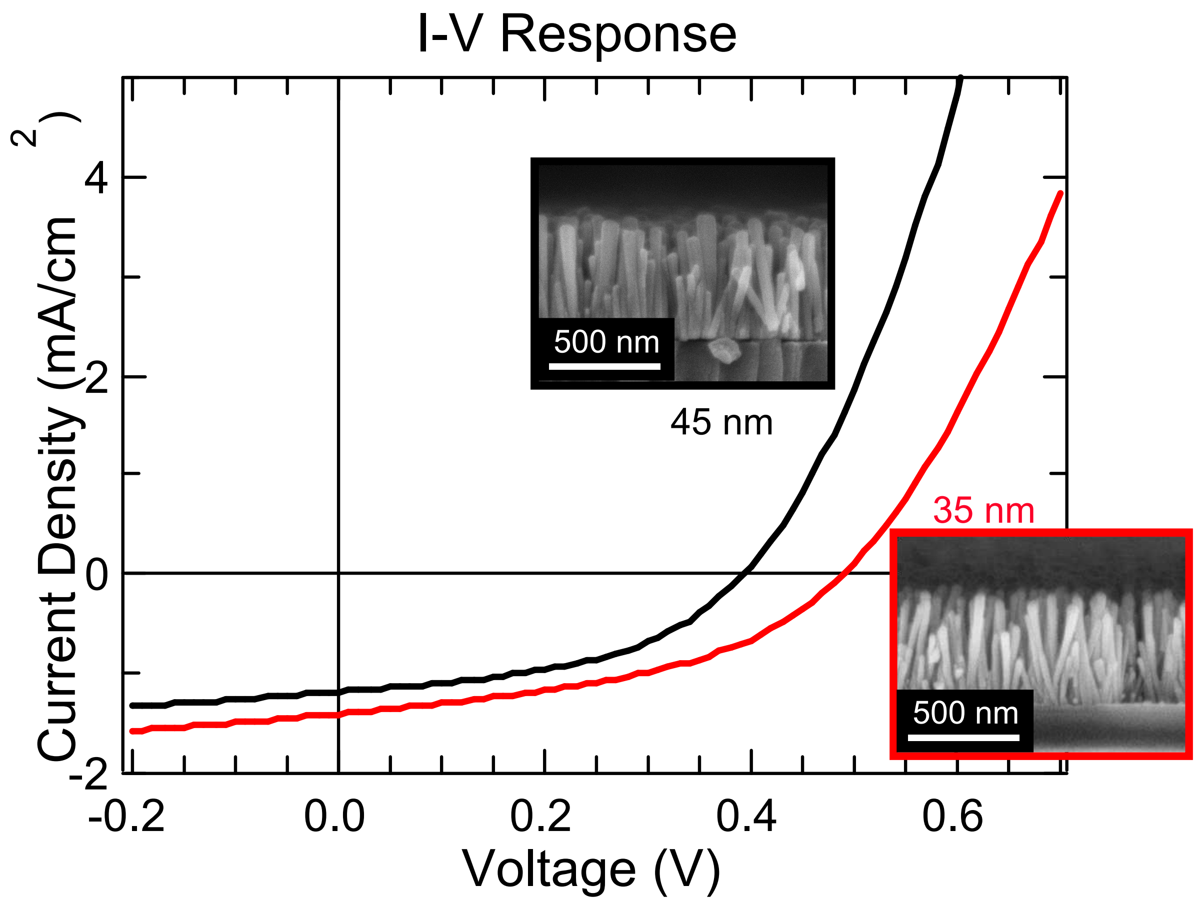
# Effect of Nanorod Alignment




| Sample | $V_{oc}$ (mV) | $J_{sc}$ (mA/cm$^2$) | FF (%) | η (%) |
|---|---|---|---|---|
| Ord 45 nm | 390 | 1.18 | 46 | 0.21 |
| Disord 45 nm | 400 | 0.98 | 42 | 0.16 |

- $J_{sc}$ increases with alignment
- No effect on $V_{oc}$
- Similar response for D = 35 nm rods

