Silicon and Germanium Nanocrystal Electronic Devices

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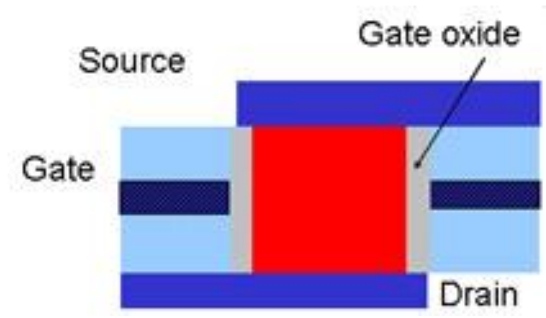
Outline

- Motivation
- Nanocrystal synthesis
- Nanocrystal characterization
- Nanocrystal thin films
  - I: Drop-casting of functionalized Ge NCs
  - II: Impaction
  - III: Spin-casting of bare Ge NCs
- Hybrid solar cells
- Summary

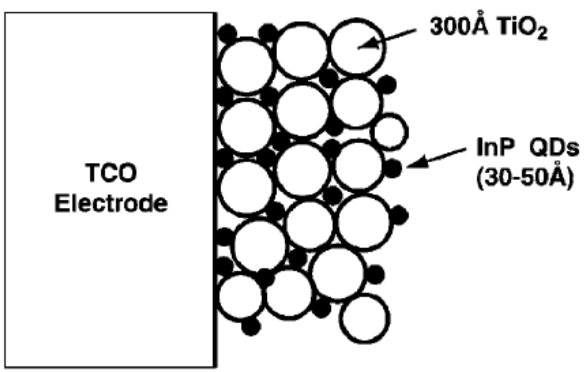
Motivation

Semiconductor nanocrystal applications

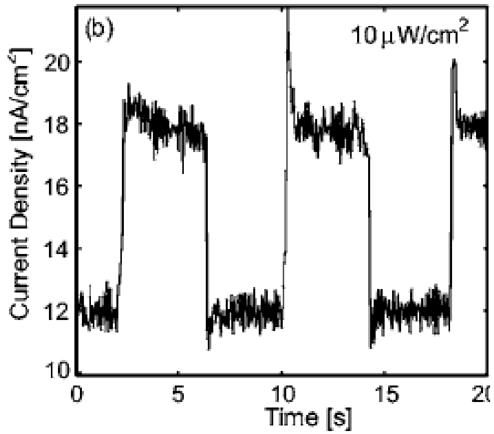
- •Transistors
- •LEDs
- •Photodiodes
- •Solar cells



Y. Ding, et al., *IEEE Trans. Electron. Devices* **53**, 2525 (2006).



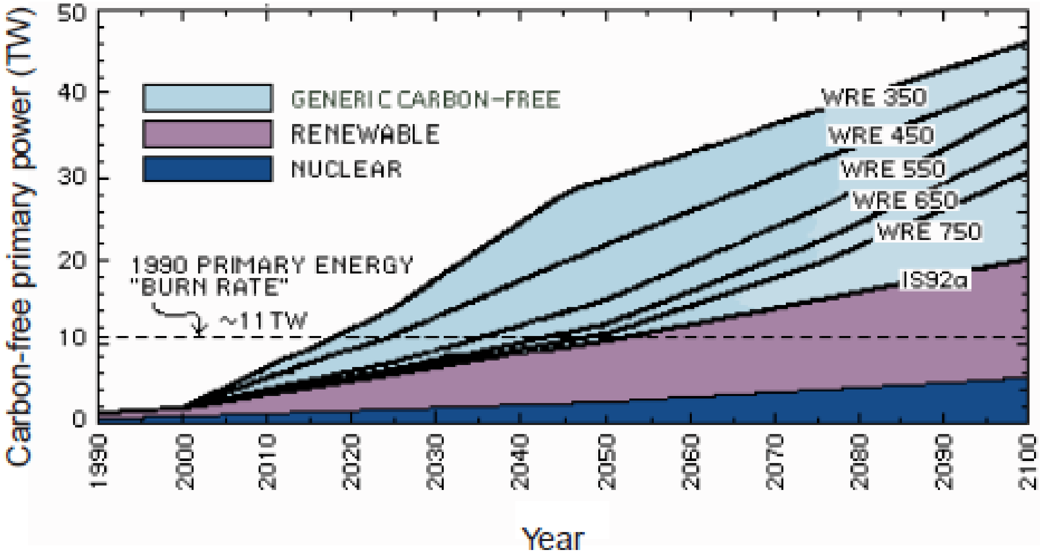
A. Nozik, *Physica E* **14**, 115 (2002).



D. Oertel, et al., *Appl. Phys. Lett.* **87**, 213505 (2005).

Rowher, et al., Sandia Natl. Lab. (2003).

Motivation



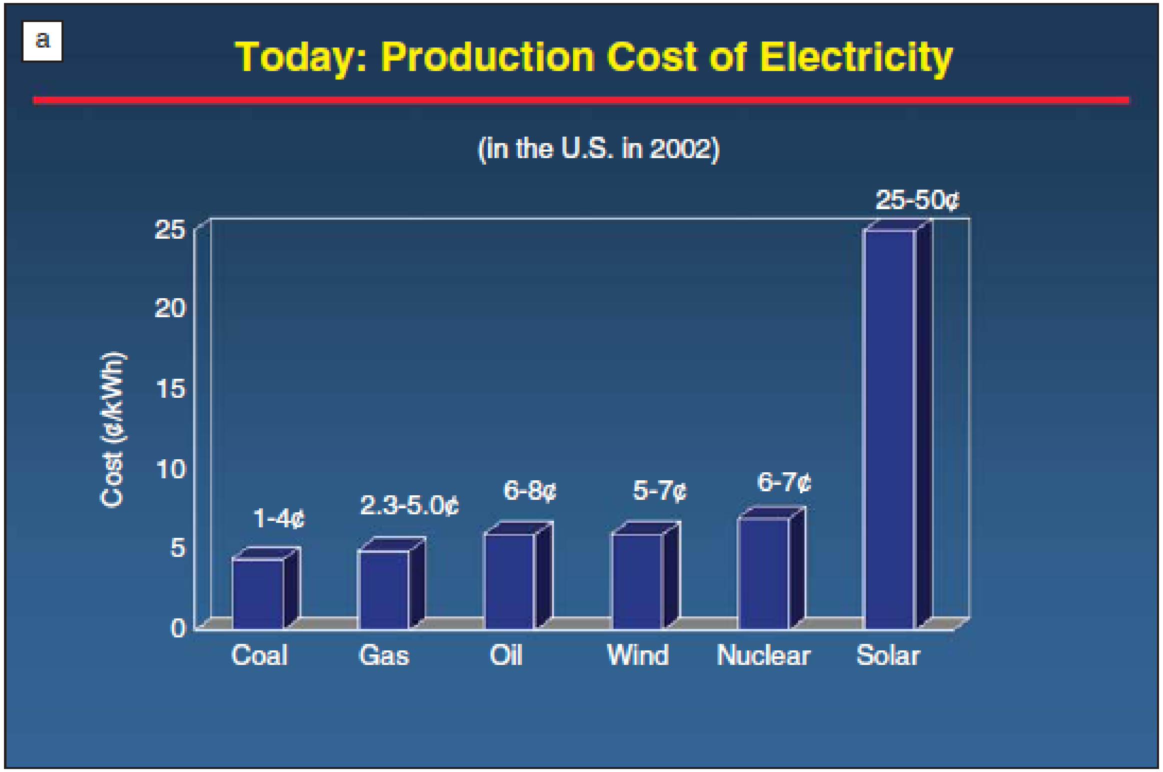
M.I. Hoffert, et al., *Nature* **395**, 881 (1998).

Need >10 TW of carbon-free power by 2050.

Source	Theoretical Resources	Practical Resources
Hydro	4.6 TW	1.5 TW
Wind		2 TW
Geothermal	12 TW	< 10 TW
Biomass	50 TW	< 10 TW
Solar	120,000 TW	> 50 TW

N.S. Lewis, *MRS Bull.* **32**, 808 (2007).

