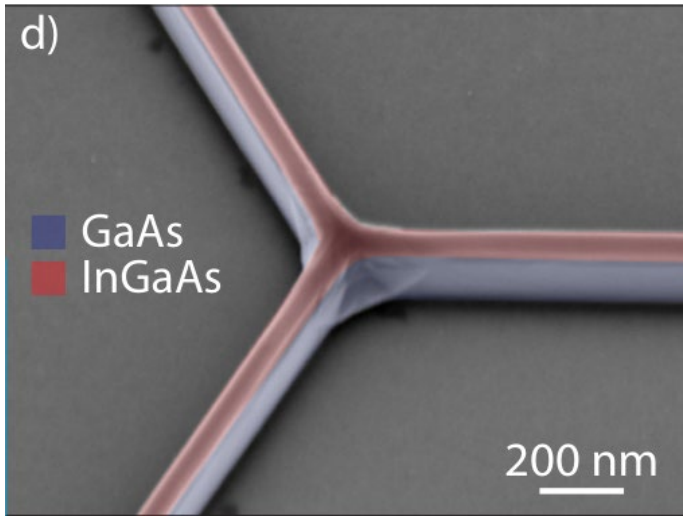
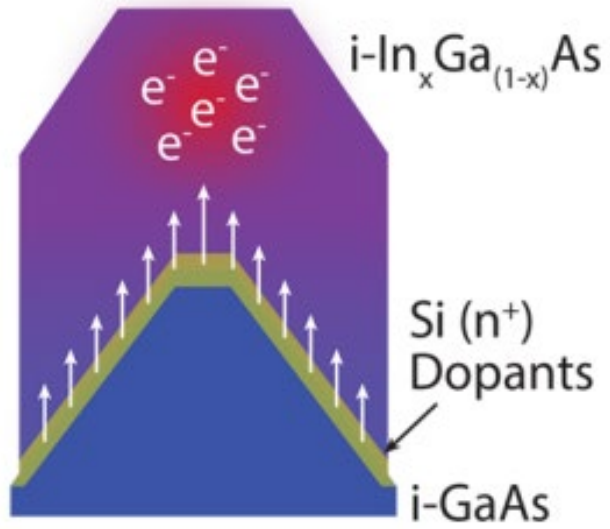
Modulation Doping of Template-Defined InGaAs Nanowires





Kris Cerveny
QSIT Lunch Talk 04/02/2021

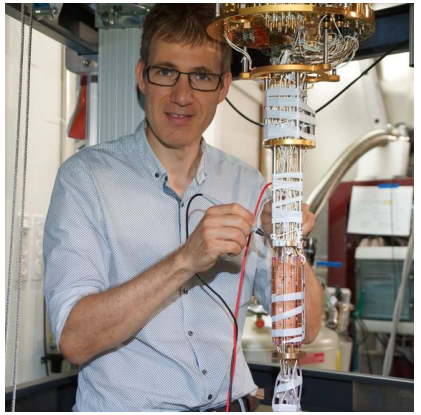
Acknowledgements

FNSNF
Swiss National Science Foundation

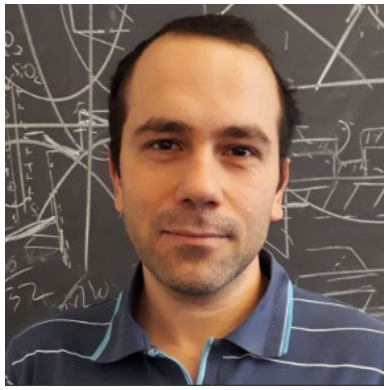
UNI BASEL

QSIT Quantum Science and Technology
National Centre of Competence in Research

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



Prof. Dominik Zumbühl



Dr. Mohammad Samani

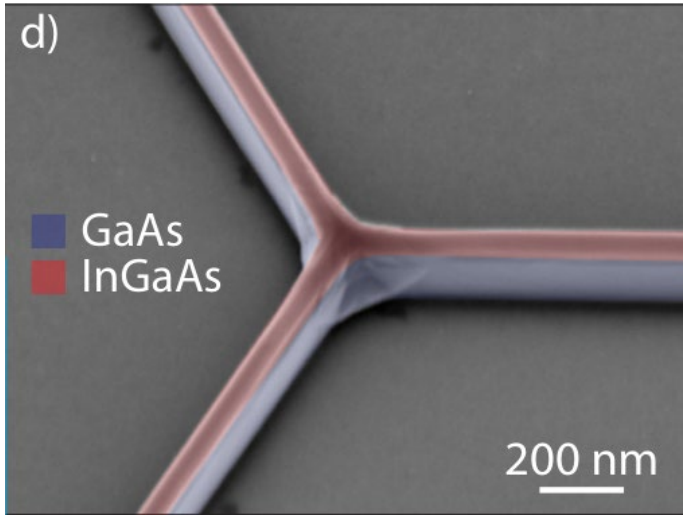
Prof. Anna Fontcuberta

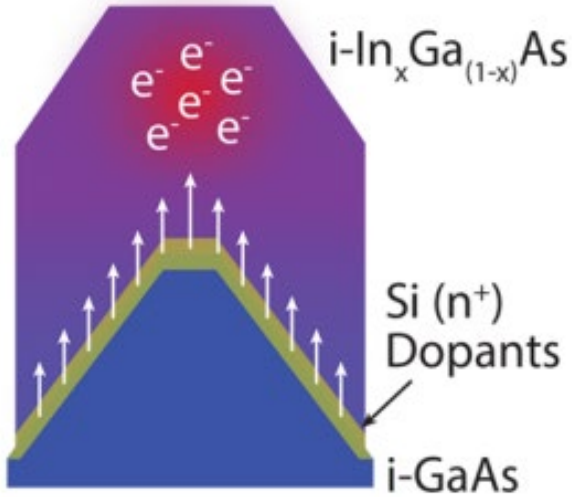
Martin Friedl

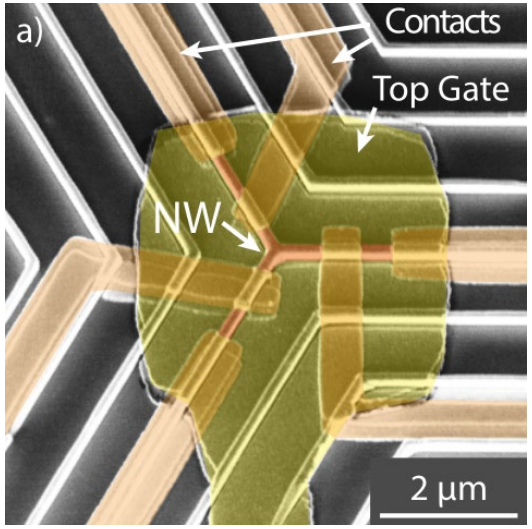
Didem Dede

Outline

- Selective area growth InGaAs nanowires
- Traditional doping
- Weak (anti-)localization
- Modulation doping approach
- Mobility measurements
- Wrap-around gate effect
- Outlook

