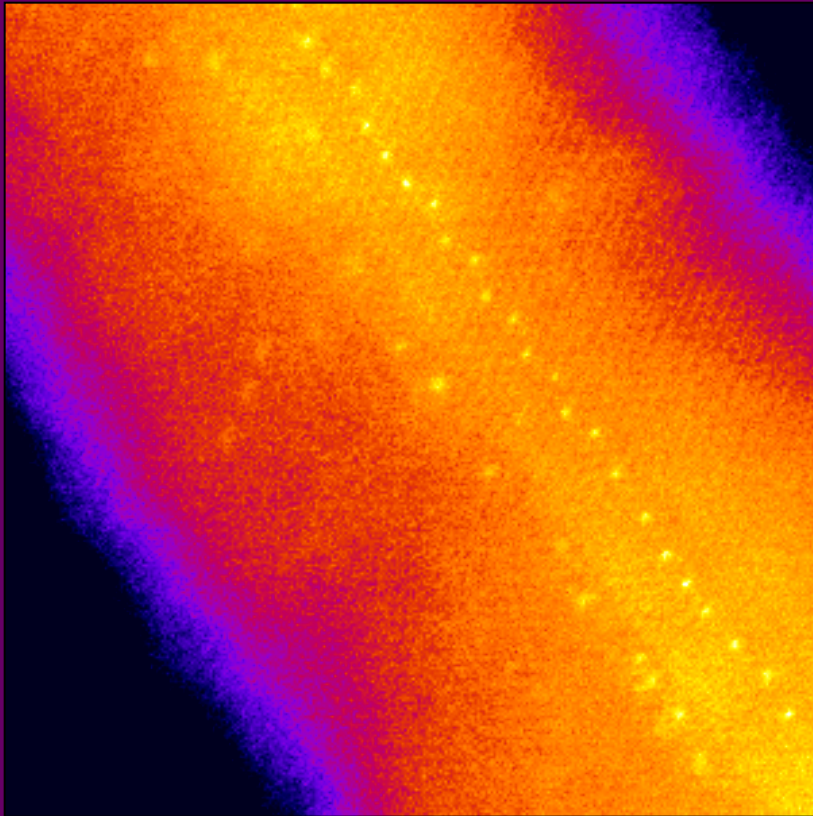


Atom-by-atom deconstruction and functional imaging of semiconductor nanostructures



Lincoln J. Lauhon

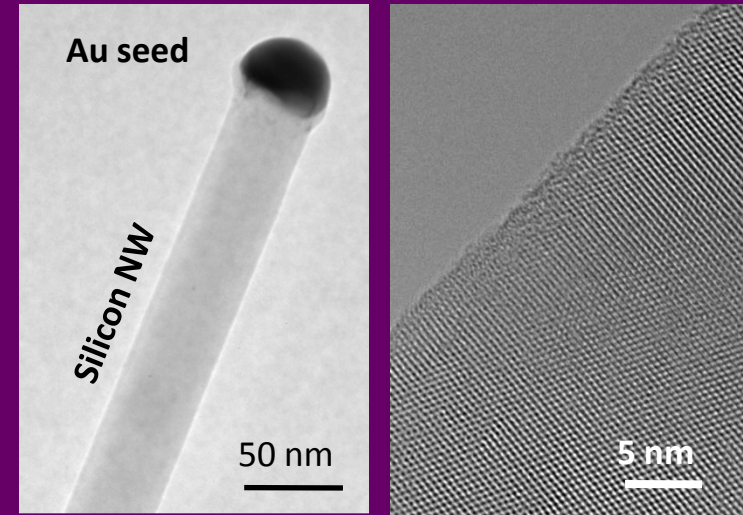
Department of Materials
Science & Engineering,
MRSEC



NORTHWESTERN
UNIVERSITY

New materials require new methods

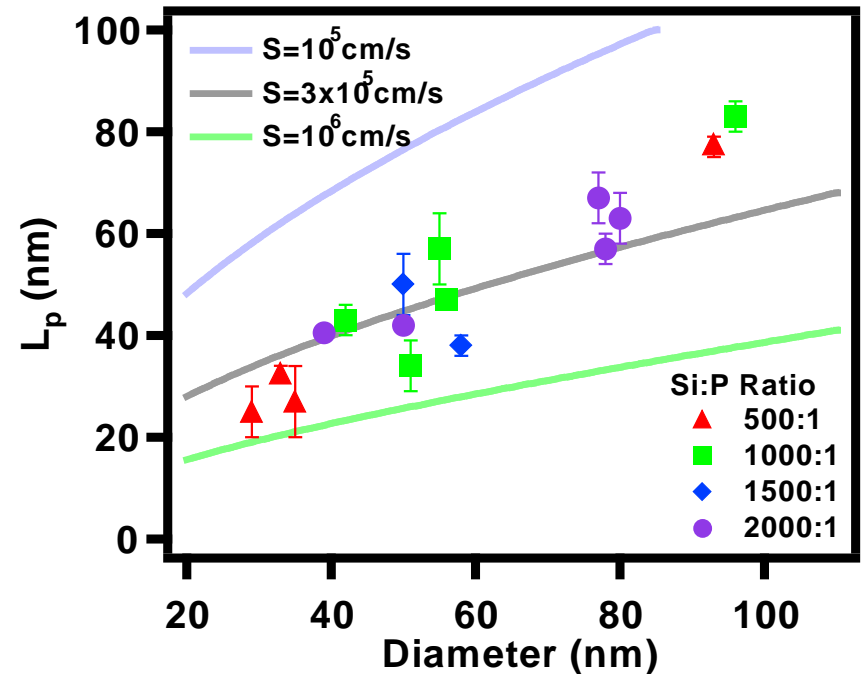
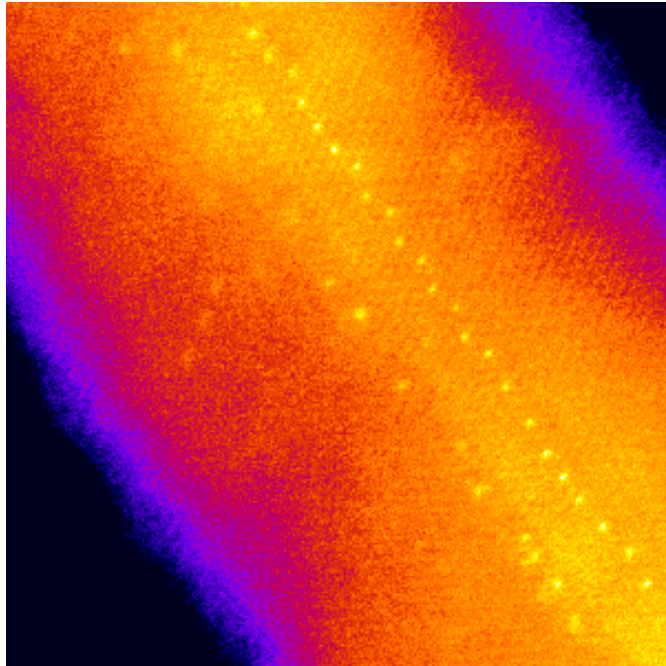
- ***Semiconductor Nanowires***
 - Nanoscale in 2 dimensions
 - Microscale in 1 dimension
 - Tunable size and composition
 - Novel electronic, optical properties



- **Key challenges in characterization**
 - Composition of individual nanowires, including doping
 - Spatially resolved electronic properties of single nanowires