Motivation

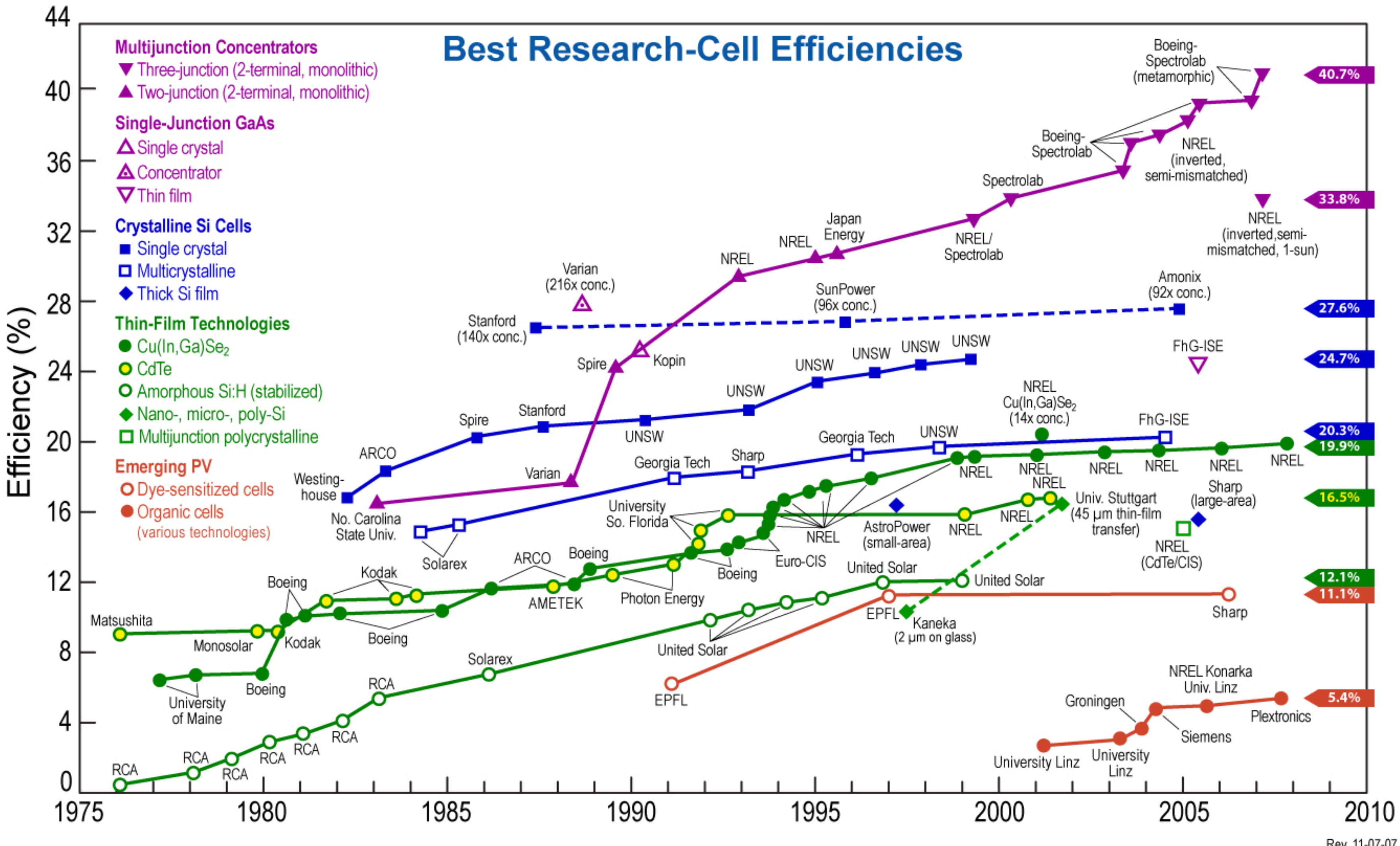


N.S. Lewis, *MRS Bull.* **32**, 808 (2007).

Metric (cost/energy output) is ~10x too large.

Motivation

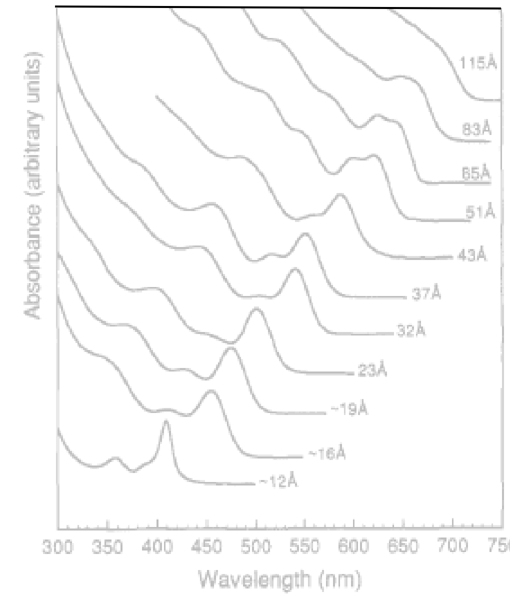
Kortshagen Group



Little improvement in efficiency.
“Breakthrough technology” needed.

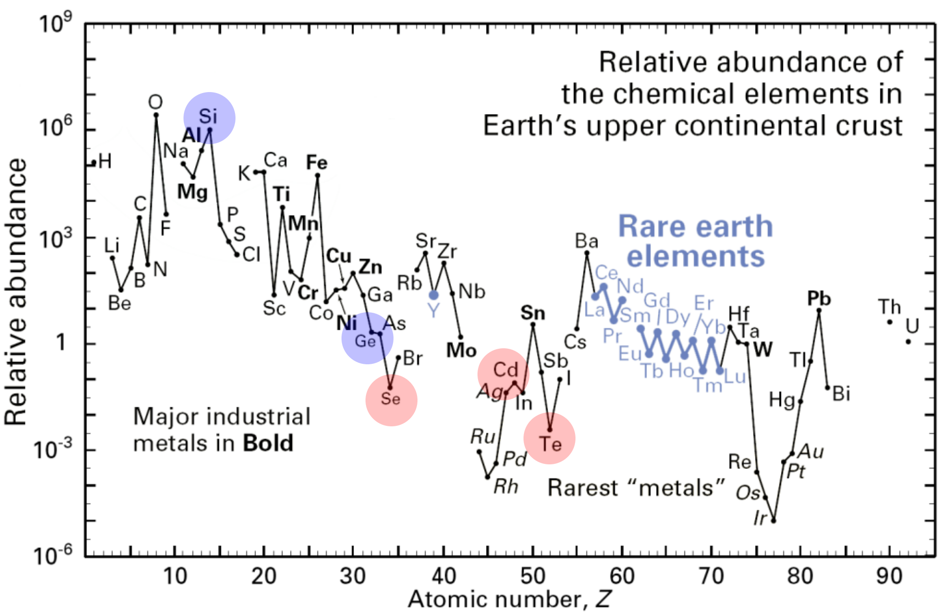
Motivation

C.B. Murray, et al., *J. Am. Chem. Soc.* **115**, 8706 (1993).



Nanocrystal solar cells

- Tunable absorption » Multijunction devices
- Large conductivities & mobilities » High efficiencies
- Easily processed » Cost reduction opportunities



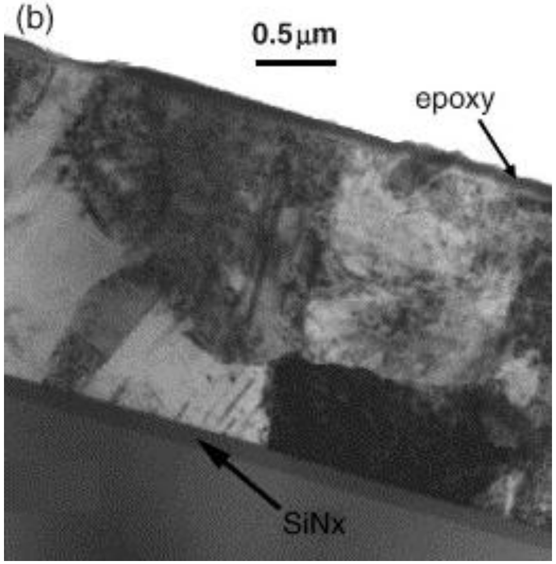
US Geological Survey, Fact Sheet 087-02 (2002).