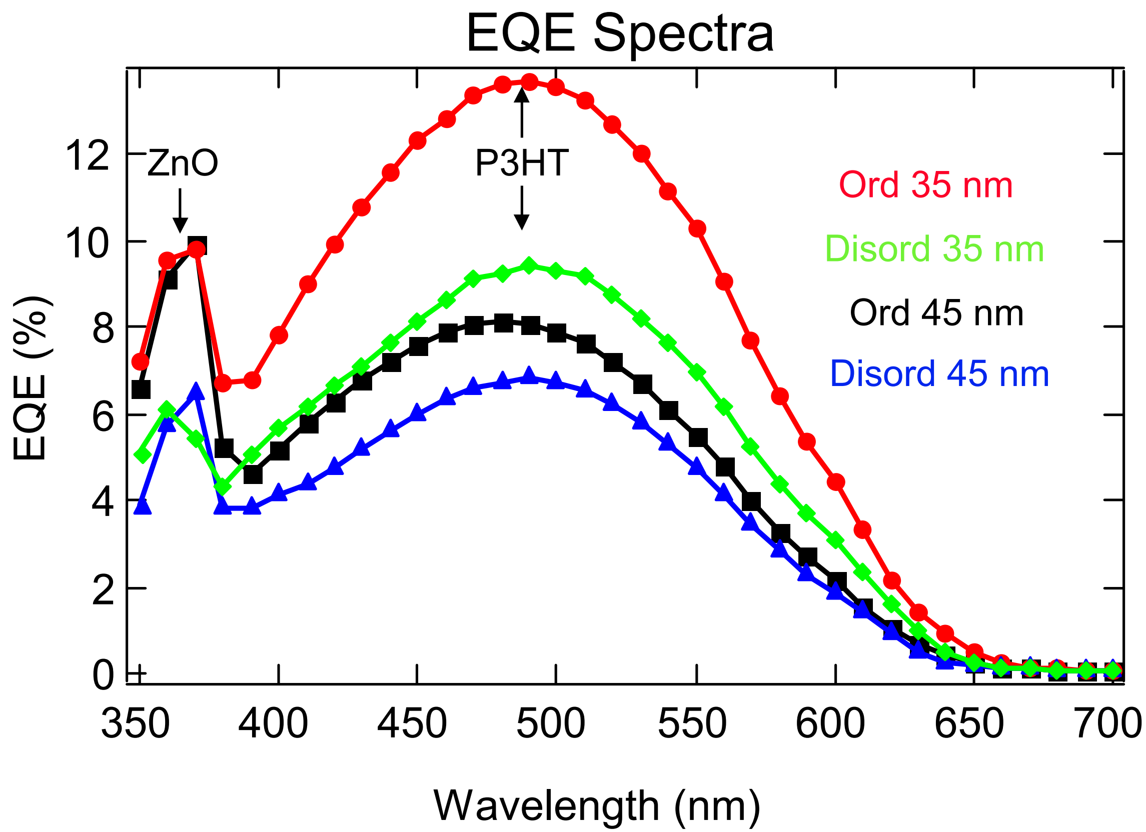
# Effect of Nanorod Diameter




| Sample | $V_{oc}$ (mV) | $J_{sc}$ (mA/cm²) | FF (%) | η (%) |
|---|---|---|---|---|
| Ord 45 nm | 390 | 1.18 | 46 | 0.21 |
| Ord 35 nm | 490 | 1.40 | 44 | 0.30 |

- Smaller diameter increases $V_{oc}$
- Smaller diameter increases $J_{sc}$
- Similar FF values

# Effect of Morphology on EQE




| Sample | $V_{oc}$ (mV) | $J_{sc}$ (mA/cm$^2$) | FF (%) | η (%) |
|---|---|---|---|---|
| Ord 45 nm | 390 | 1.18 | 46 | 0.21 |
| Ord 35 nm | 490 | 1.40 | 44 | 0.30 |
| Disord 45 nm | 400 | 0.98 | 42 | 0.16 |
| Disord 35 nm | 450 | 1.24 | 47 | 0.26 |

- Shifts mainly in EQE magnitude
- EQE improves with ordering, ↓ diameter
- OD ~ 0.9; interface/transport still need to be improved