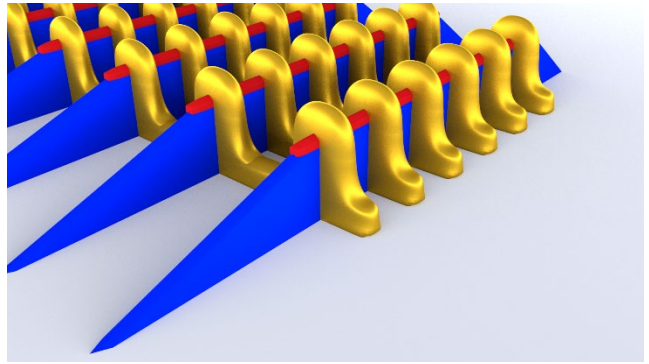


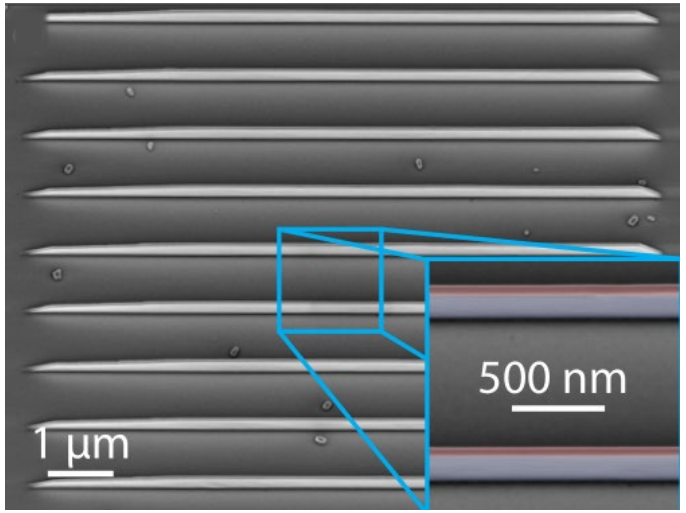


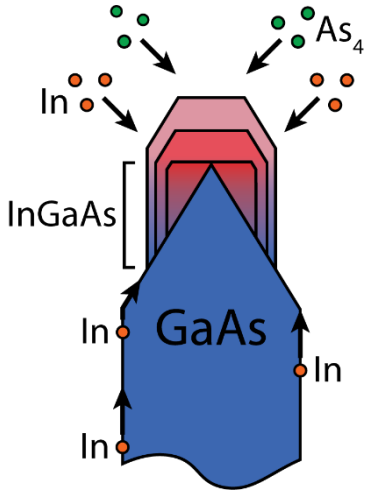


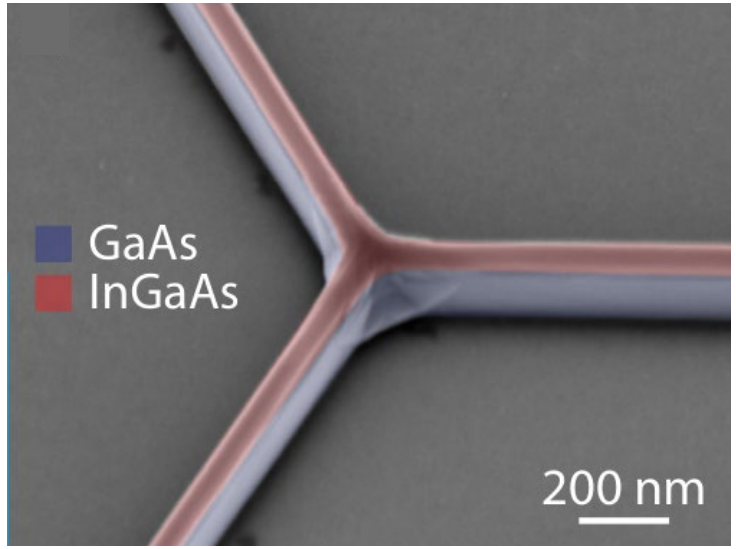
In(Ga)As on GaAs Membranes

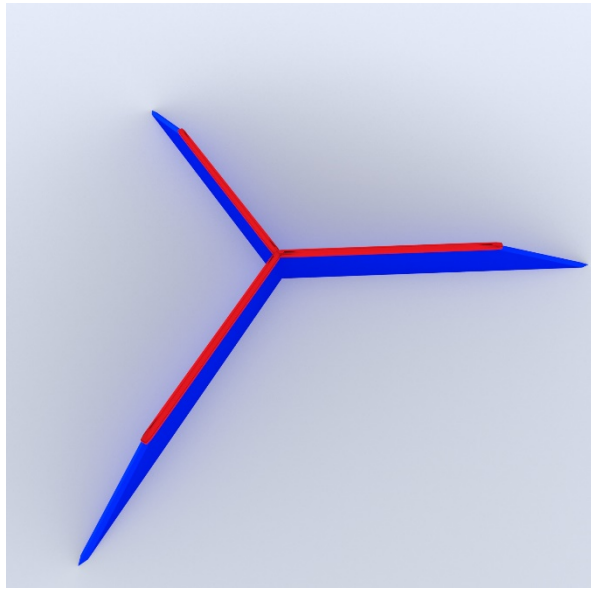
- MBE-grown, defect-free GaAs membranes with In(Ga)As Nanowires atop
- 3 growth directions equivalent to <11$\bar{2}$> enables *branched* structures