Si & Ge nanocrystals (NCs)

- Non-toxic
- Abundant
- Compatible with Si technologies

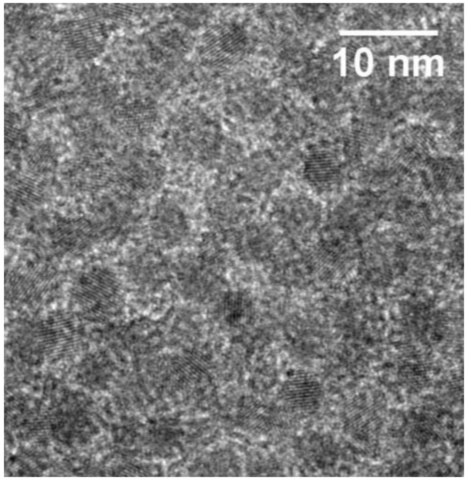
Motivation

NC seeded crystallization of a-Si:H

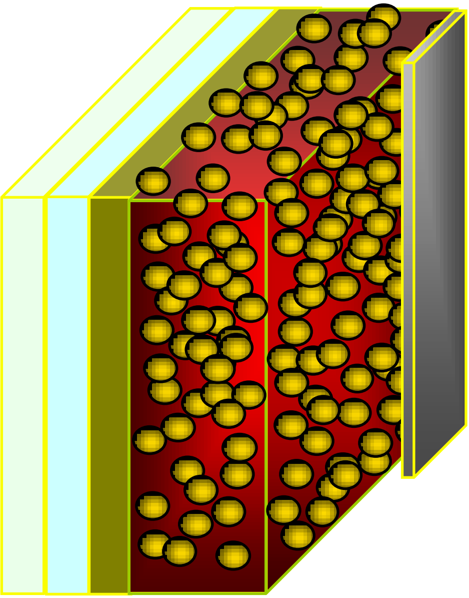


Song et al., Thin Solid Films, 2006

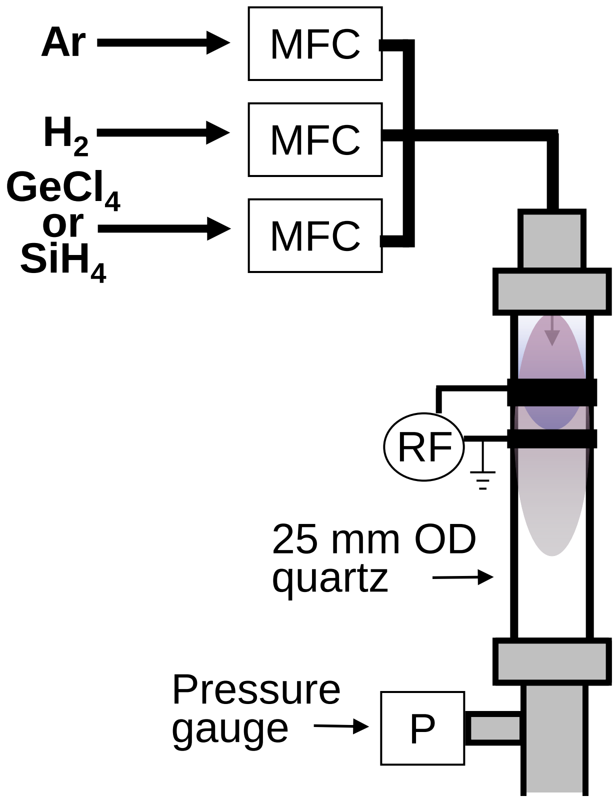
NC-only thin films



NC/polymer hybrid solar cells



NC synthesis



5 nm Ge NC recipe

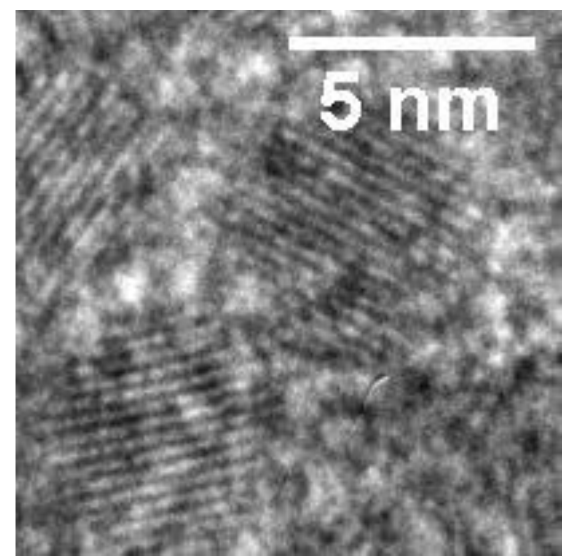
Ar Flow: 42 sccm

$GeCl_4$ Flow: 2 sccm

H_2 Flow: 30 sccm

Pressure: 2 Torr

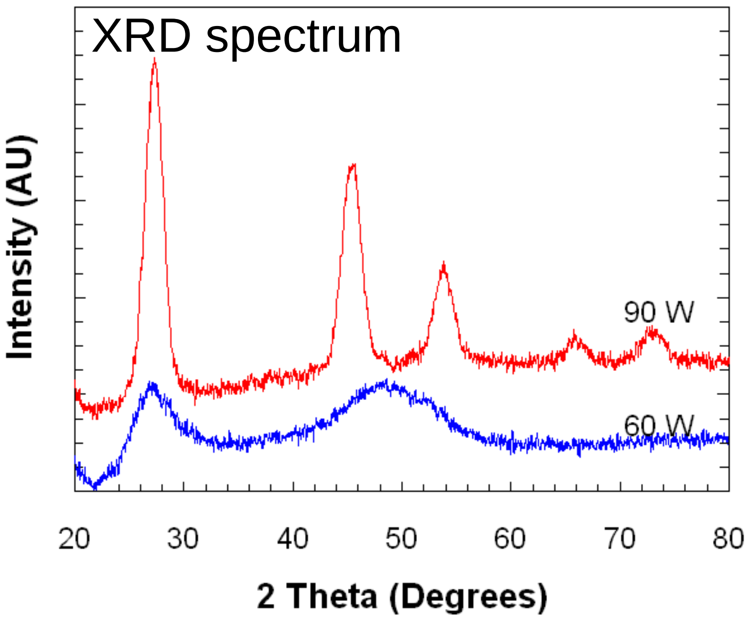
Power: 125 W



L. Mangolini, et al., *Nano Lett.* **5**, 655 (2005).

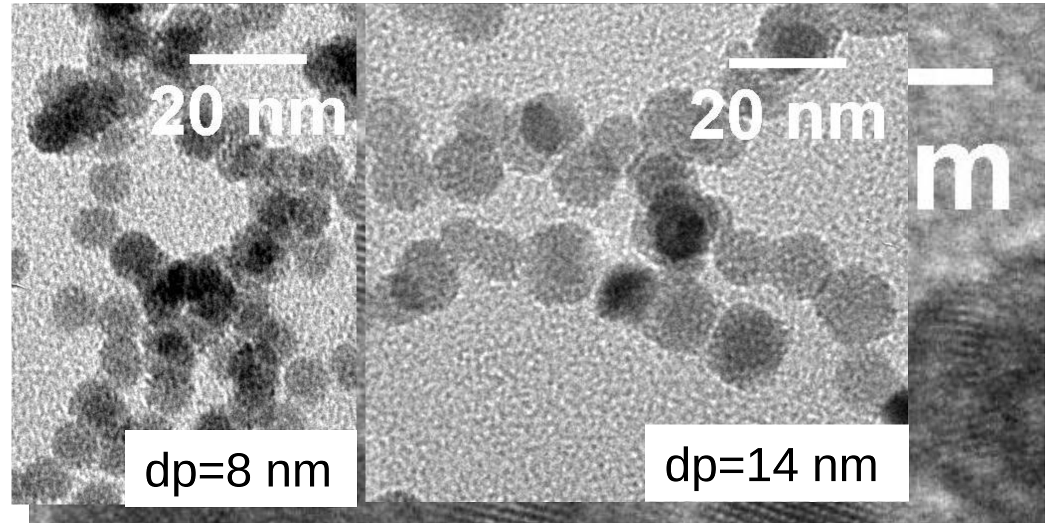
R. Gresback, et al., *Appl. Phys. Lett.* **91**, 093119 (2007).

NC characterization



Si & Ge NC properties

- •Spherical
- •Freestanding
- •Tunable size (3-50 nm)
- •Relatively monodisperse (std. dev. 10-15% <d_p>)
- •Controllable crystallinity

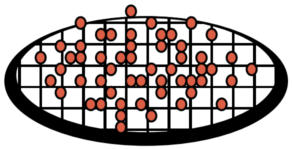


R. Gresback, et al., *Appl. Phys. Lett.* **91**, 093119 (2007).

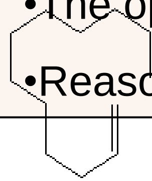
Film formation I

For devices, need films that have...