New characterization techniques are needed

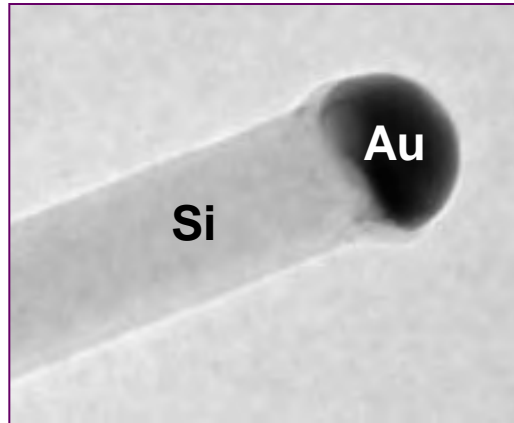
Atomic Structure-Property Correlation



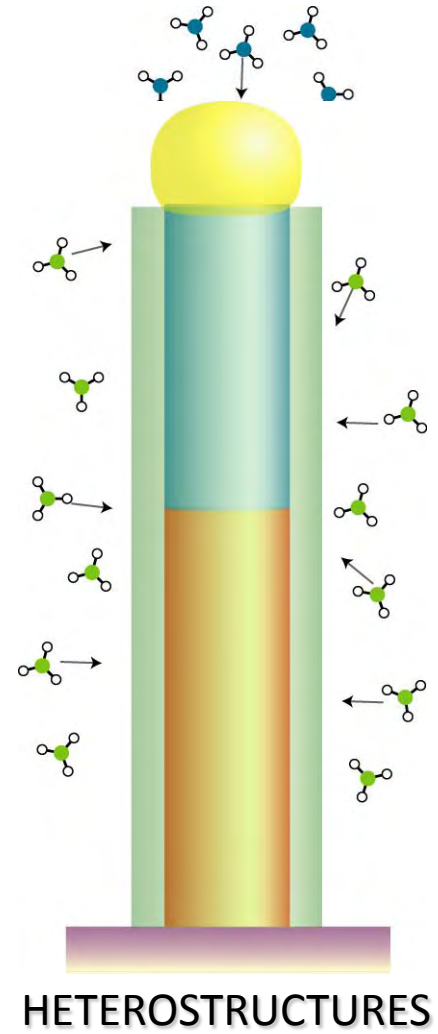
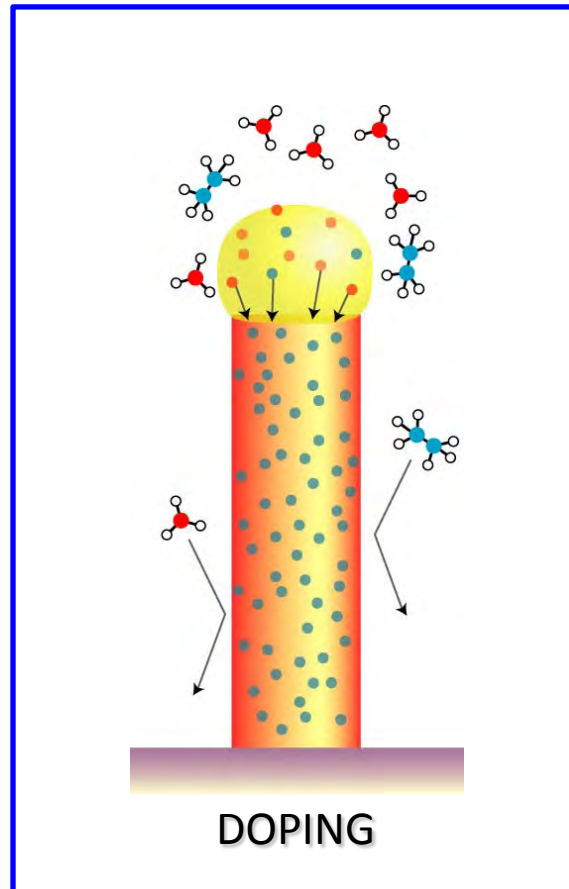
- Au detected in silicon nanowires at single atom level.
- Au atoms are present in excess of equilibrium concentration.

- Surfaces dominate recombination
- Passivation ineffective
 - Surfaces are different
 - Substrate limitations

Targets for VLS Nanowire Synthesis



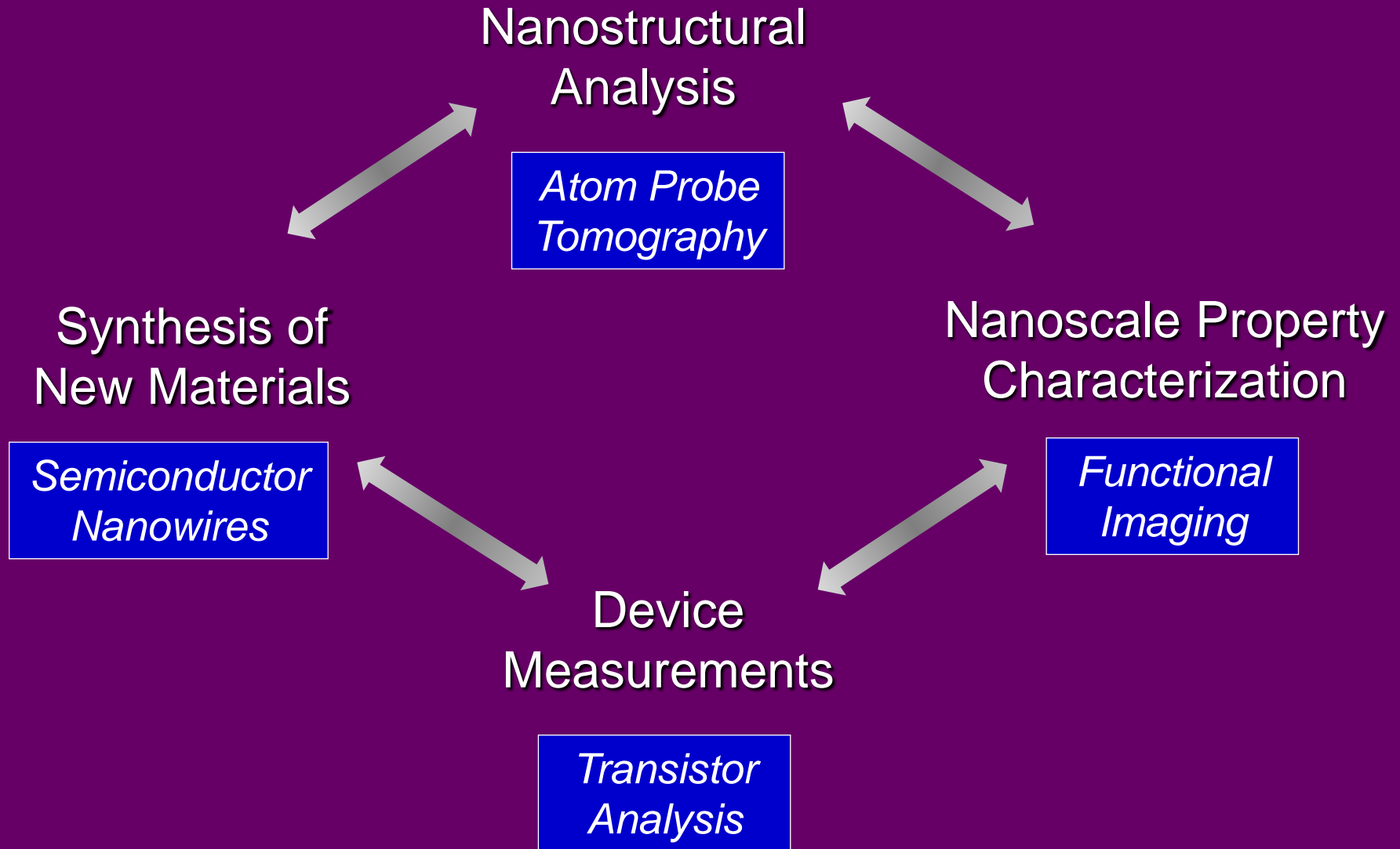
Focus of talk



Axial Heterostructures: *Nature* **415**, 617 (2002).
M. S. Gudiksen, L. J. Lauhon, J. Wang, D. C. Smith & C. M. Lieber

Radial Heterostructures: *Nature* **420**, 57 (2002).
L. J. Lauhon, M. S. Gudiksen, D. L. Wang & C. M. Lieber

