Nanowire week

Chamonix, France, April 25 – 29, 2022

Free-standing InSb nanoflags for quantum device applications

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Motivation

InSb:

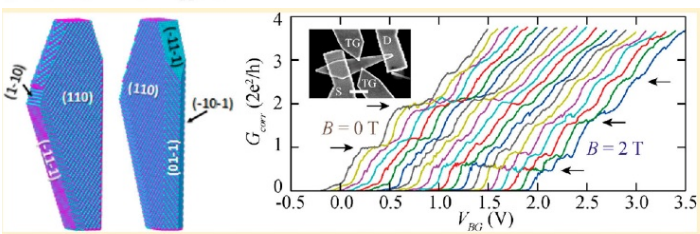
- Small bandgap, low electron effective mass, high electron mobility, high Landè g-factor and strong spin-orbit interaction
  → promising material for optoelectronics, thermoelectrics, spintronics and quantum computing

- Large lattice mismatch with all other III-Vs → difficult integration of defect-free InSb in planar epitaxy
- Sb acts as an surfactant → difficult to control/tune the InSb morphology during the growth

Free-standing InSb (1D and 2D)

Twin-Induced InSb Nanosails: A Convenient High Mobility Quantum System

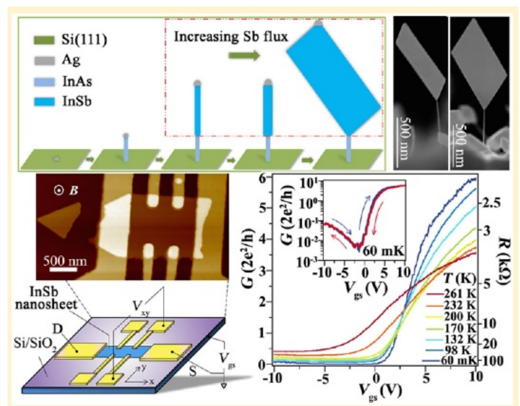
María de la Mata,[†] Renaud Leturcq,[*,‡,§] Sébastien R. Plissard,[∥] Chloé Rolland,[‡] César Magén,[⊥] Jordi Arbiol,[*,†,#] and Philippe Caroff[*,‡,∇]



Nano Lett. 16 (2016) 825

Free-Standing Two-Dimensional Single-Crystalline InSb Nanosheets

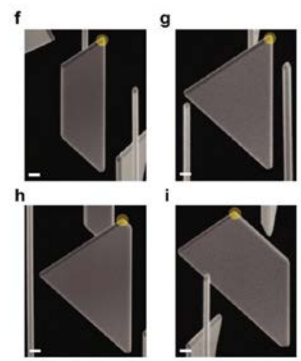
D. Pan,[†] D. X. Fan,[‡] N. Kang,[‡] J. H. Zhi,[‡] X. Z. Yu,[†] H. Q. Xu,[*,‡] and J. H. Zhao[*,†]



Adv. Mater. 31 (2019) 1808181

Bottom-Up Grown 2D InSb Nanostructures

Sasa Gazibegovic, Ghada Badawy,* Thijs L. J. Buckers, Philipp Leubner, Jie Shen, Folkert K. de Vries, Sebastian Koelling, Leo P. Kouwenhoven, Marcel A. Verheijen, and Erik P. A. M. Bakkers*