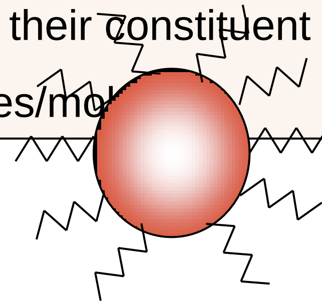
- The optical properties of their constituent particles
- Reasonabl ities/mo



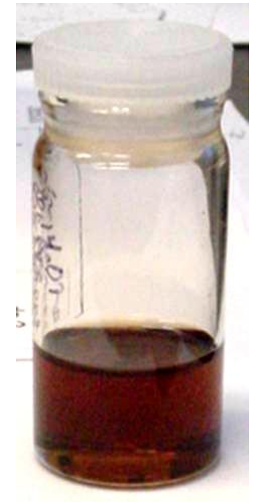
Nanocrystals collected on mesh

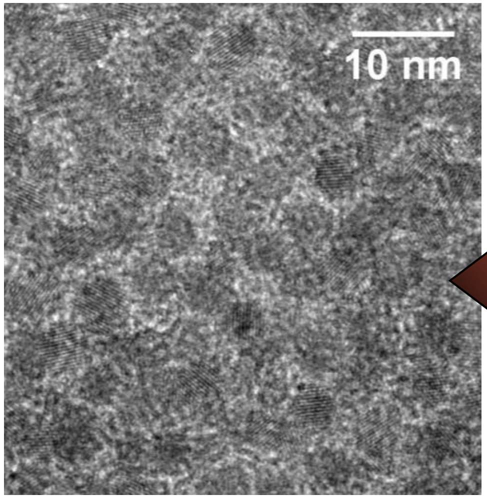


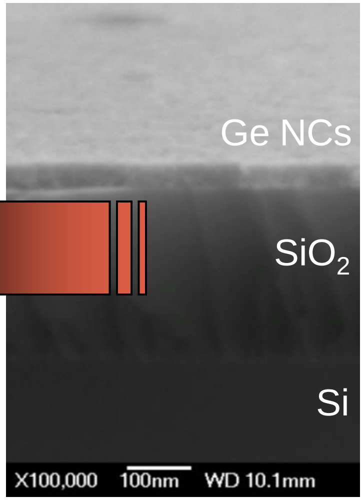
1-Dodecene
$C_{12}H_{24}$

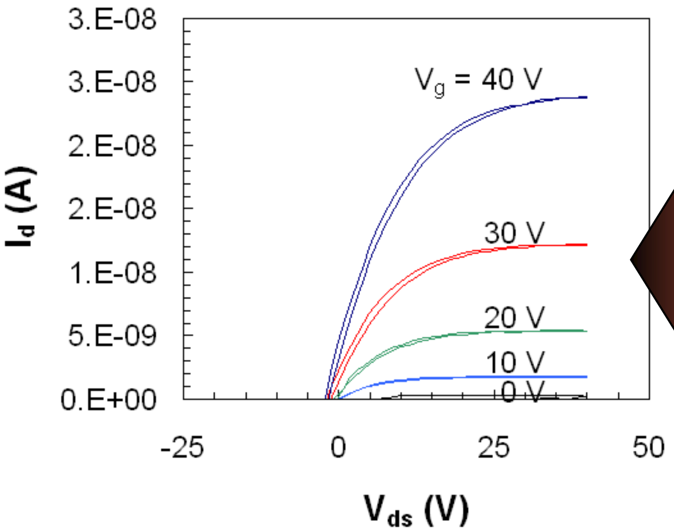


Dissolves in common non-polar solvents

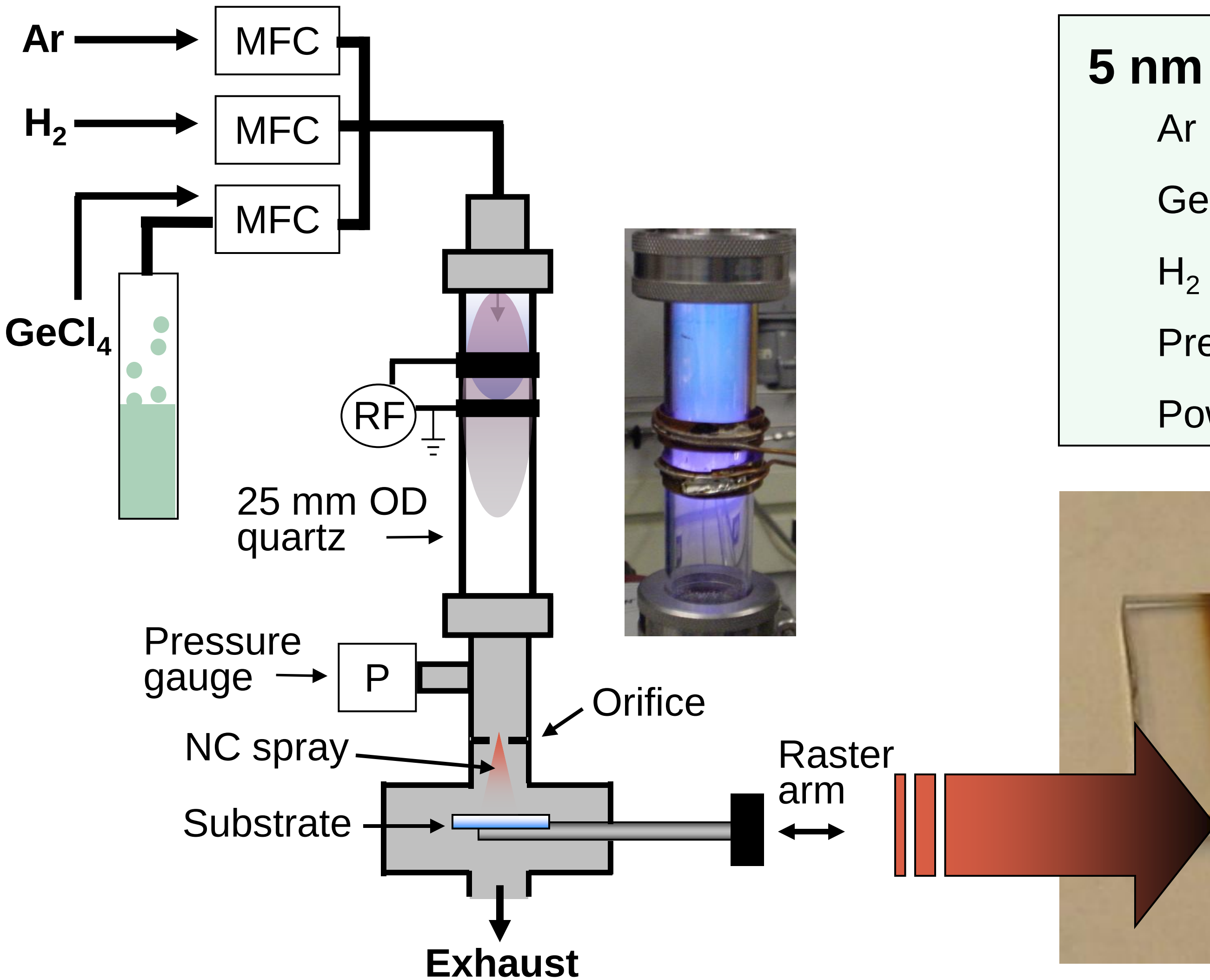








Film formation II