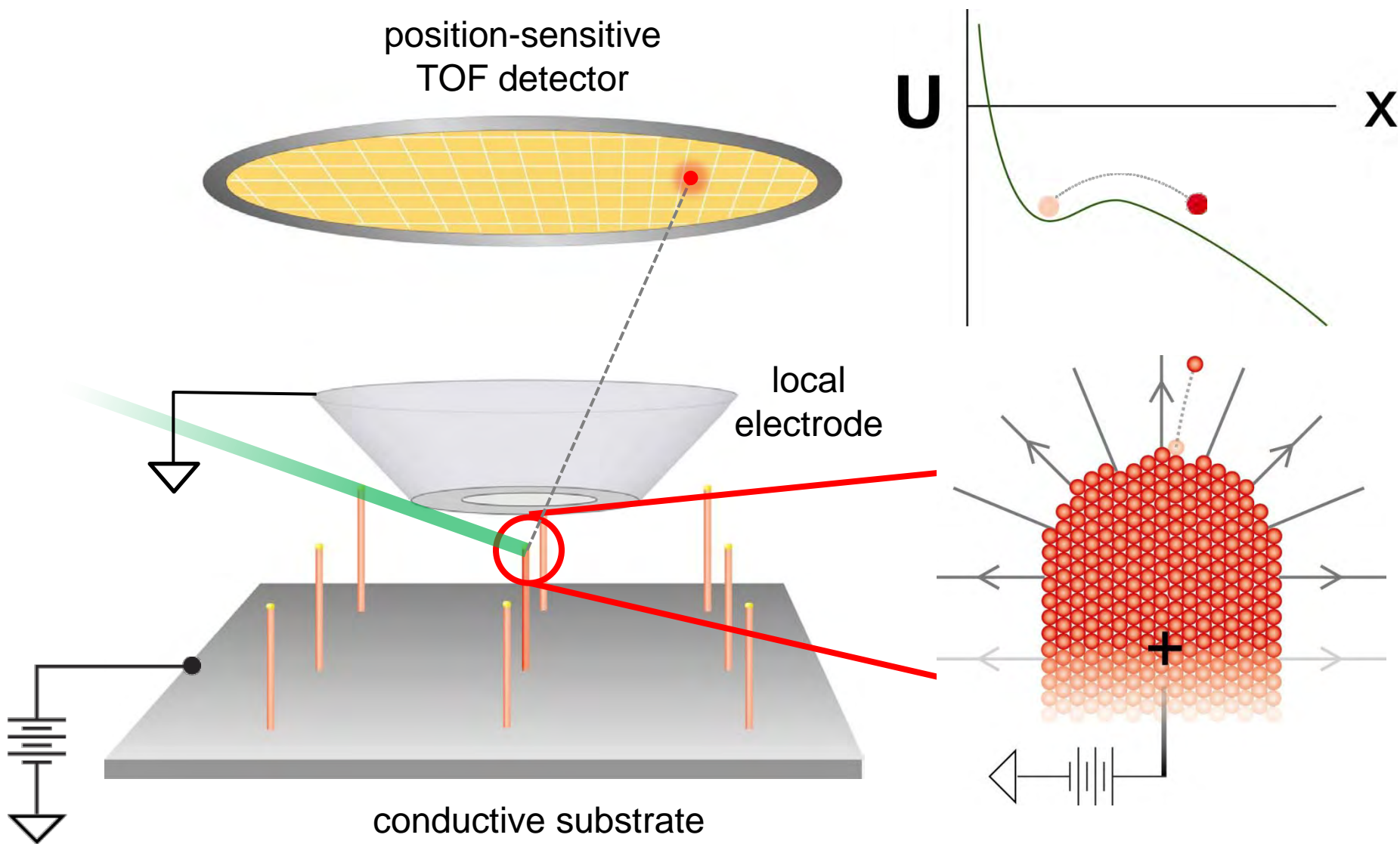
Approach to nanocharacterization



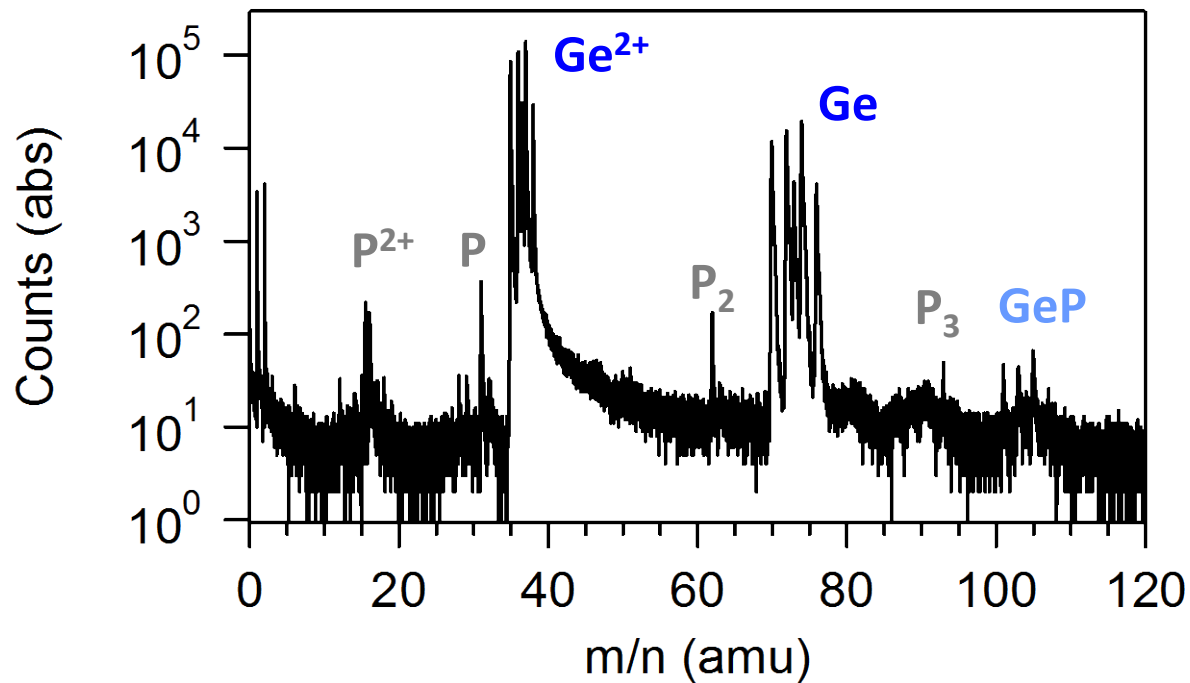
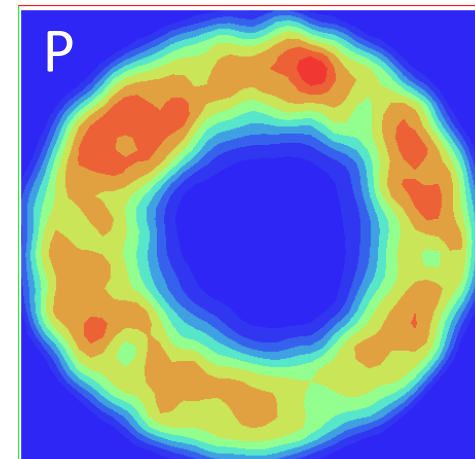
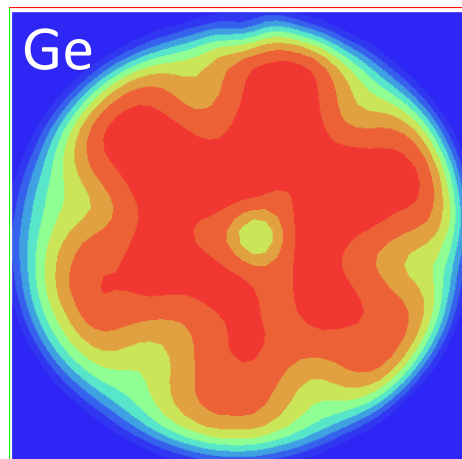
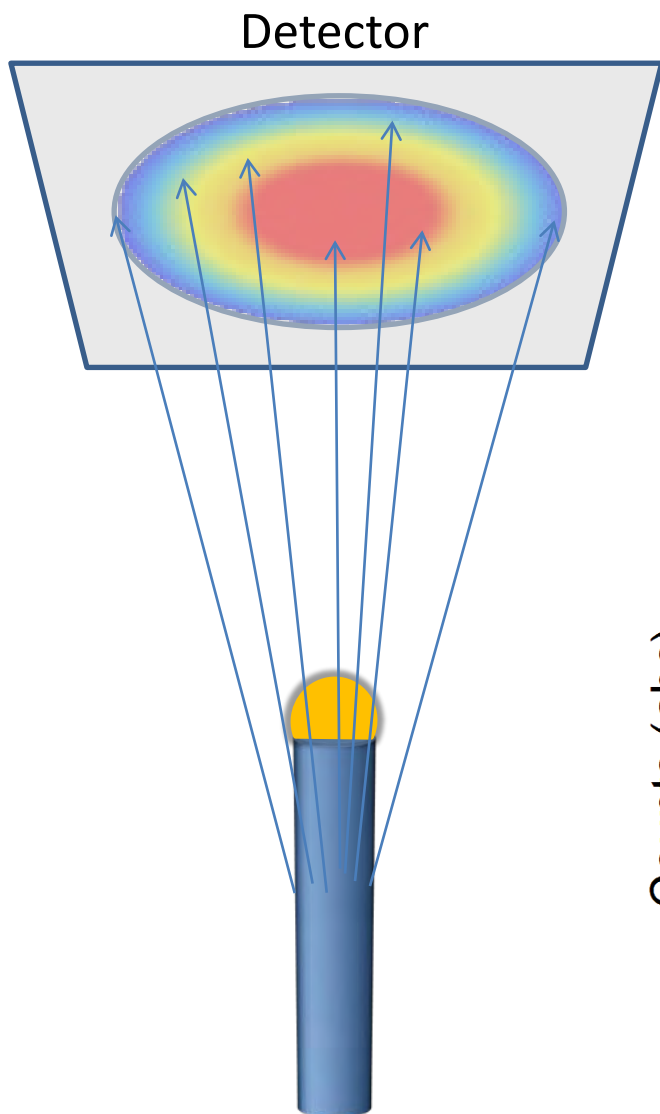
More on Atom Probe Tomography