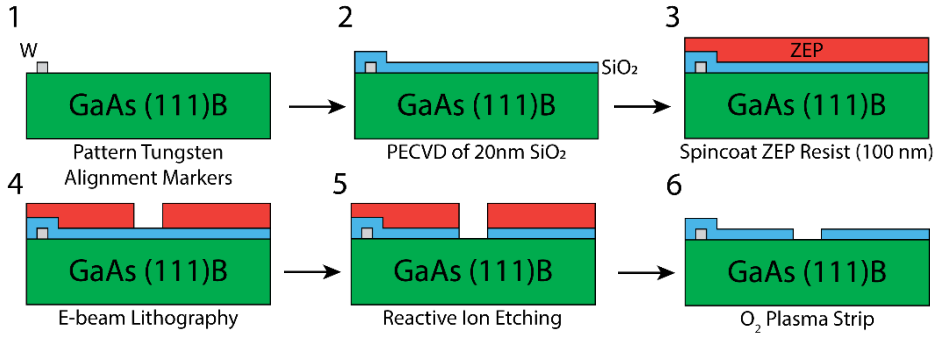


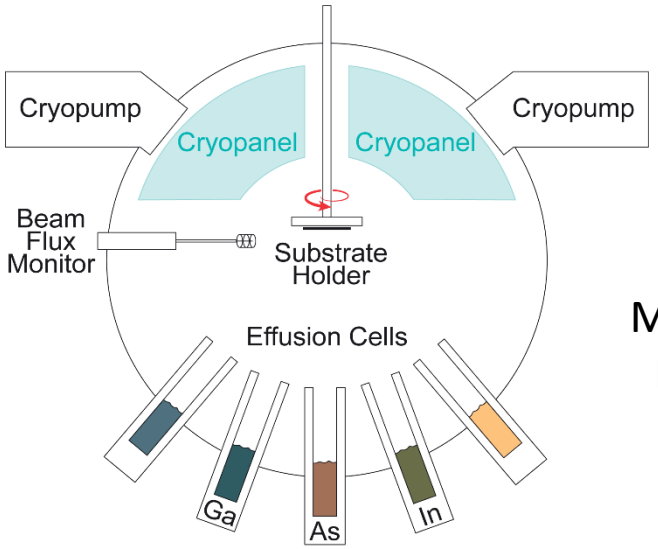


Friedl, KC et al. Nano Lett. **18,** 2666-2671 (2018)
Friedl, KC et al. Nano Lett. **20**, 3577-3584 (2020)

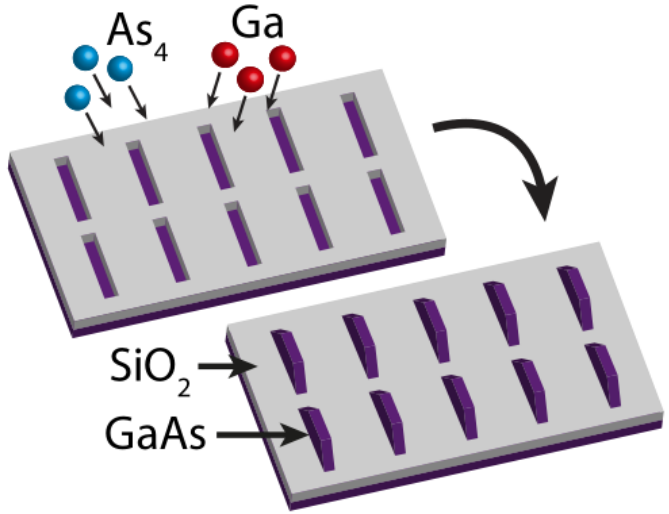
Membrane Definition and GaAs Growth

- Tungsten alignment marks
- Aligned etching of SiO_2
- Openings 16 – 44 nm wide





Molecular Beam Epitaxy (MBE) Chamber



Friedl, KC et al. Nano Lett. **18,** 2666-2671 (2018)
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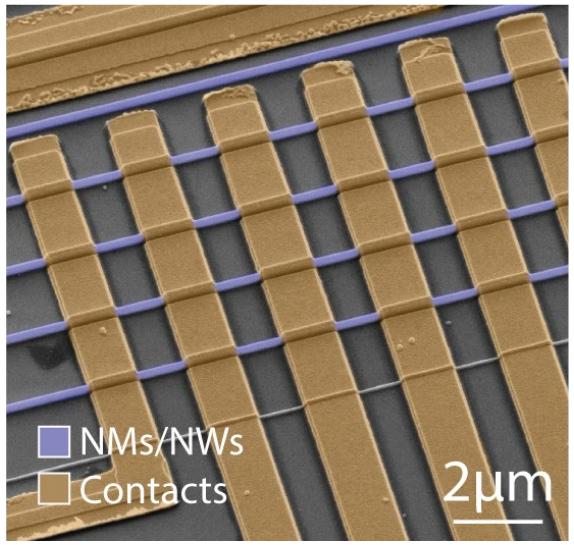
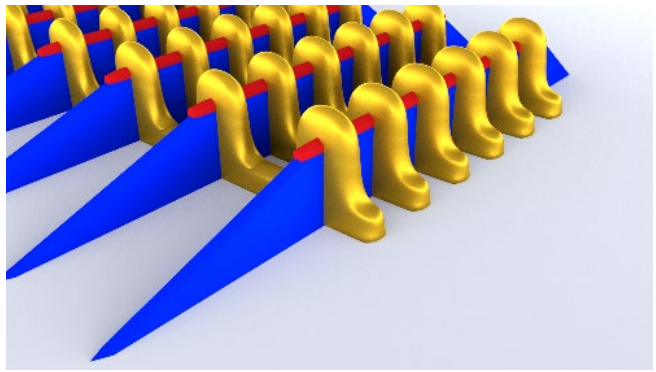
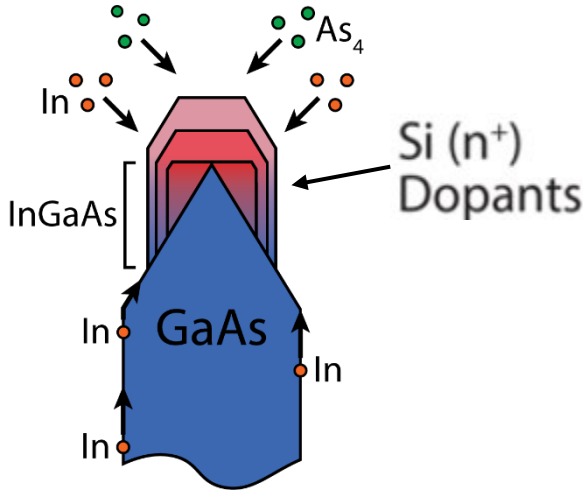
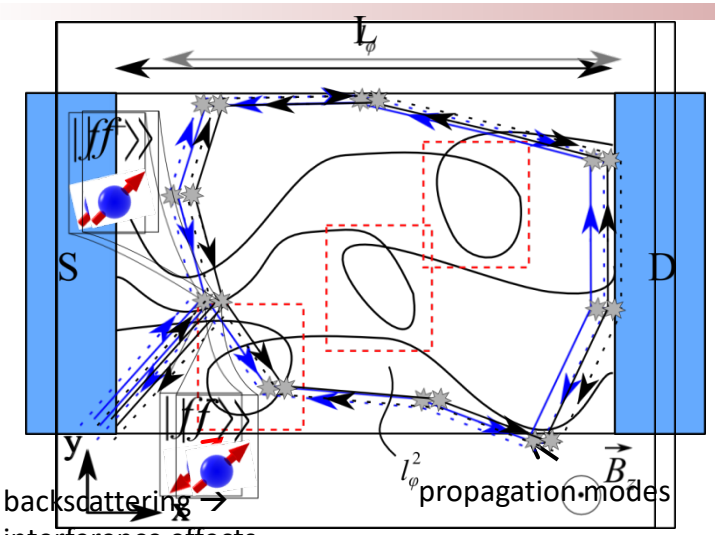
Traditional Doping