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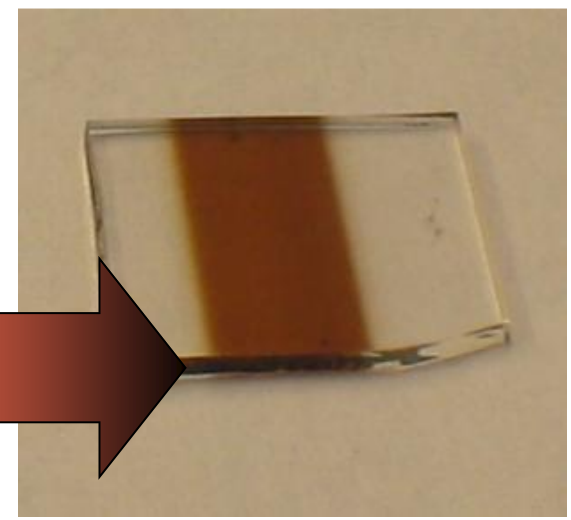
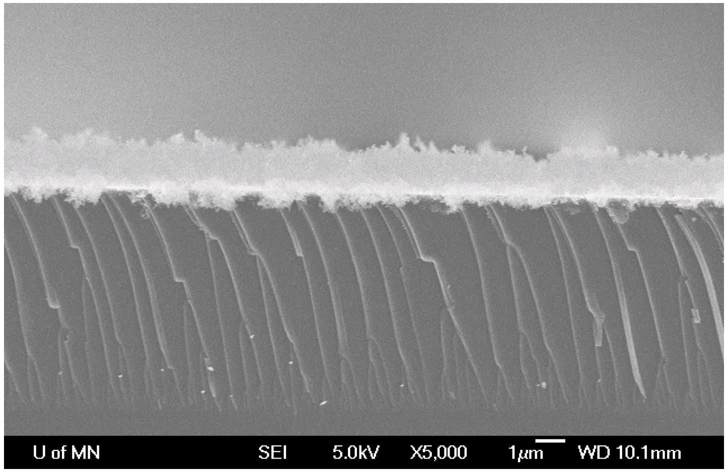
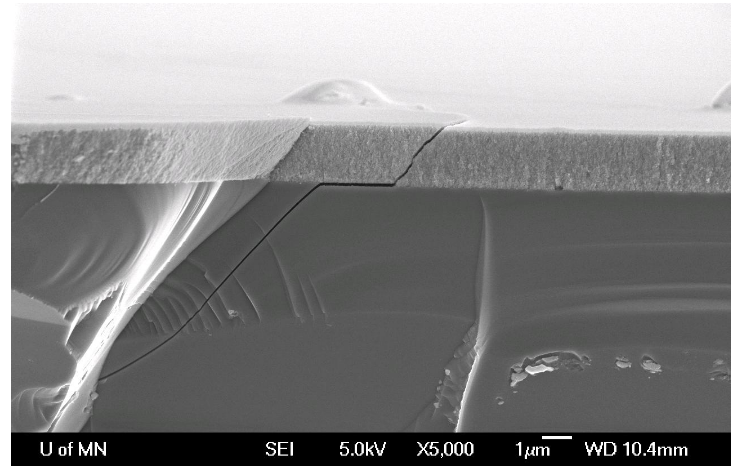


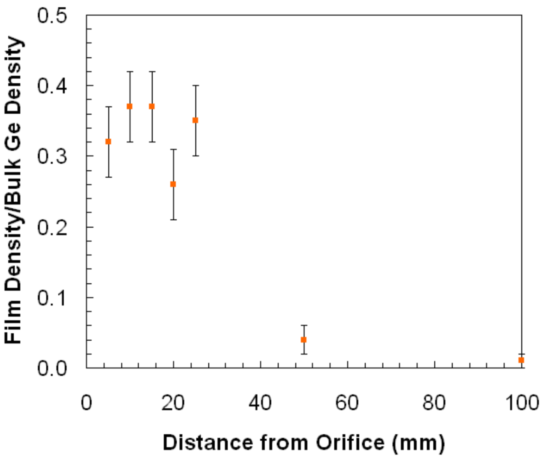
Film formation II

Kortshagen Group

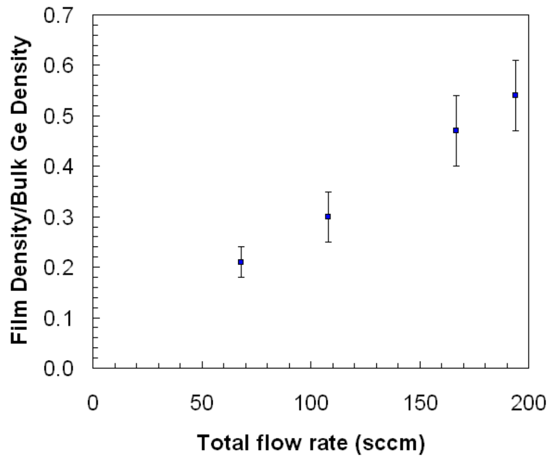




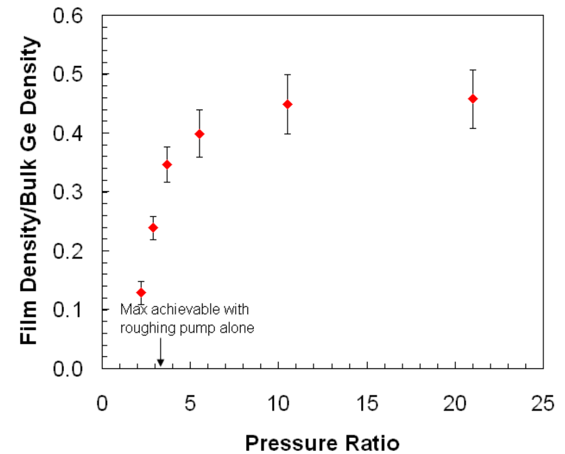
Total flow rate = 74 sccm,
Pressure ratio ~ 4



Distance from orifice ~10-20 mm,
Pressure ratio ~ 4



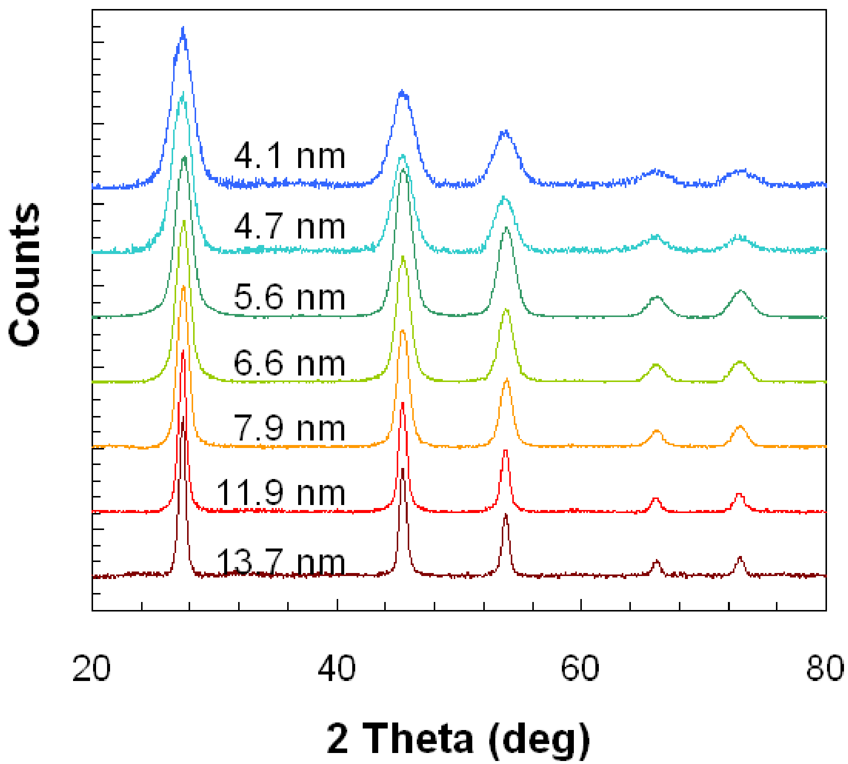
Total flow rate = 113 sccm,
Distance from orifice ~10-20 mm