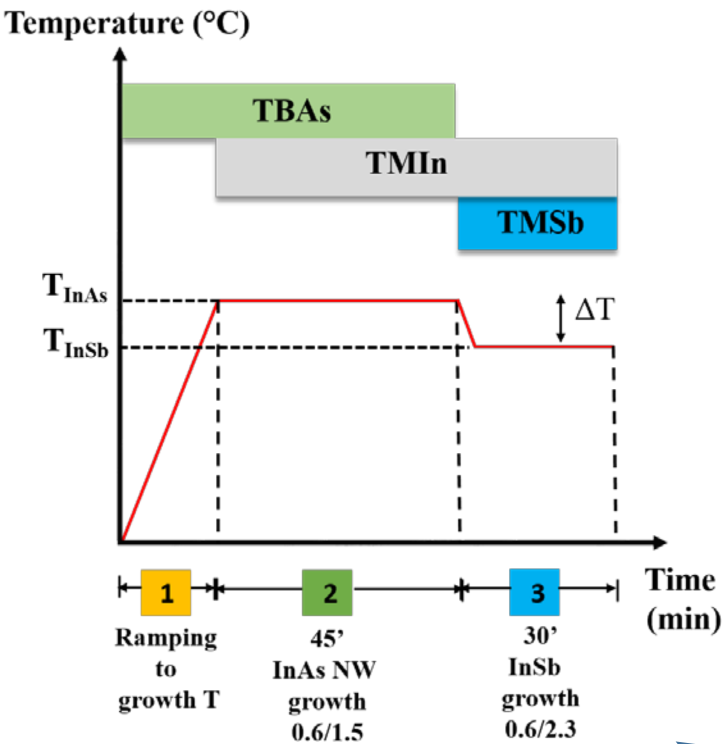


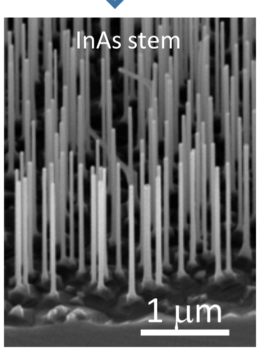
Nano Lett. 16 (2016) 834

OUR GOALS: - **morphology control** of high quality InSb nanostructures by tuning the growth parameters
- develop a directional growth protocol to achieve **free standing** InSb nanoflags (2D) on NW stems

OUR APPROACH: Au assisted Chemical Beam Epitaxy using Au nanoparticle from colloidal solutions

Morphology control of InSb nanostructures

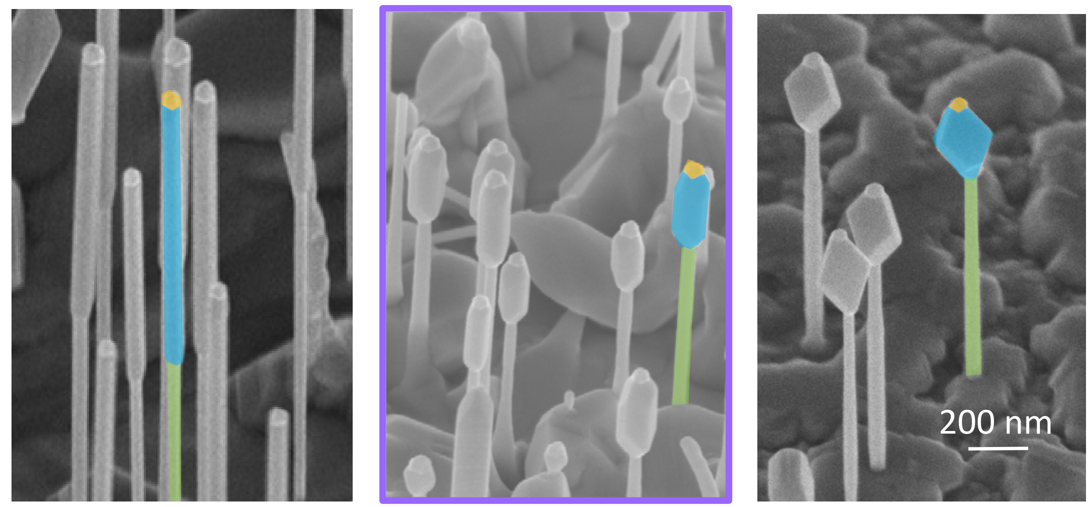




T_{InAs} : 385°C
Au NPs: 30 nm colloids
MO precursors:
TBAs, TMIn, TMSb
Sample rotation: 5 rpm