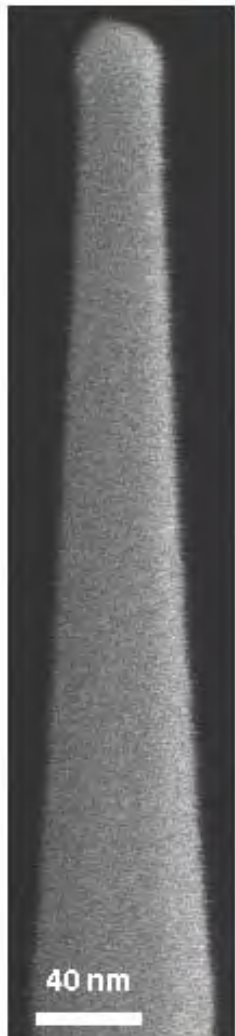
Pulsed Laser Atom Probe Tomography



Atom Probe Data: $x, y, z(t), q/m$



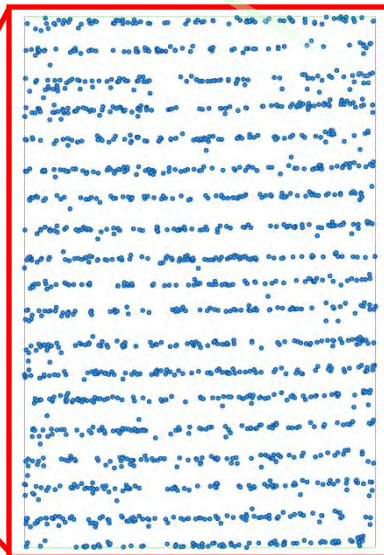
Tomography of a phosphorous doped Ge nanowire



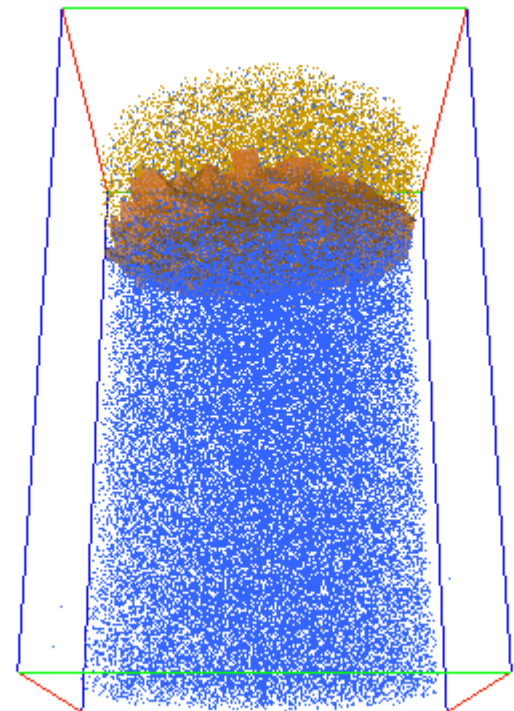
43 x 42 x 236 nm³



(111) planes



4 x 6 nm²



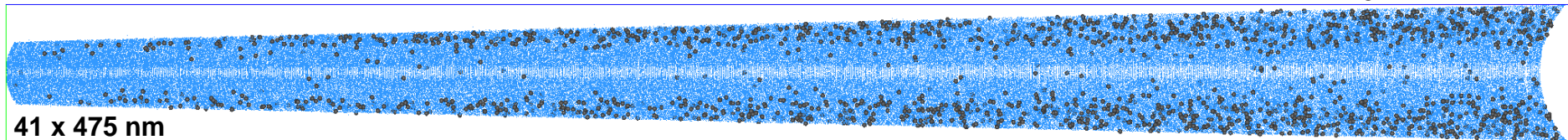
25x25x40 nm³

Phosphorous doping is not uniform

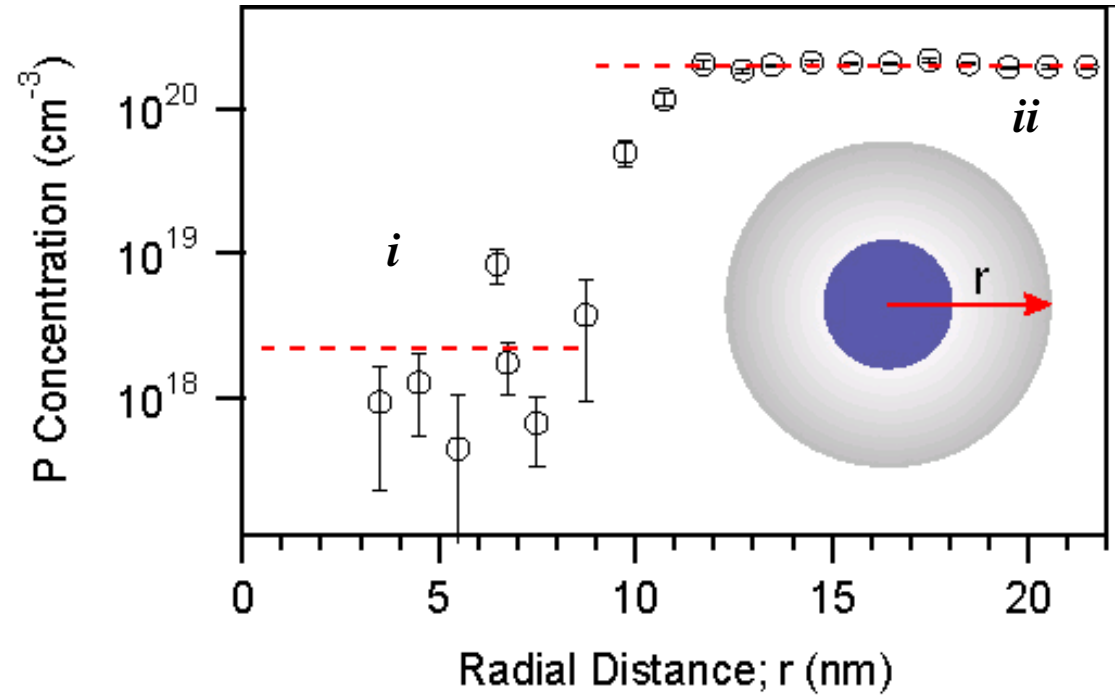
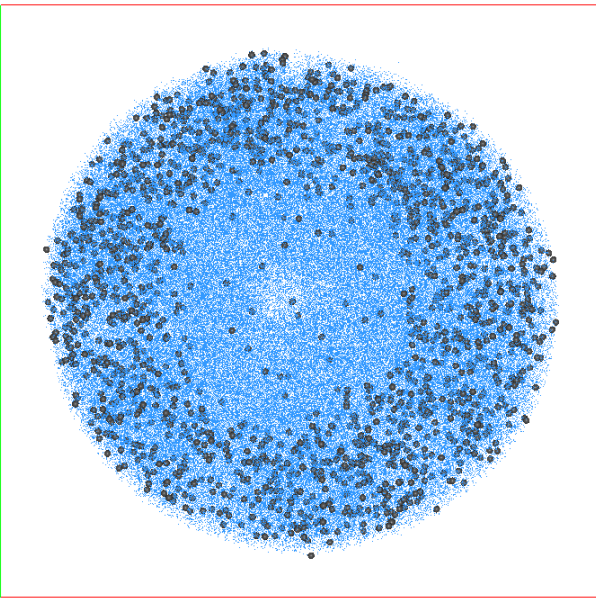
380 °C