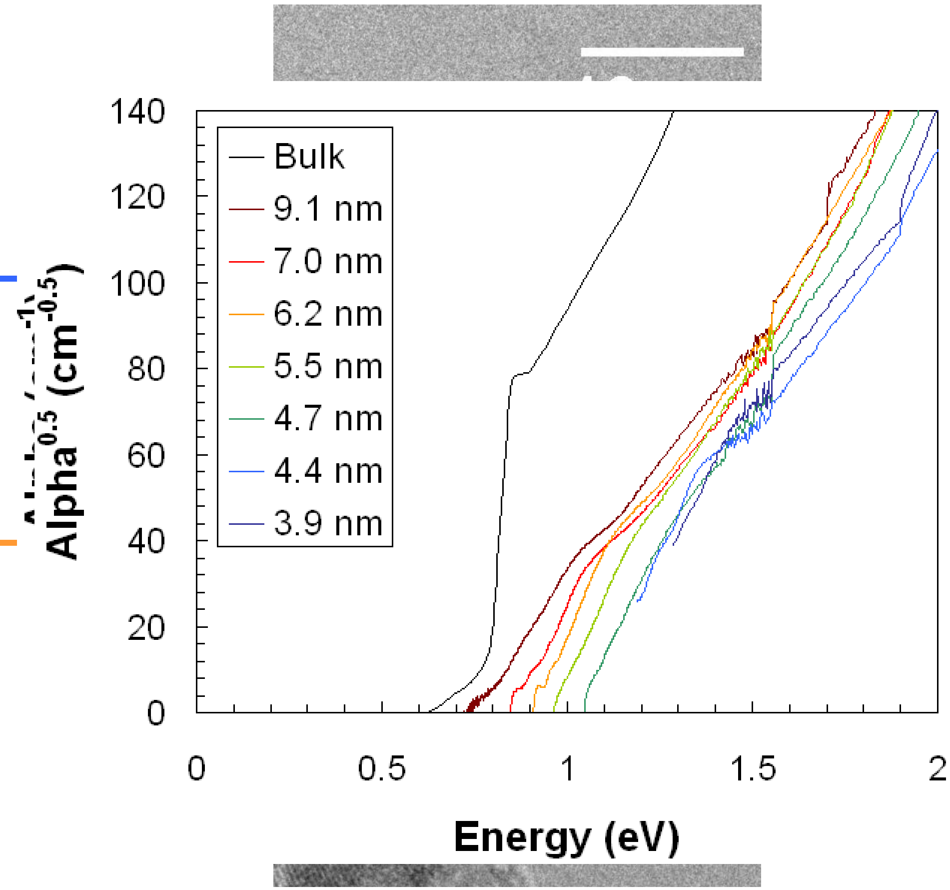


Film densities approaching 60% bulk value

Film formation II

Kortshagen Group





Average crystallite

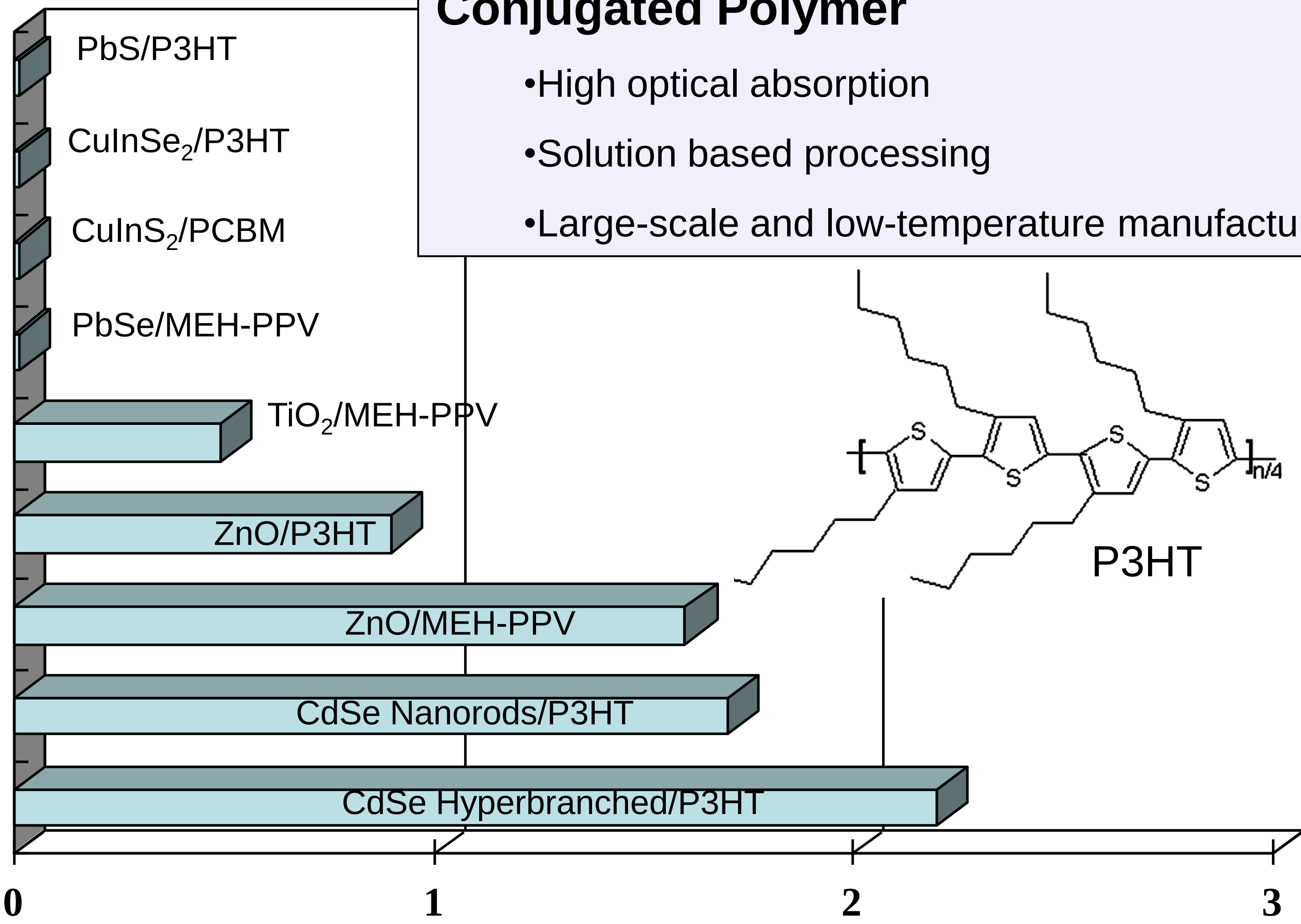
Bandgap widens to >1 eV

from 4-14 nm

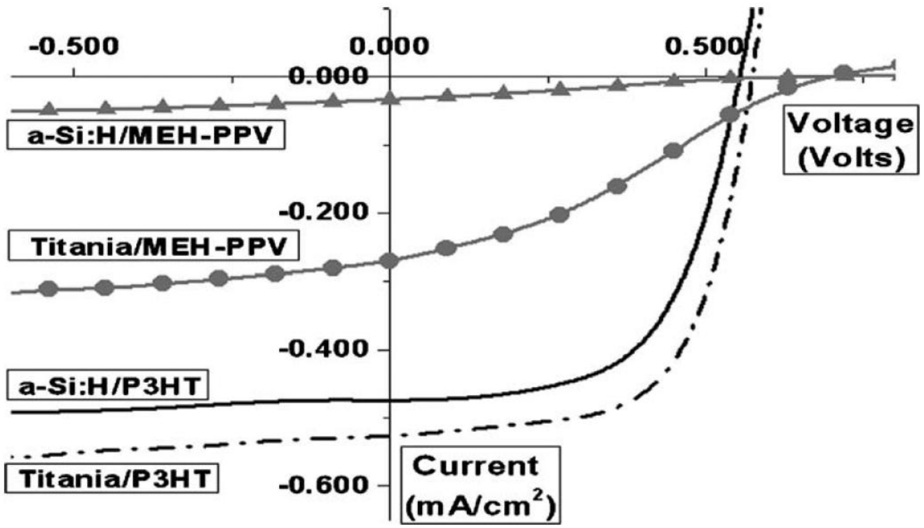
Hybrid solar cells

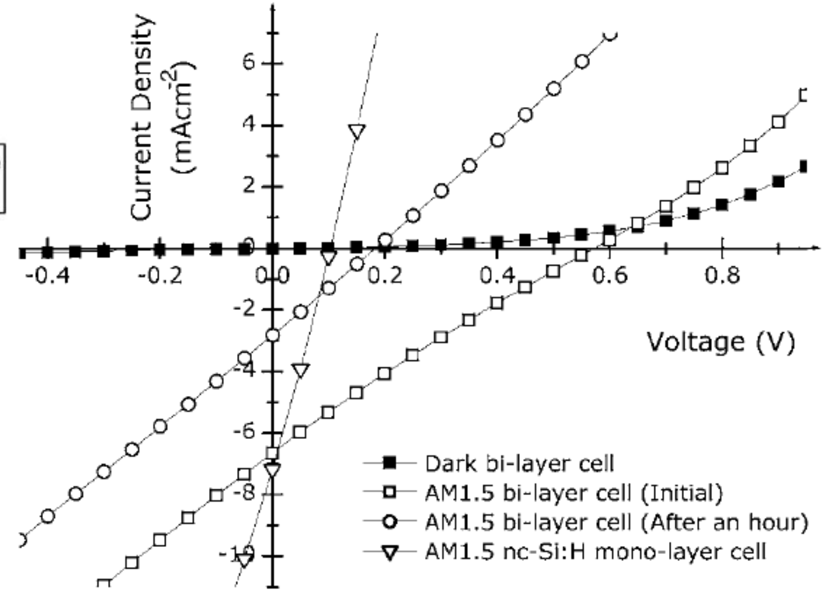
Conjugated Polymer

- High optical absorption
- Solution based processing
- Large-scale and low-temperature manufacturing