Weak (Anti-)Localization



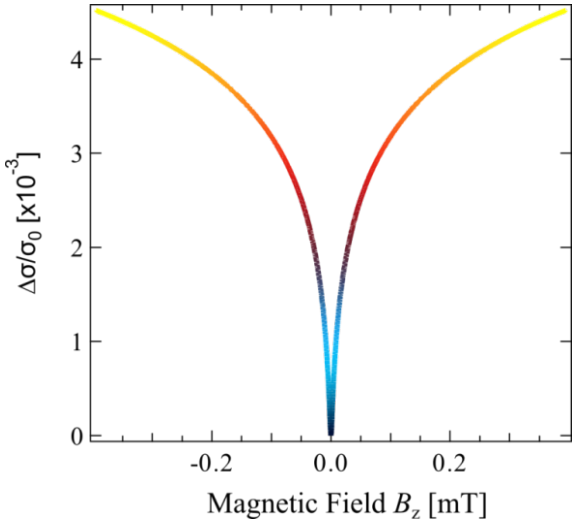
backscattering → interference effects

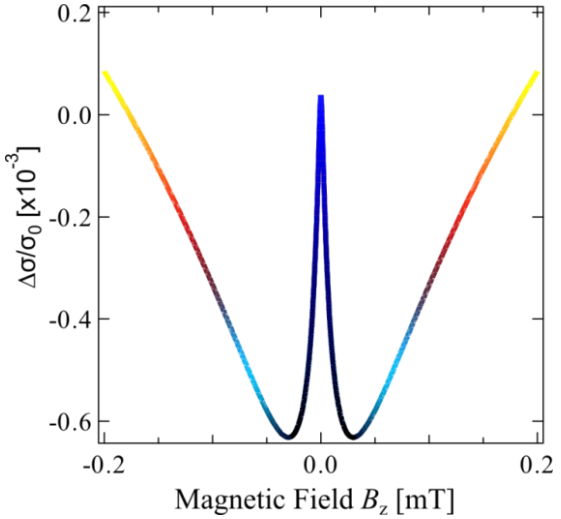
propagation modes

- Coherence of wave functions and no B-field
  - → Increased return probability
  - → Weak localization

B-field causes dephasing

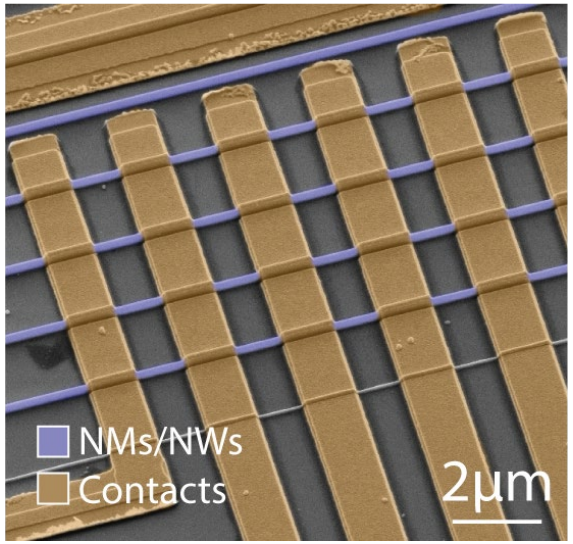
- Strong SOI
  - → Decreased return probability at B = 0



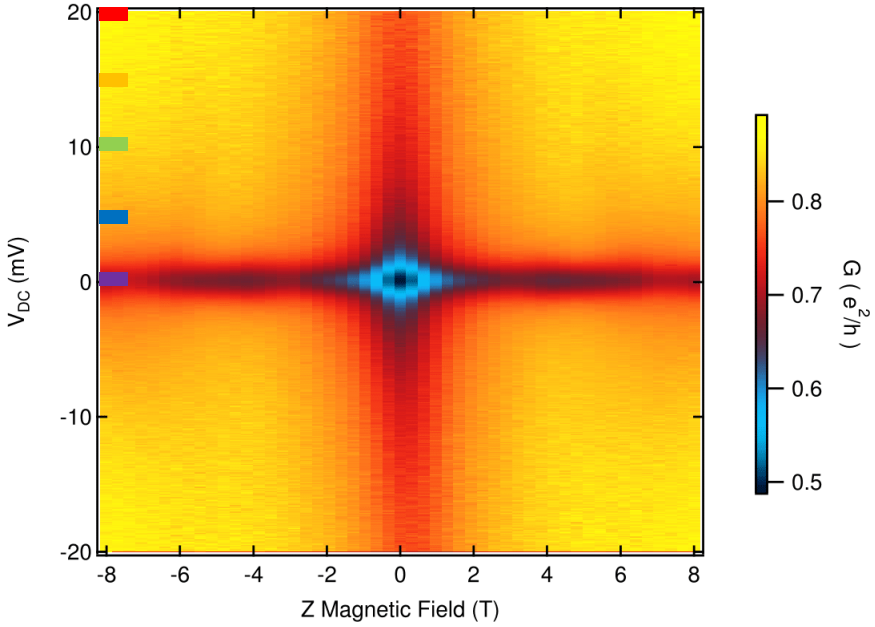


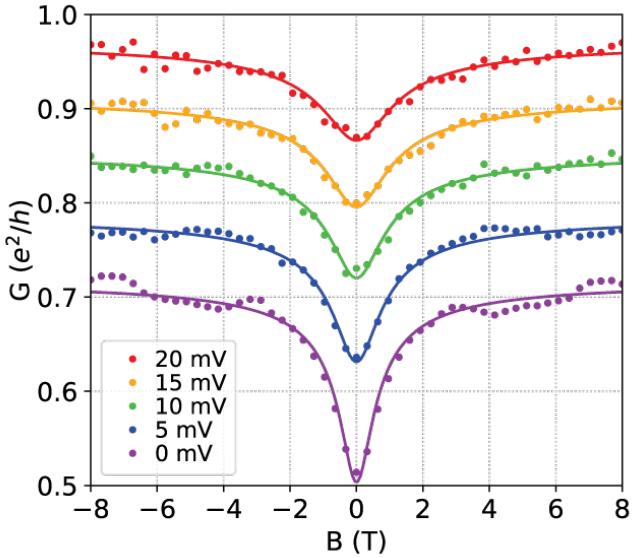
Bergman, Physics Reports **107**, 1 (1984)
Additional diagrams courtesy of P. Weigele