$\text{GeH}_4:\text{PH}_3 \rightarrow 1000:1$

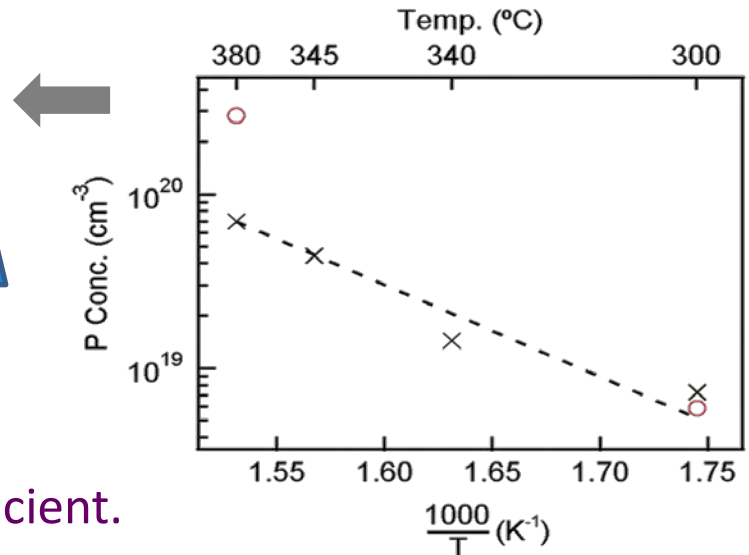
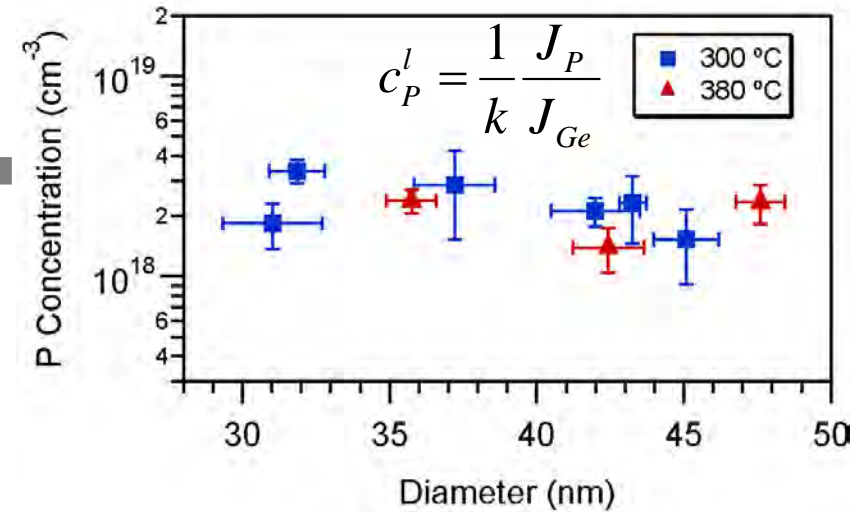
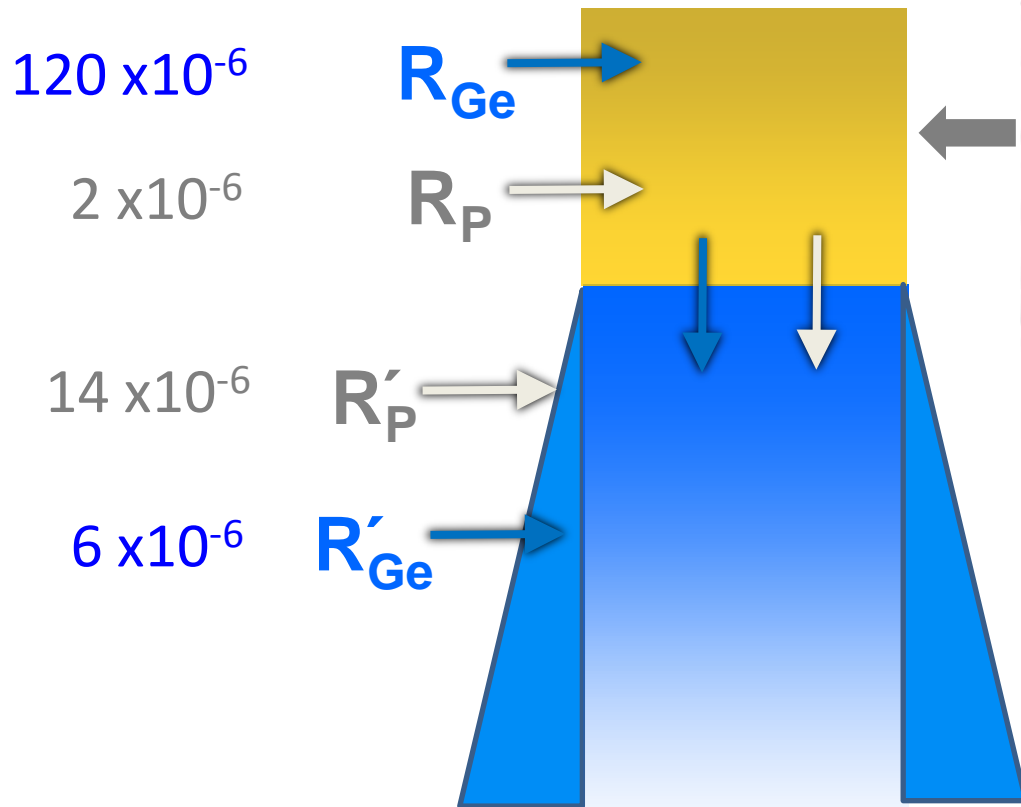
● Ge ● P