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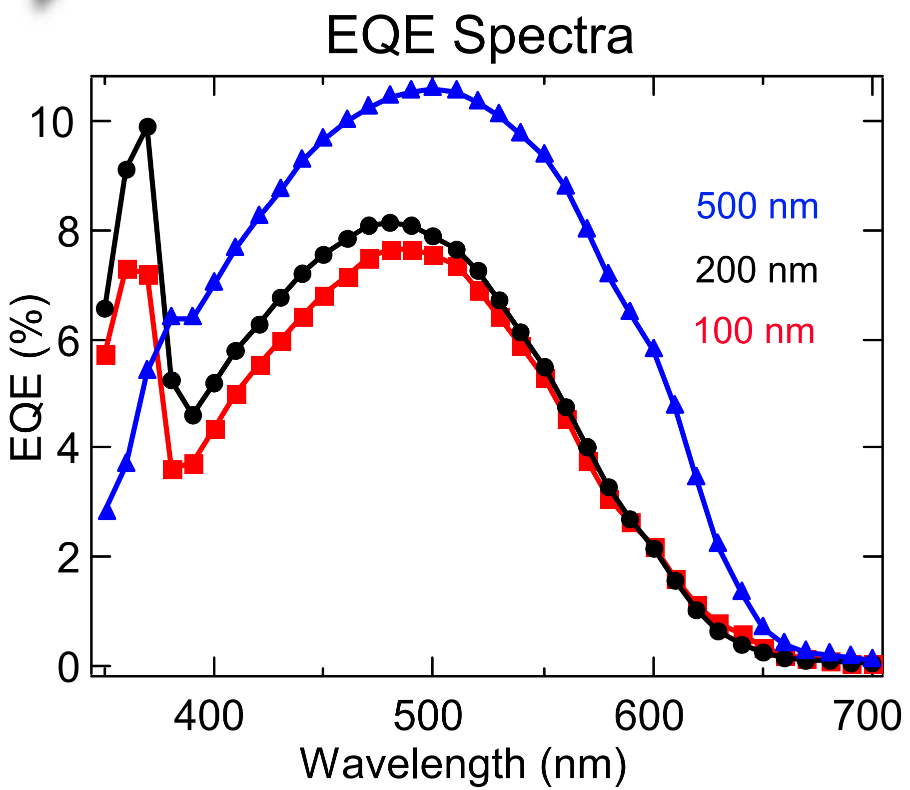
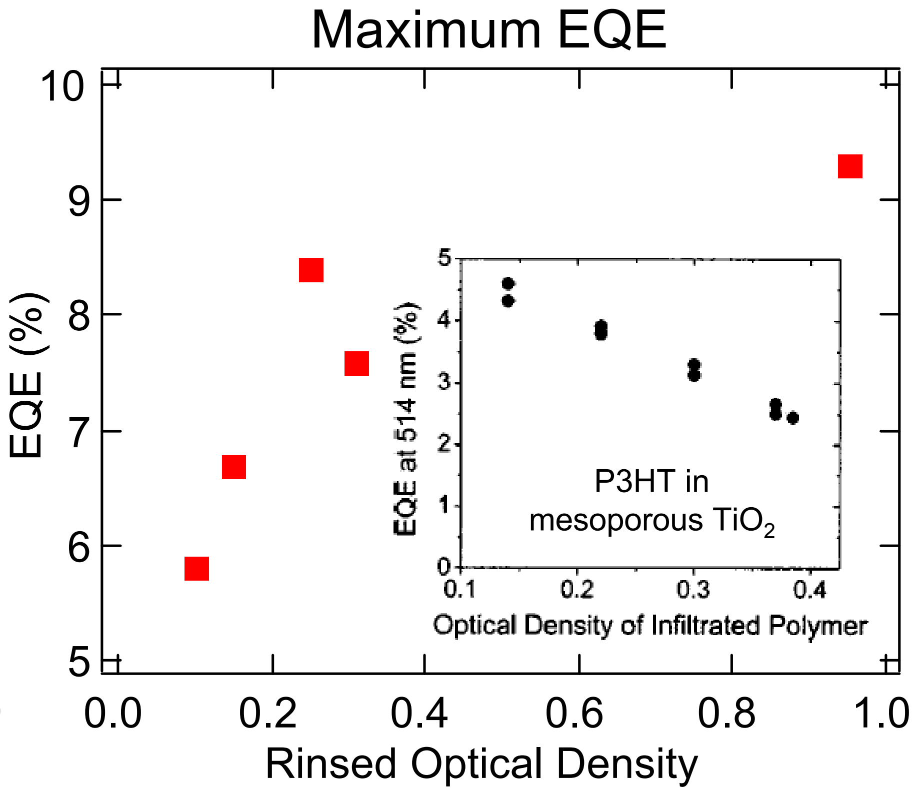
# Effect of Length on EQE




- Improvement in EQE with nanorod length/amount of polymer
- Opposite trend compared to P3HT in mesoporous $TiO_2$
- Hole transport apparently not an issue; what about interface?
- For more information, see Z8.6 (D. Olson)

K. M. Coakley and M. D. McGehee, *Appl. Phys. Lett.* **83**, 3380 (2003)

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# Conclusions and Future Work

- Aligned ZnO NRA improves efficiency by ~ 20%
  - Increased interfacial area → higher $J_{sc}$

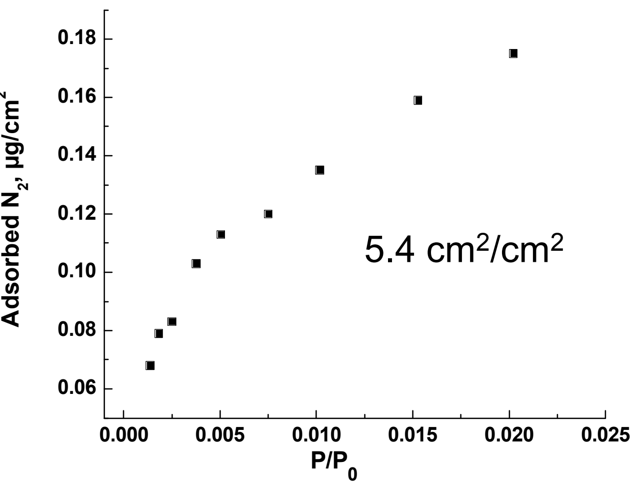
- NaOH ZnO NRA (D = 35 nm) improves efficiency by ~ 50%
  - Surface chemistry → higher $V_{oc}$?
  - Smaller diameter → increased P3HT quantity and $J_{sc}$

- Increase in ZnO NRA length improves EQE
  - Carrier transport not limiting factor for nanorod length up to 500 nm
  - Further improvement in $\eta$ possible

- Future work:
  - Enhance control of nanorod spacing
  - Improve P3HT infiltration and order

# Surface Area

Ord 45 nm




- TBD



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