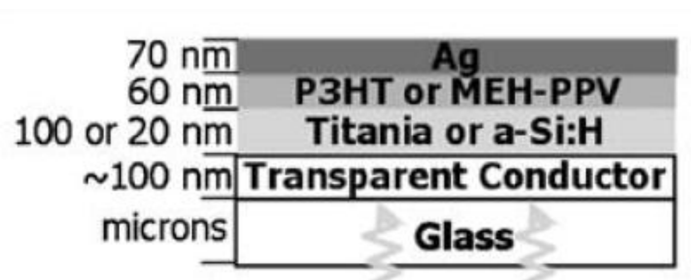
Hybrid solar cells

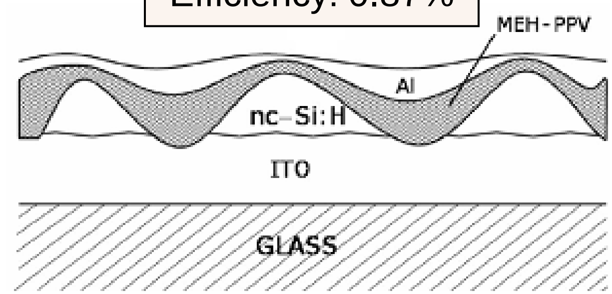




Efficiency: 0.16%

Efficiency: 0.87%





V. Gowrishankar, et al., *Appl. Phys. Lett.* **89**, 252102 (2006)

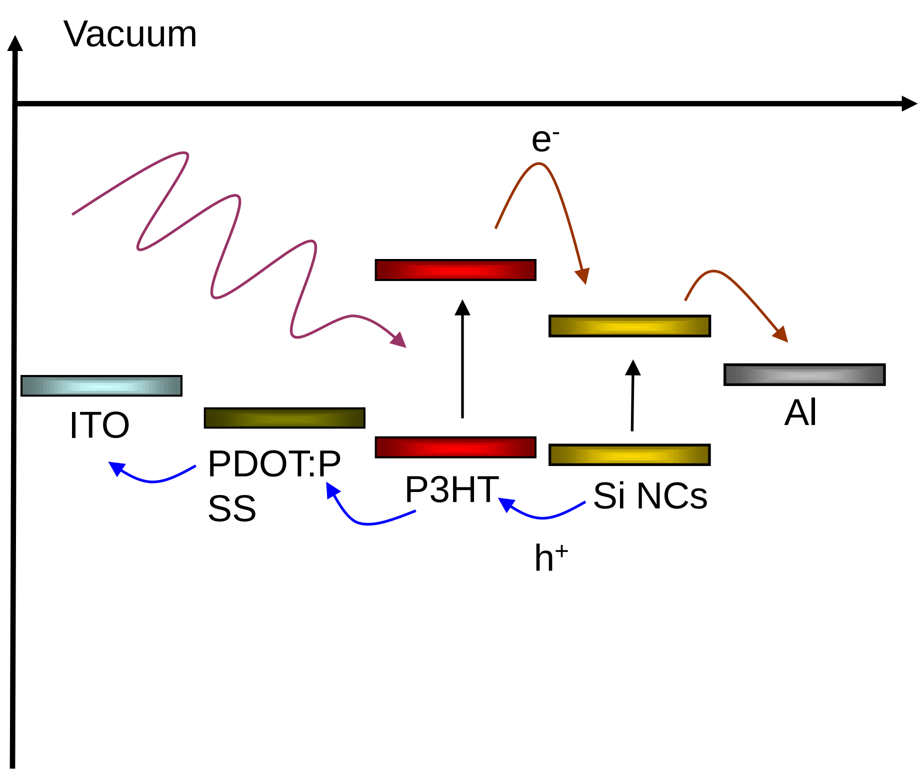
A. A. D. T. Adikaari, et al., *Appl. Phys. Lett.* **90**, 203514 (2007).