Magnetoconductance



B_z

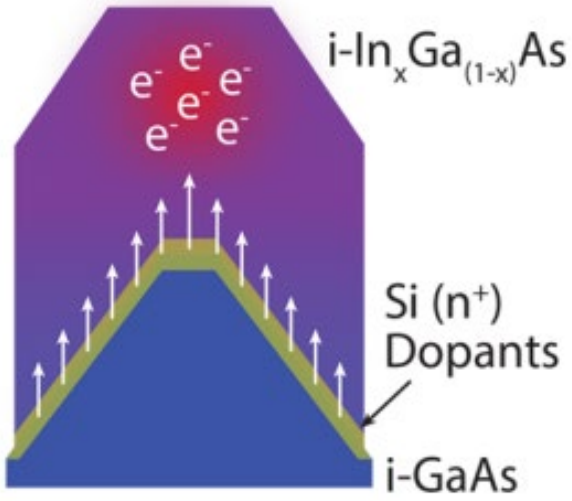


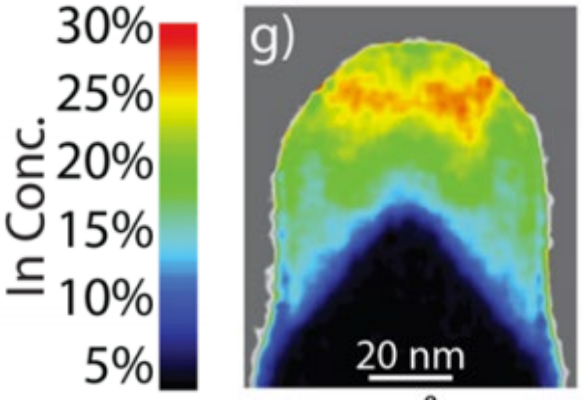


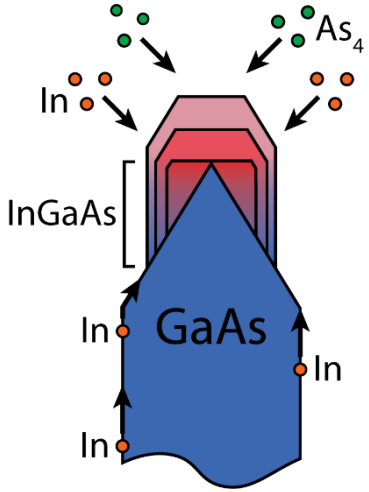
$$\Delta G = -\frac{2e^2}{hL}\left(\frac{1}{l_\varphi^2}+\frac{1}{l_B^2}\right)^{\frac{-1}{2}}$$

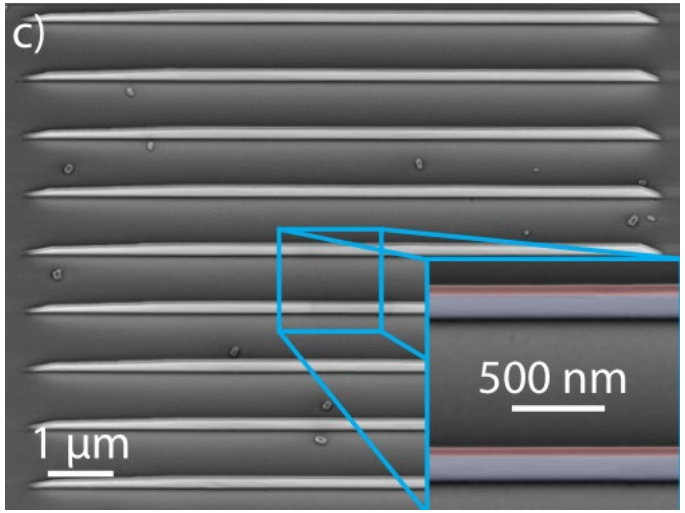
Modulation Doping

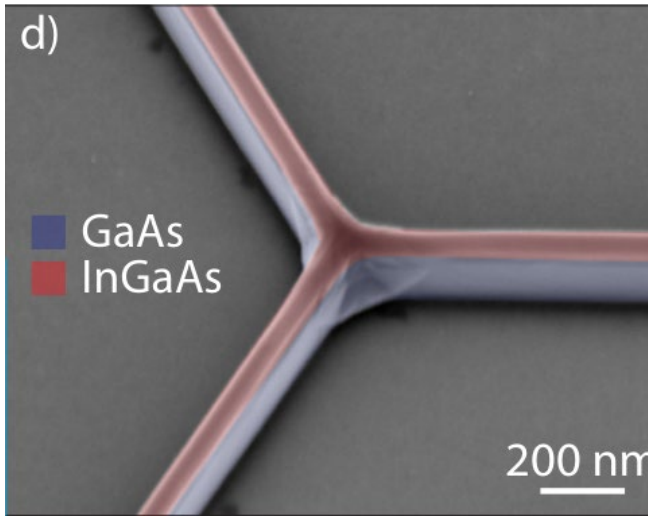
- Idea: carriers without local scattering sites
- Increased indium content