● Ge ● P

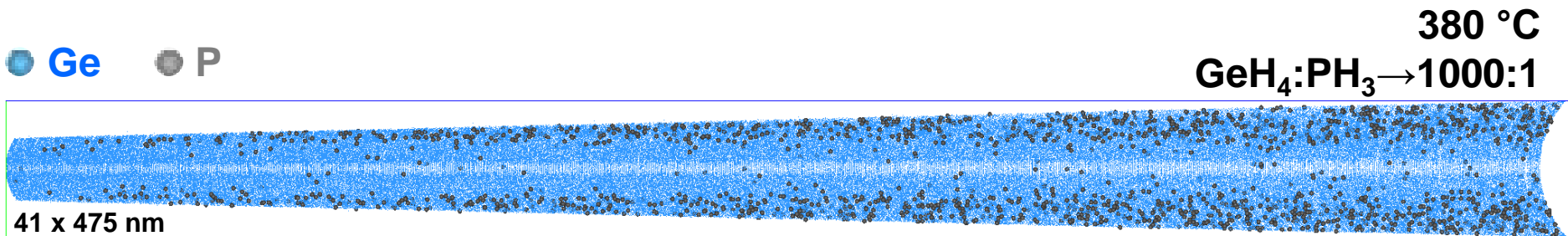


Unequal core and shell doping rates



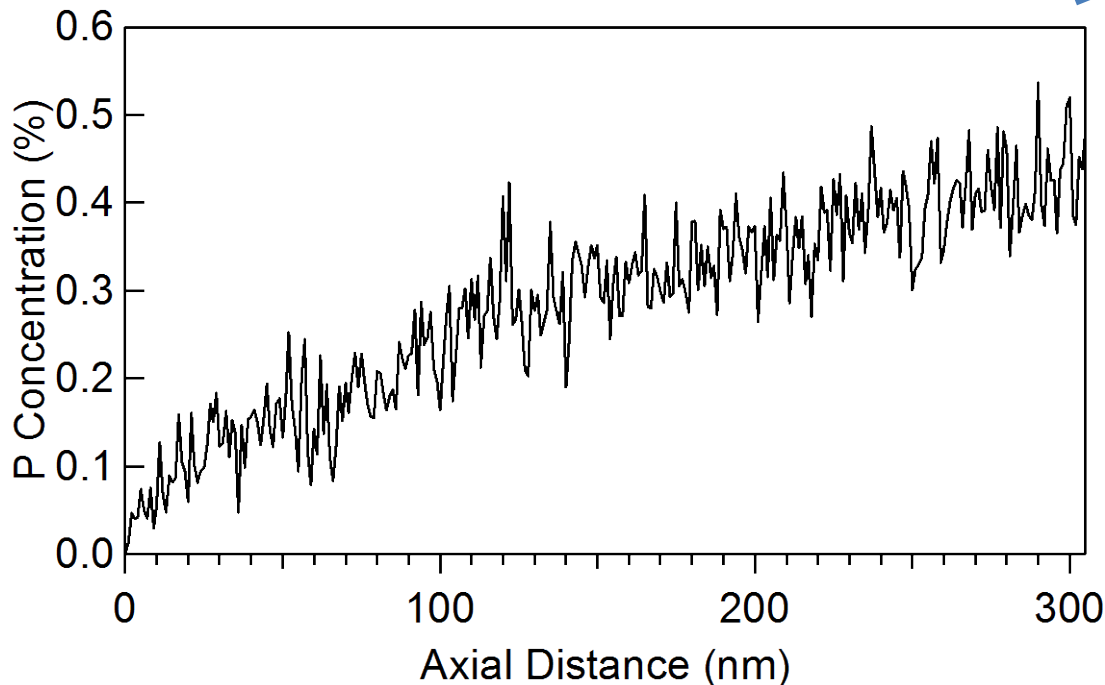
- Surface doping is thermally activated.
- VLS doping controlled by distribution coefficient.

Effective doping varies along the nanowire



lightly doped

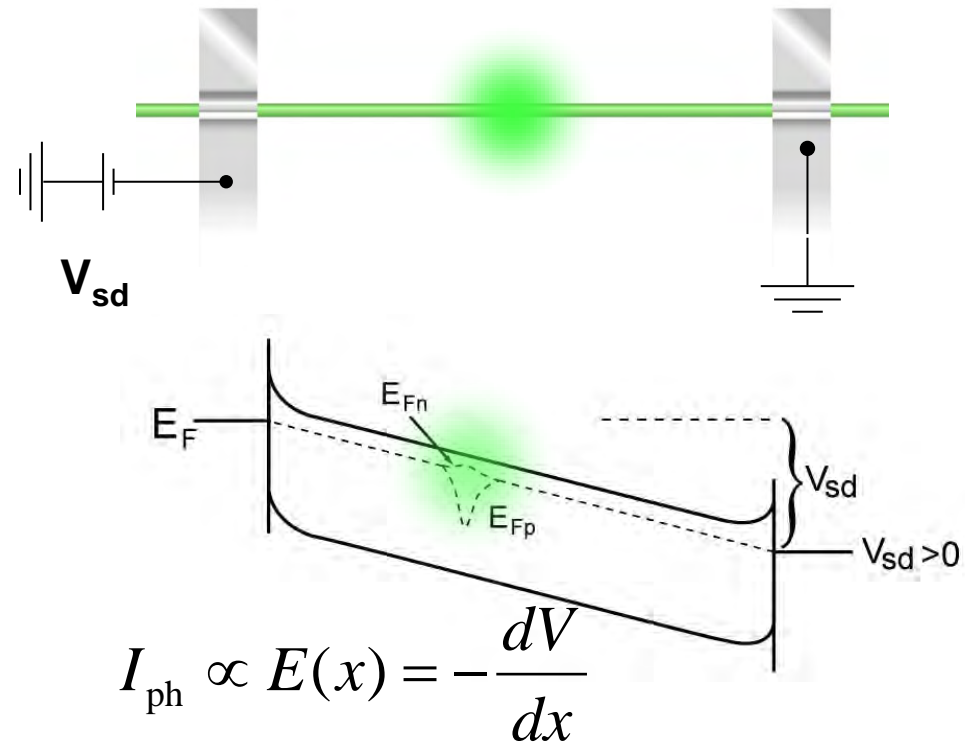
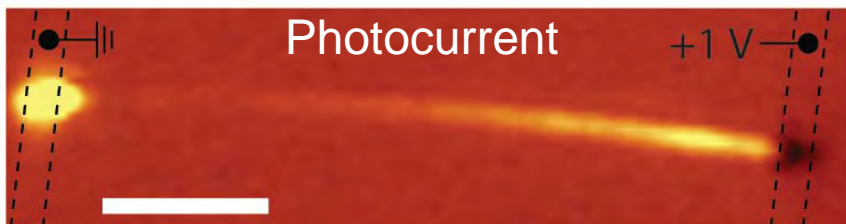
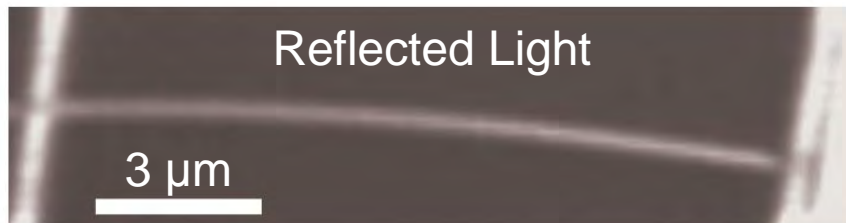
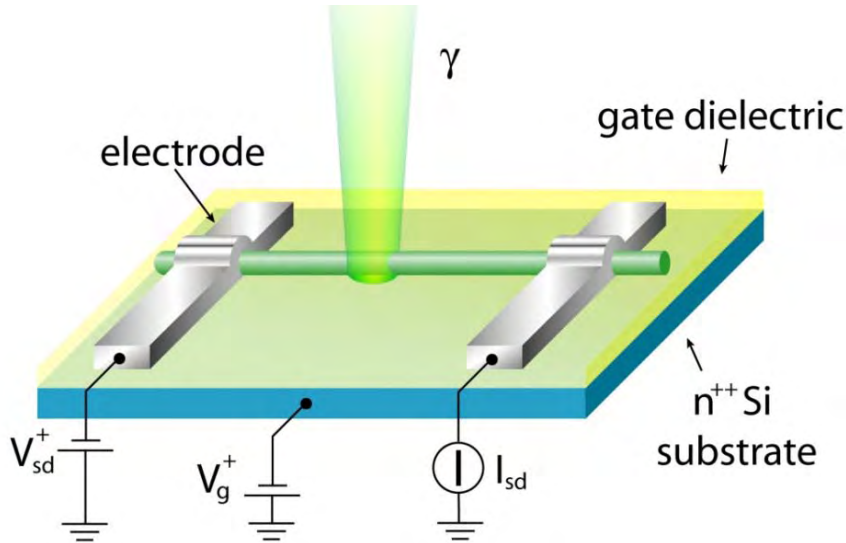
heavily doped



What are the implications?