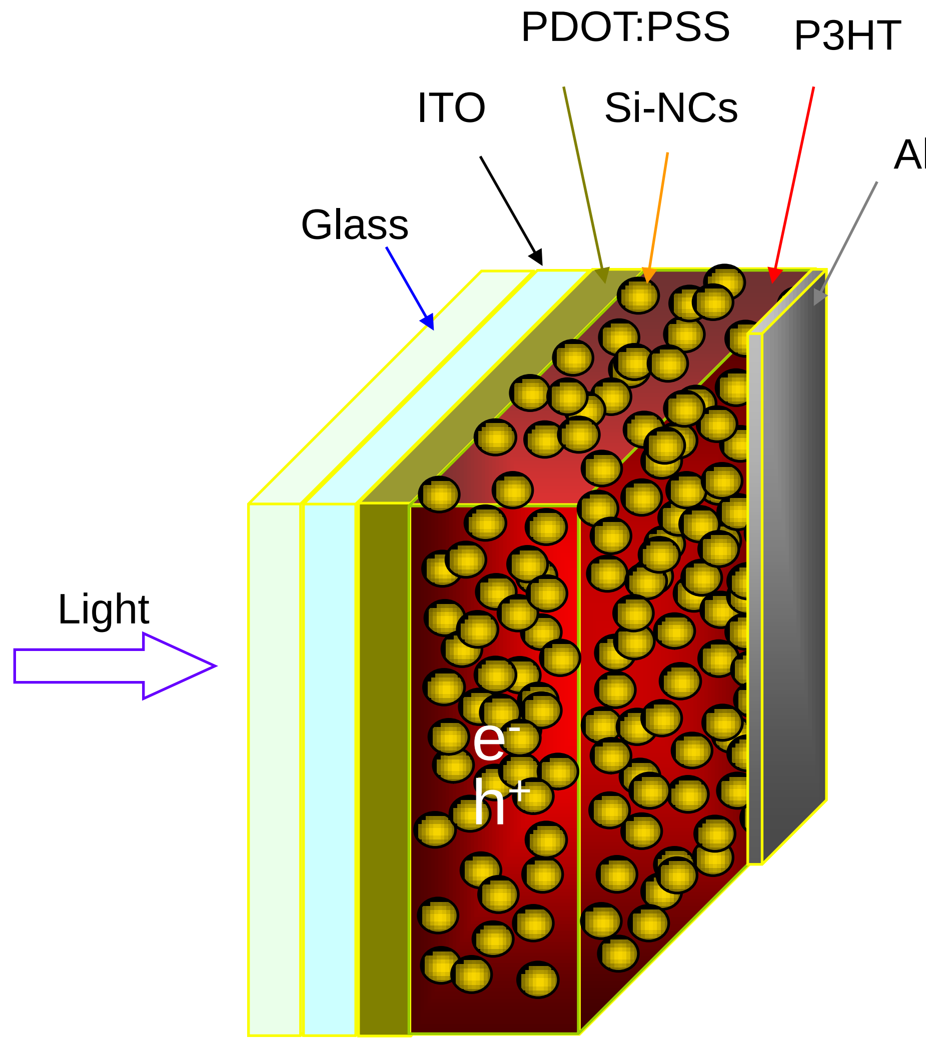
Hybrid solar cells

Kortshagen Group

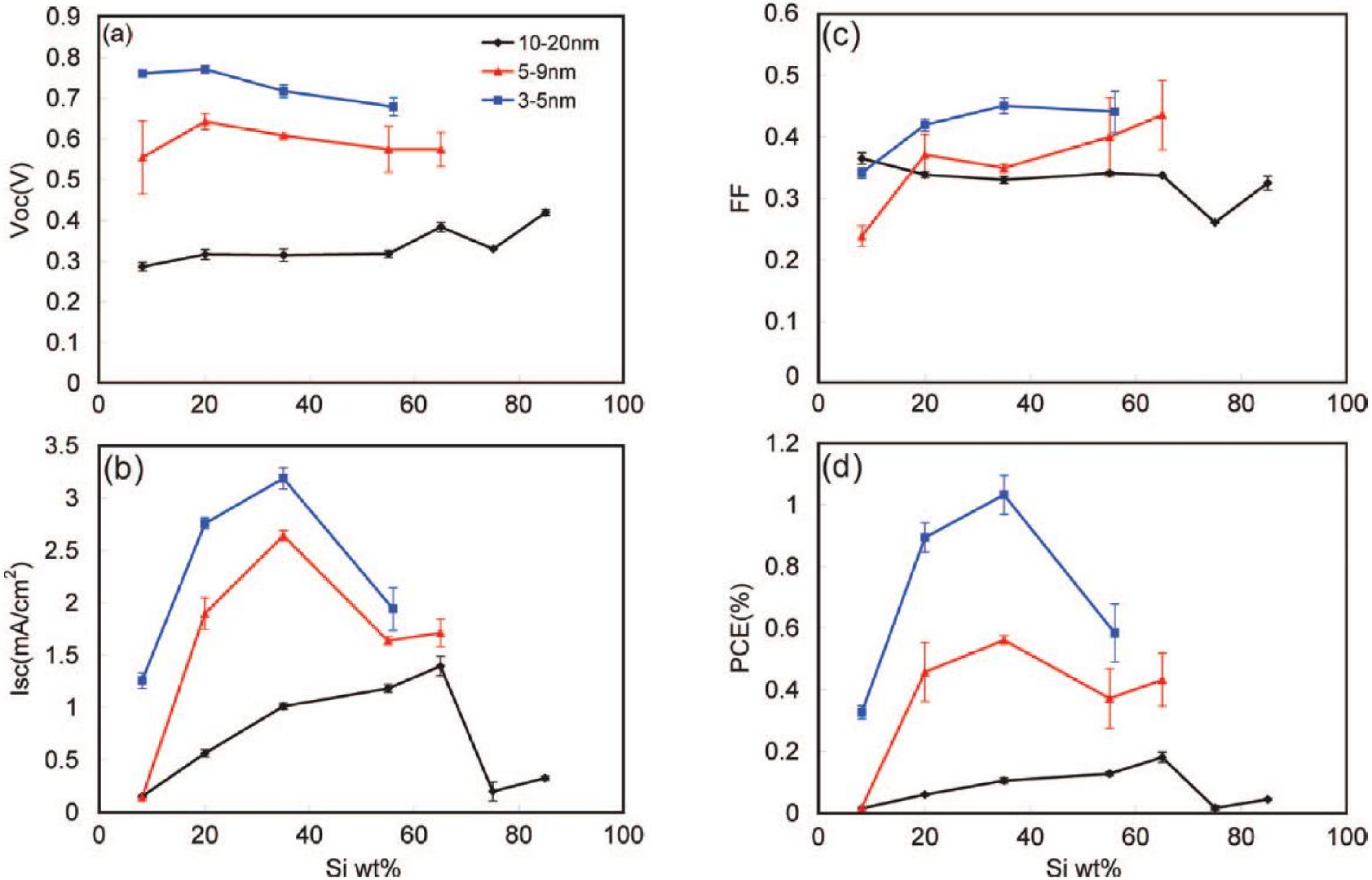
Si NCs/P3HT Solar Cells

- Light absorption in P3HT and Si NCs
- Exciton dissociation
- Carrier transport



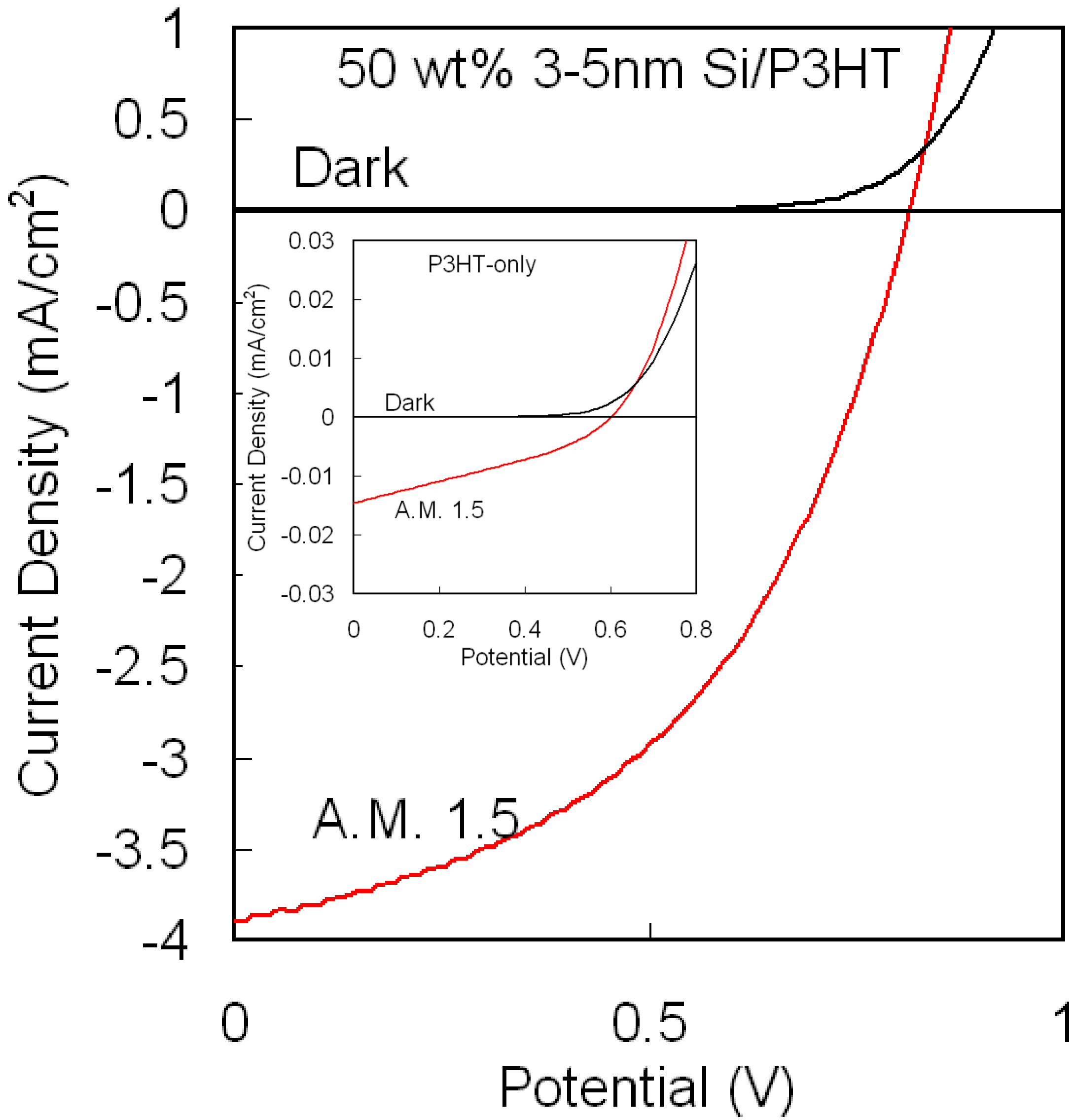


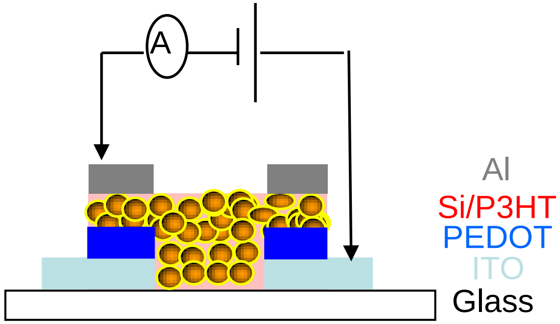
Hybrid solar cells



C.-Y. Liu, et al., *Nano Lett.* **9**, 449 (2009).

Hybrid solar cells





I_{sc} = 3.88 mA/cm^2

V_{oc} = 0.8 V

FF = 0.47

η = 1.48%

A.M 1.5 Direct, 100mW/cm^2

150˚C Annealing

C.-Y. Liu, et al., *Nano Lett.* **9**, 449 (2009).

Summary

- Nonthermal plasma synthesis of high quality Si & Ge NCs
- Three methods of NC thin film formation
- Tuneable film absorption by altering Ge NC size; optical bandgaps >1 eV
- Field effect mobilities of ~10^{-2} cm^2/Vs after annealing
- Si NC/P3HT hybrid solar cells with 0.8 V V_{oc} and 1.5% efficiency

Acknowledgements

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MRSEC DMR-0212302 (partial)
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