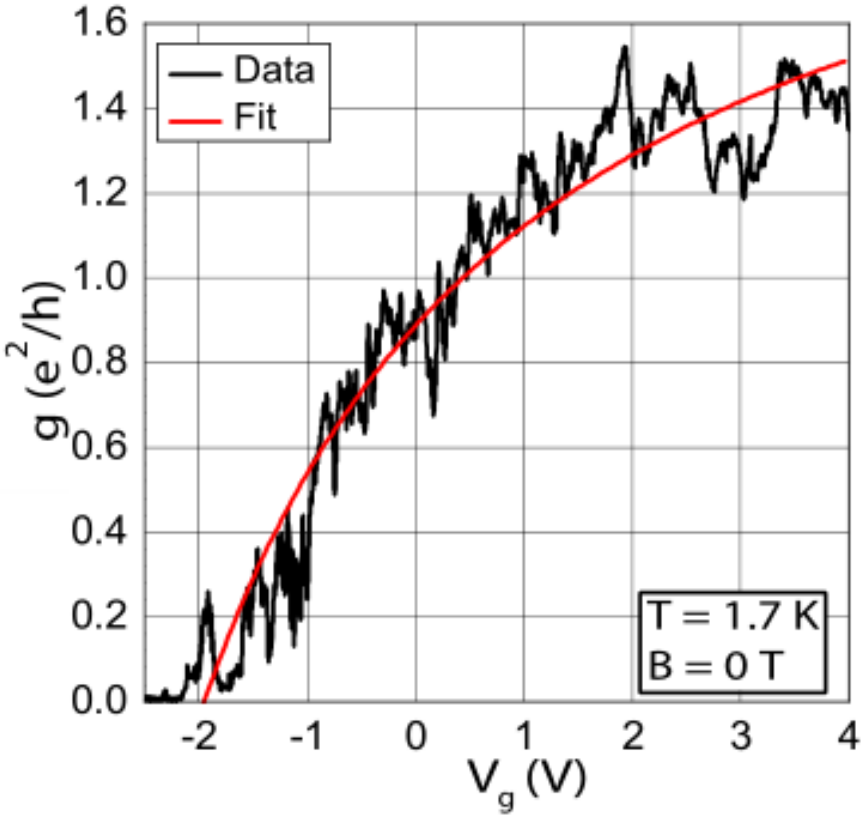






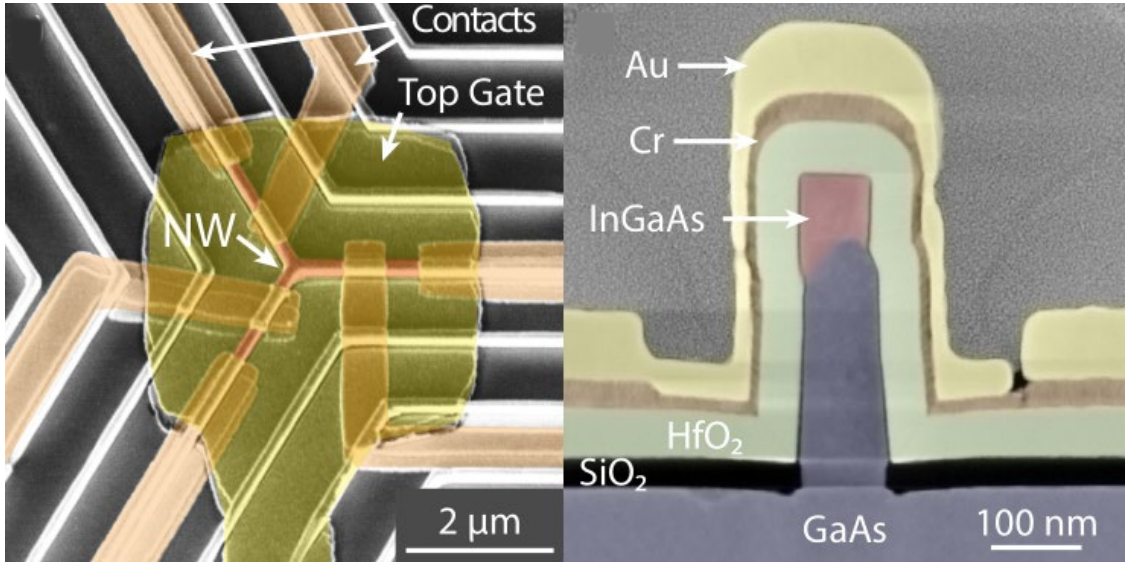


Field-Effect Mobility



$\mu \approx 500\, cm^2/Vs$

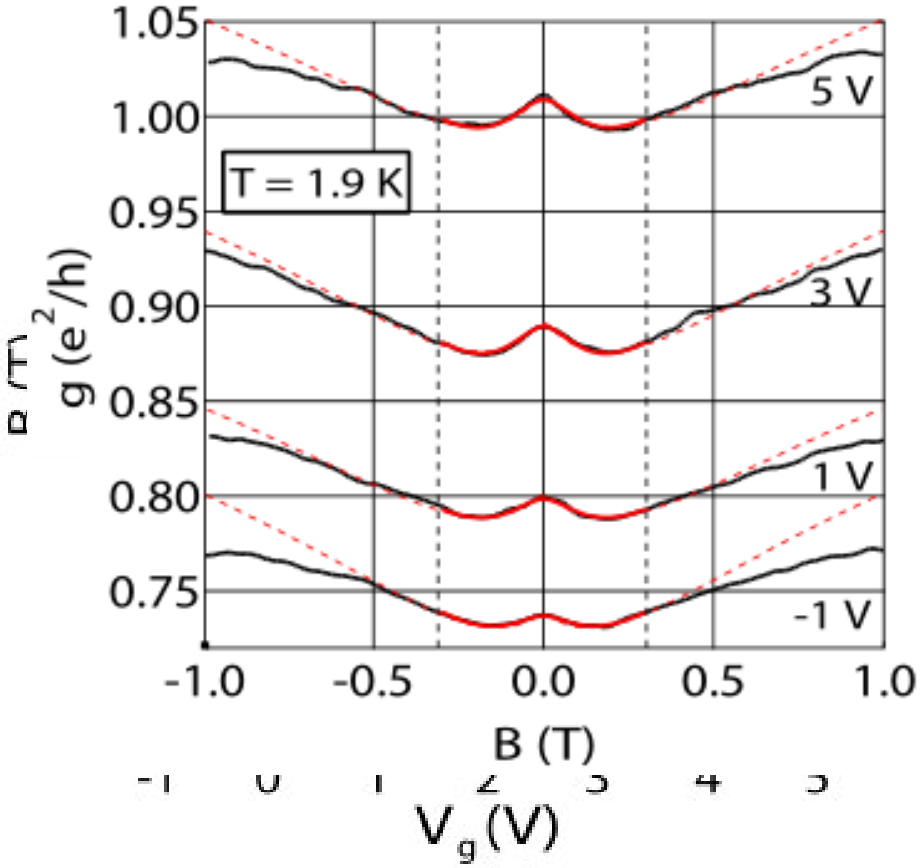
$l_e \approx 20\, nm$



$$G(V_g) = \left(R_s + \frac{L^2}{\mu C (V_g - V_{th})} \right)^{-1}$$

Friedl, KC et al. Nano Lett. **20**, 3577-3584 (2020)
Gül et al. Nanotechnology **26,** 215202 (2015)