- Similar effects are expected for related process chemistry, *e.g.* SiH_4 & BH_3 .
- VLS/VS doping anisotropy is a more general phenomenon.
- ***Can we see the effects of doping inhomogeneities in the electrical properties?***

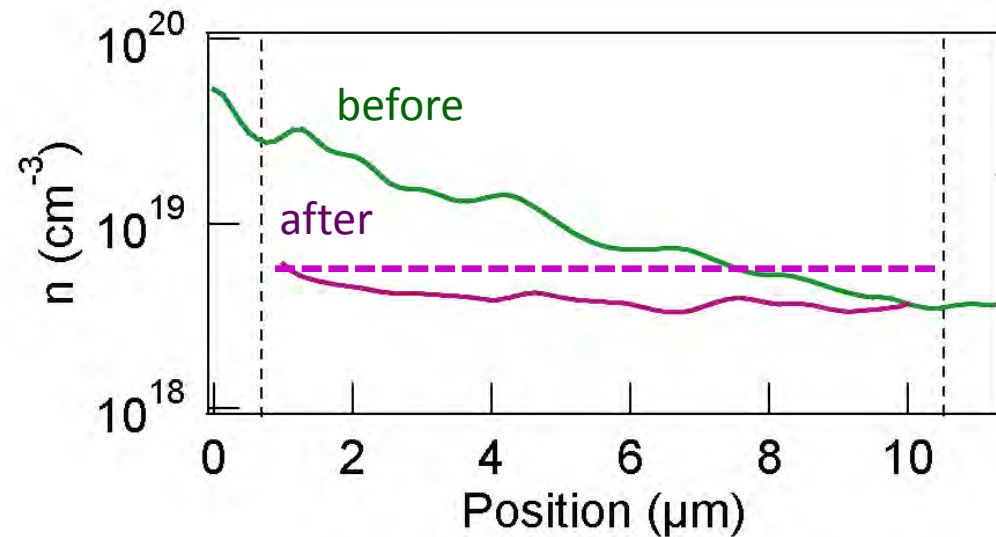
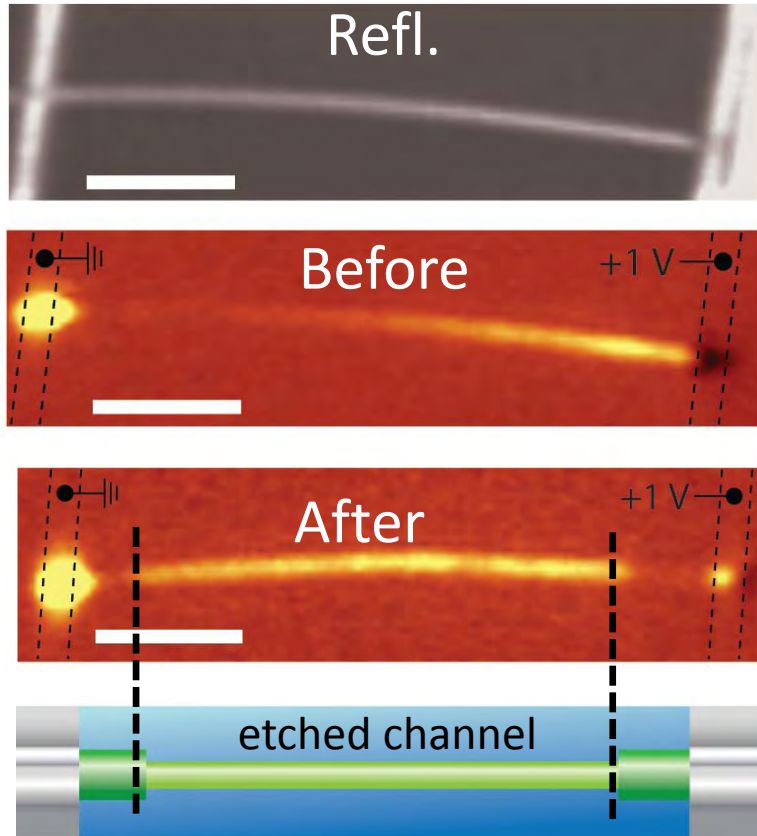
Scanning Photocurrent Microscopy of P:SiNW



$$I_{ph} \propto E(x) = -\frac{dV}{dx}$$

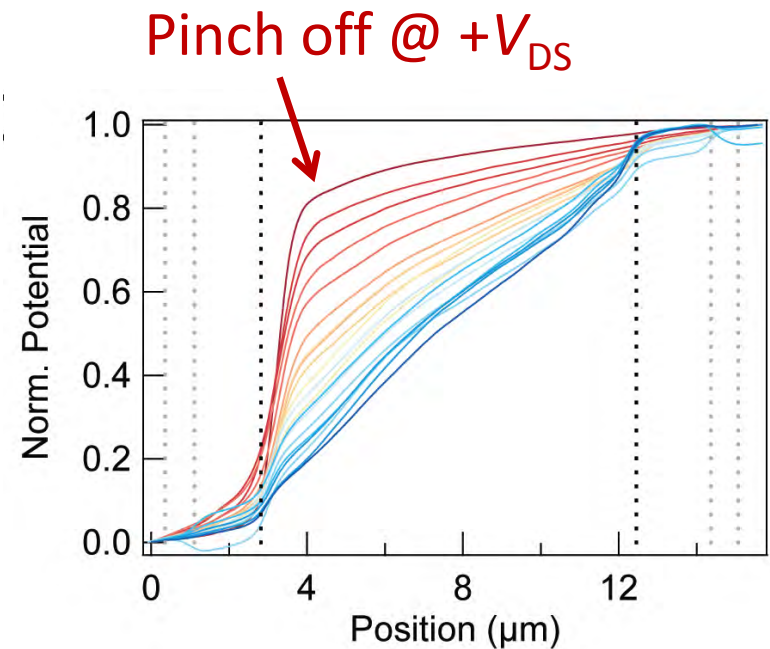
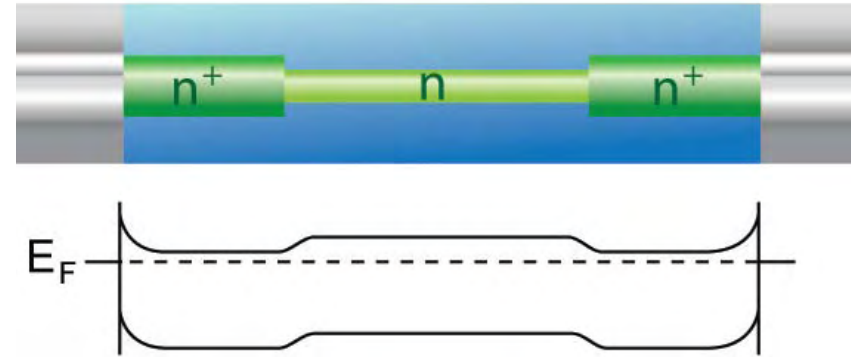
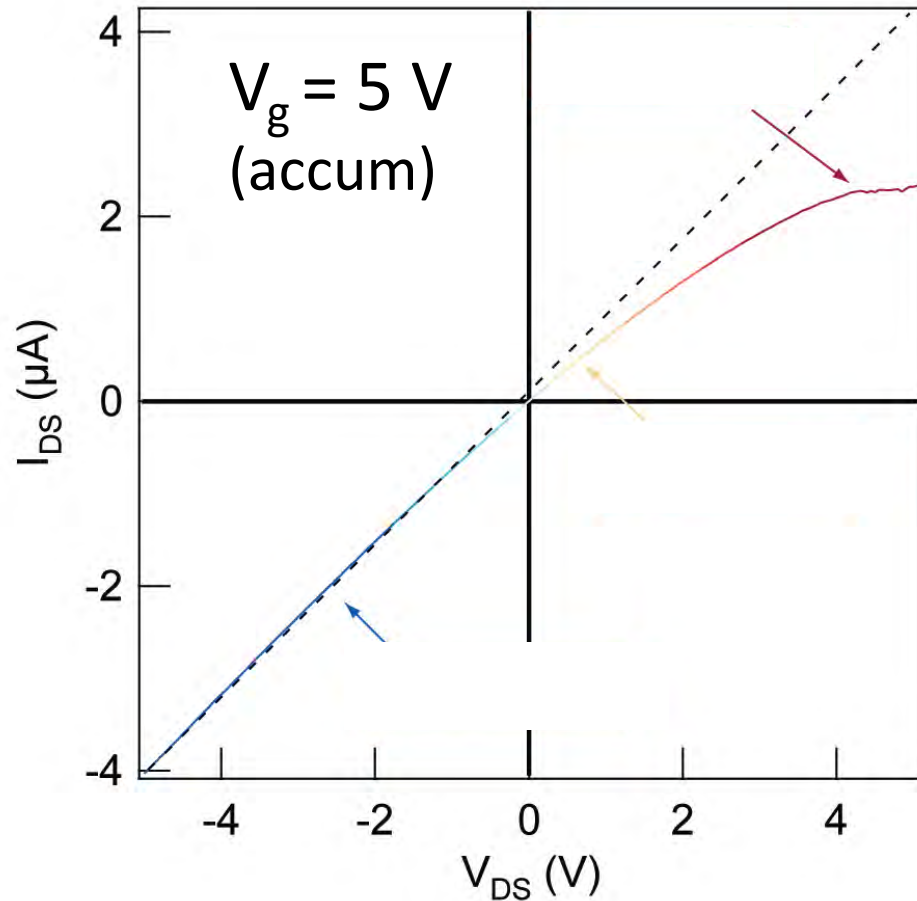
$$\frac{dn}{dx} \neq 0 \text{ or } \frac{dA}{dx} \neq 0$$