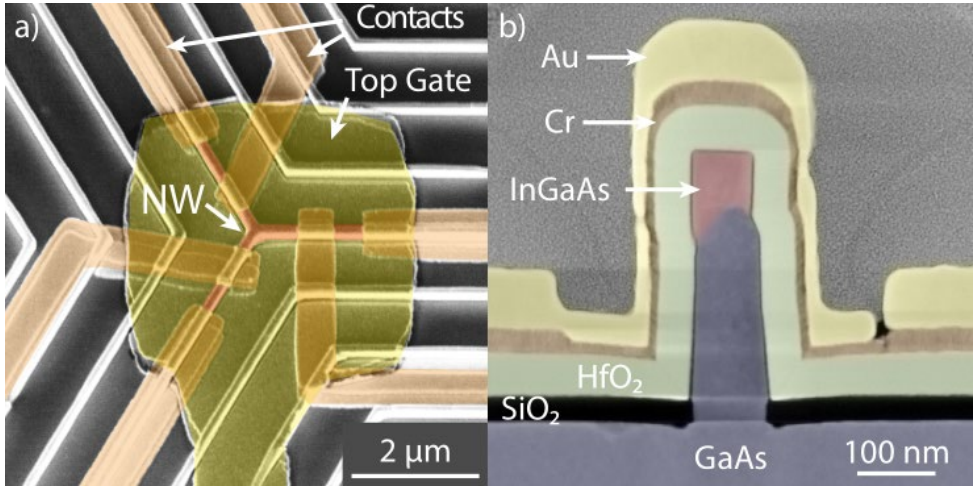
Wrap-Around Gate



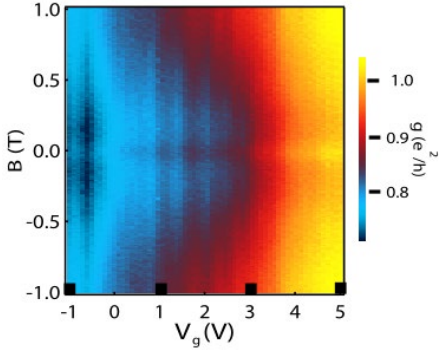
$l_{so} \approx 80\ nm$

$l_{\phi} \approx 100\ nm$

$l_e \approx 20\ nm$



B field applied perpendicular to substrate

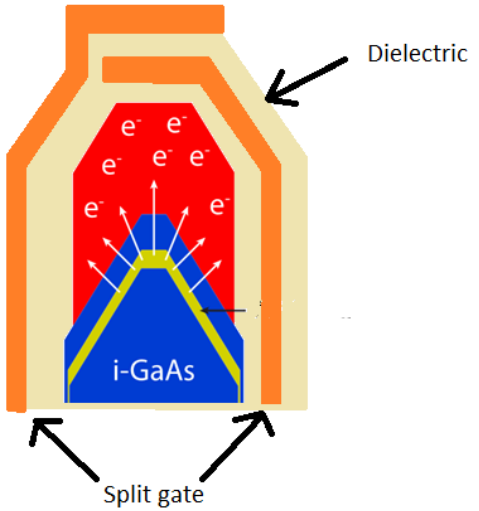


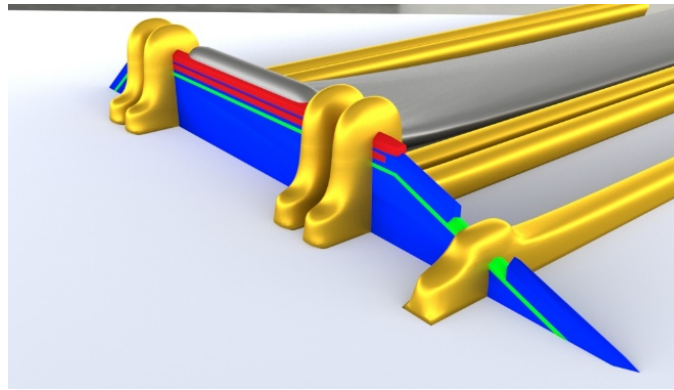
$$\Delta G = \frac{e^2}{h}\frac{1}{L}\left[3\left(\frac{1}{l_\phi^2}+\frac{4}{3l_{so}^2}+\frac{1}{l_B^2}\right)^{-1/2} - \left(\frac{1}{l_\phi^2}+\frac{1}{l_B^2}\right)^{-1/2} - 3\left(\frac{1}{l_\phi^2}+\frac{1}{l_e^2}+\frac{4}{l_{so}^2}+\frac{1}{l_B^2}\right)^{-1/2} + \left(\frac{1}{l_\phi^2}+\frac{1}{l_e^2}+\frac{1}{l_B^2}\right)^{-1/2}\right]$$

Friedl, KC et al. Nano Lett. **20**, 3577-3584 (2020)
van Weperen et al. PRB **91,** 201413 (2014)

Outlook

- Alternative gating configurations
- Exploring other substrates (<110>), Sb incorporation
- Longer term: stacked 1D wires in close proximity, coupling of superconductors





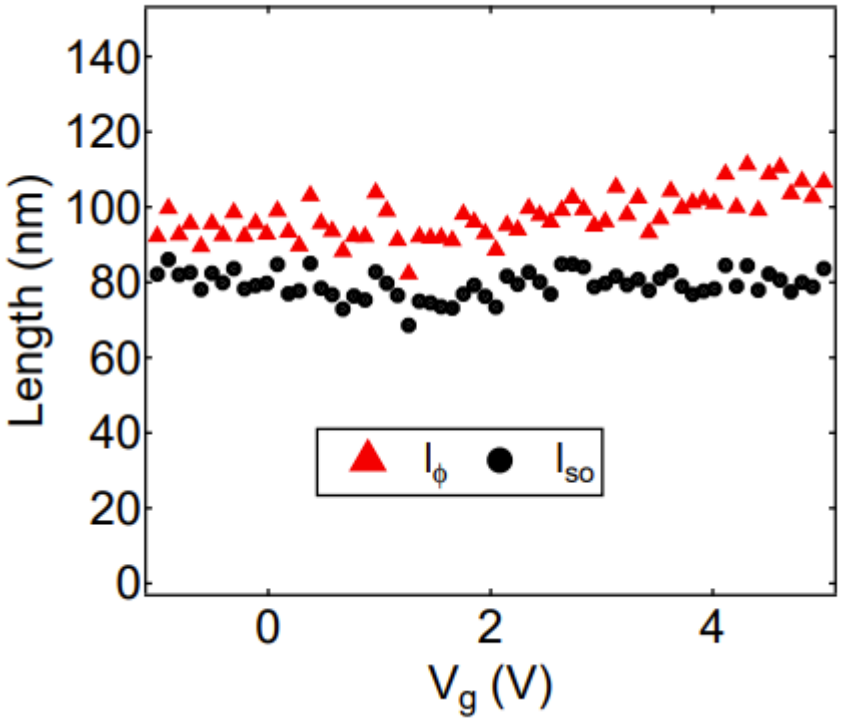
Thanks for your attention!!!!!

l_B Unpacking

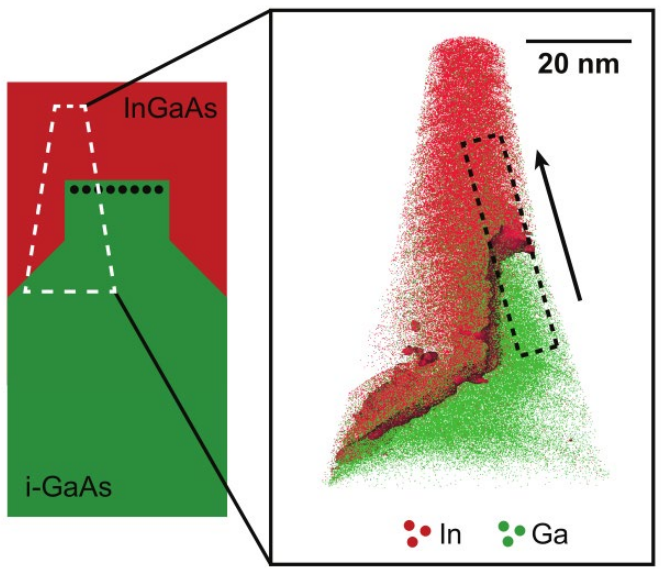
$$l_B^2 = \frac{C_1 l_e l_m^4}{W^3} + \frac{C_2 l_e^2 l_m^2}{W^2}$$

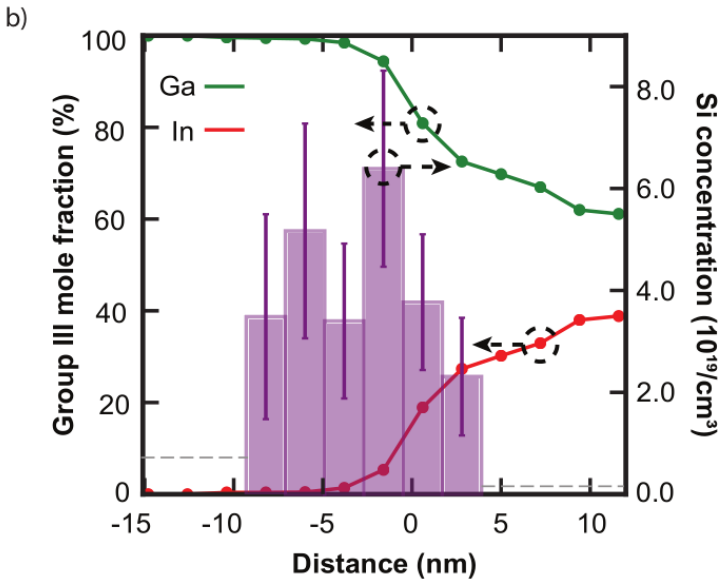
$$l_m = \sqrt{\hbar / eB}$$

l_φ & l_{SO}

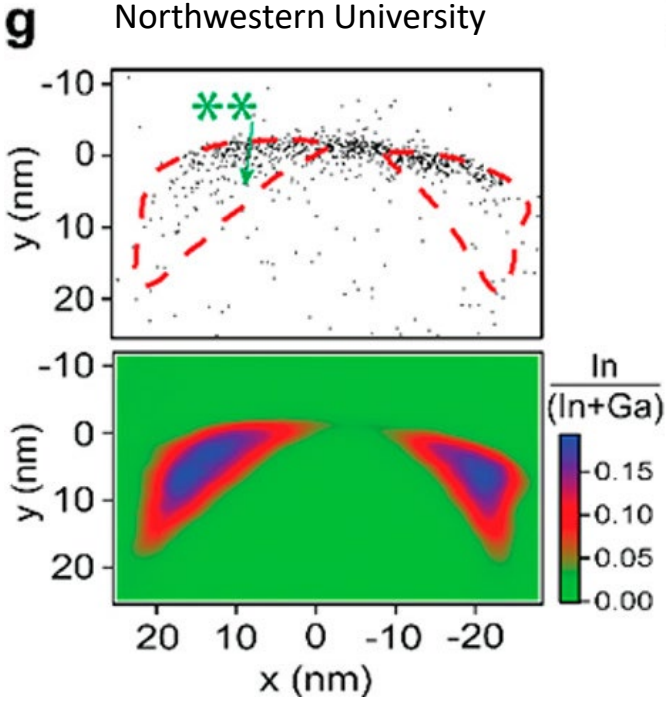


APT results





Atom Probe Tomography done by group of Lincoln Lauhon at Northwestern University



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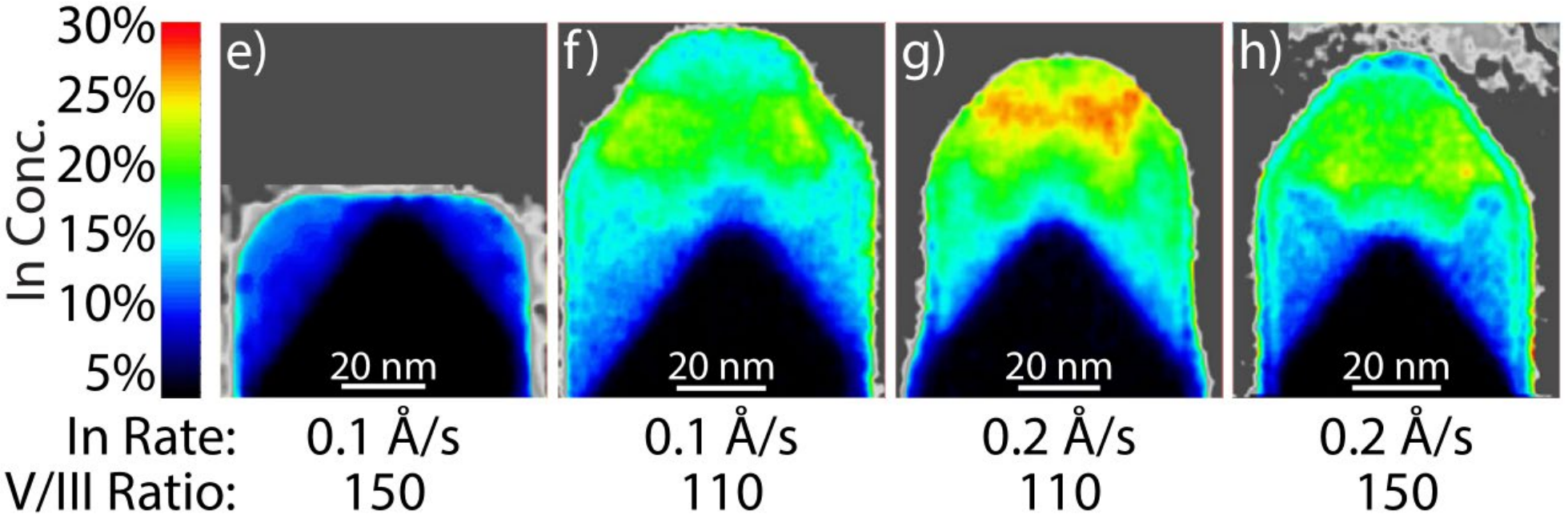
Friedl, KC et al. Nano Lett. **20**, 3577-3584 (2020)

Indium Concentration Optimization



Friedl, KC et al. Nano Lett. **20**, 3577-3584 (2020)