Etching removes the doping gradient

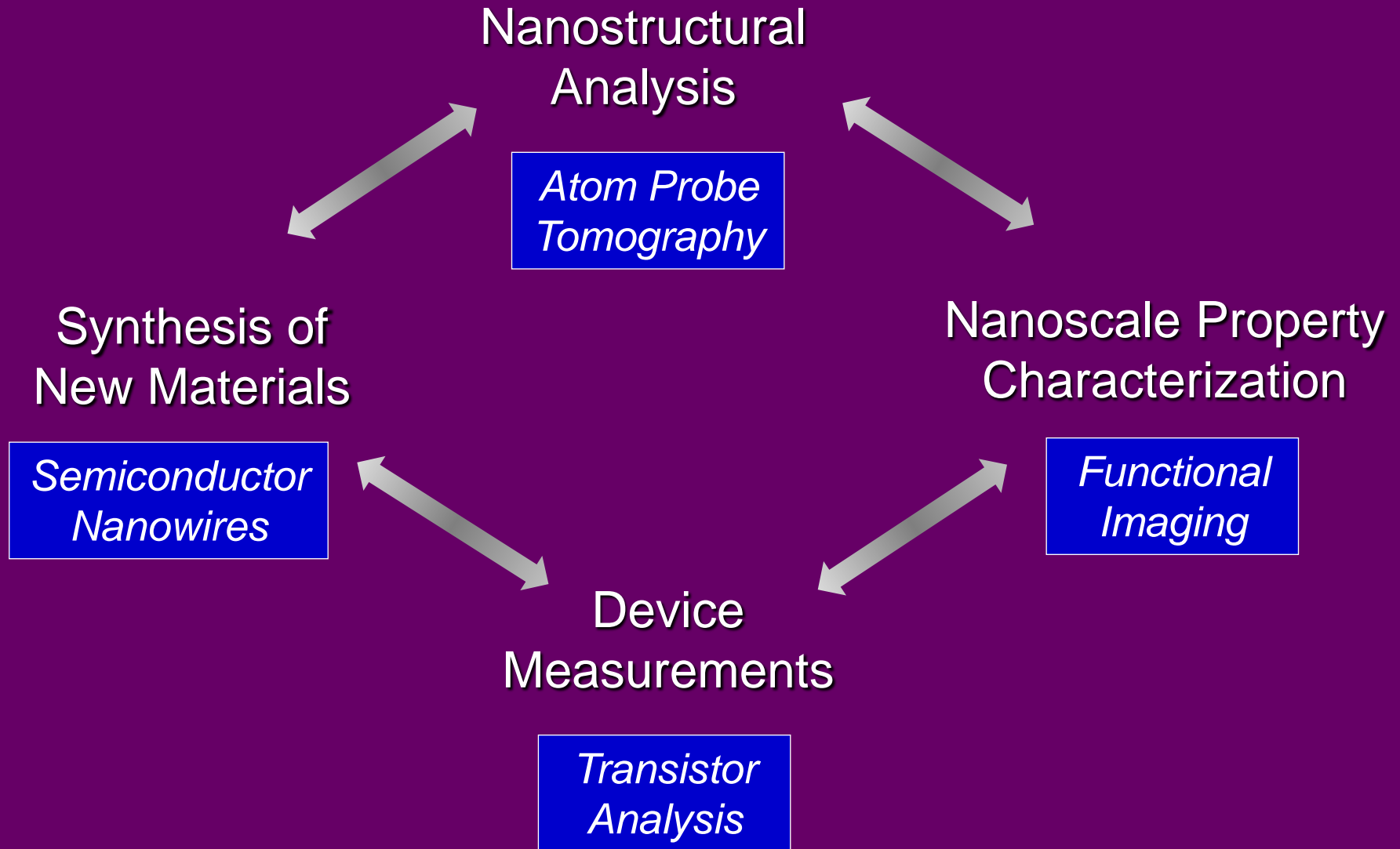


P concentration by APT is comparable to carrier concentration estimate.

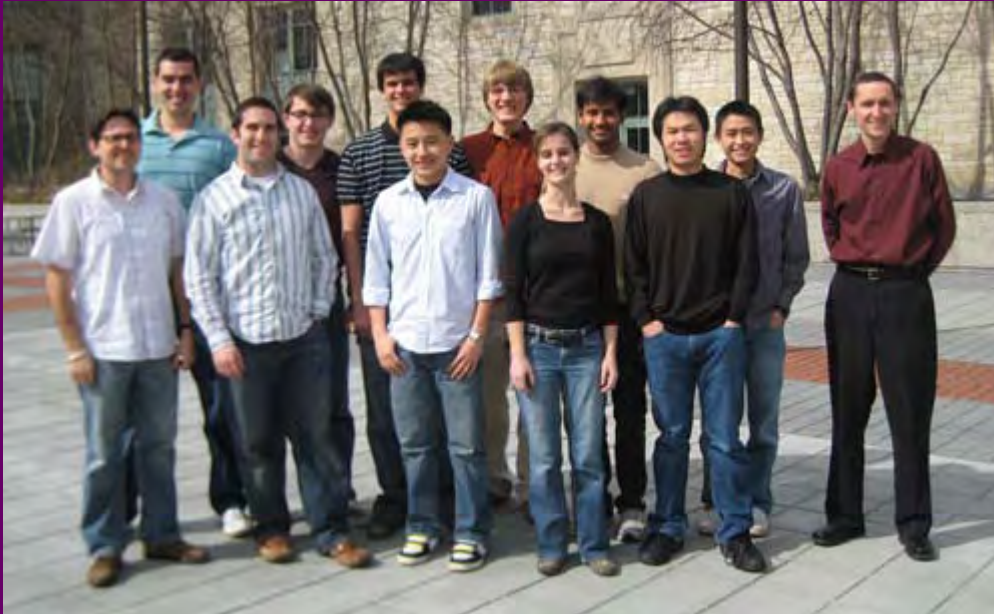
Potential profiles of NW FET



Our approach to nanocharacterization



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Camille & Henry Dreyfus Foundation

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