InSb growth T optimization

ΔT = -20°C **ΔT = -30°C** **ΔT = -40°C**

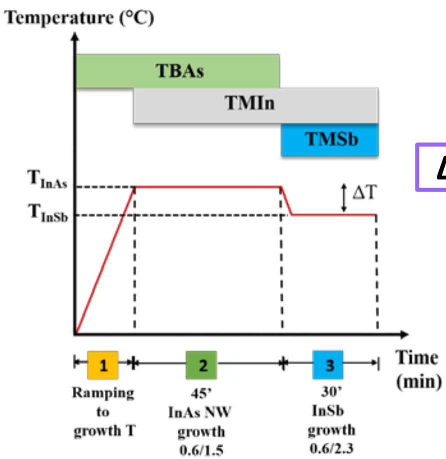


1D- like Nanowires

3D- like Nanocubes

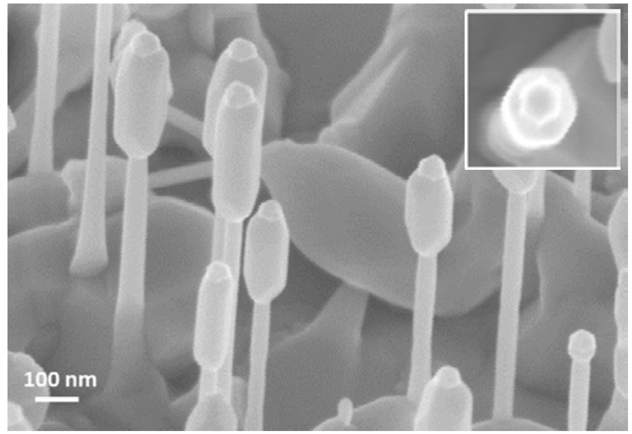
High T_{InSb} enhances the axial growth and reduces the radial growth

Directional InSb growth

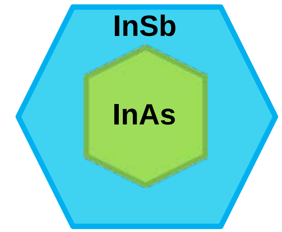


ΔT = -30°C

With sample rotation uniform growth

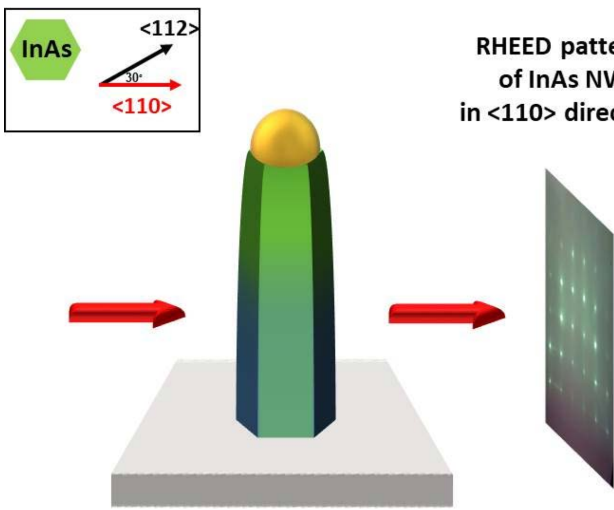


Top-view



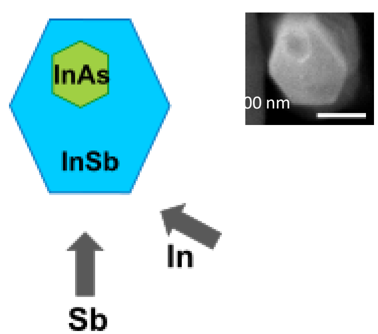
- InAs NWs have WZ crystal structure with 6 equivalent {112} sidewalls
- InSb has ZB crystal structure with 6 equivalent {110} sidewalls

Sample alignment for directional InSb growth:

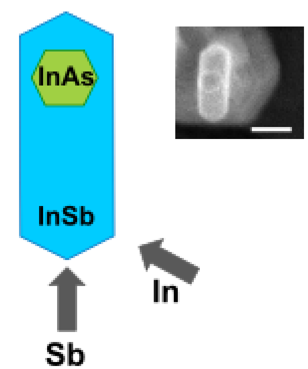


RHEED pattern of InAs NW in <110> direction

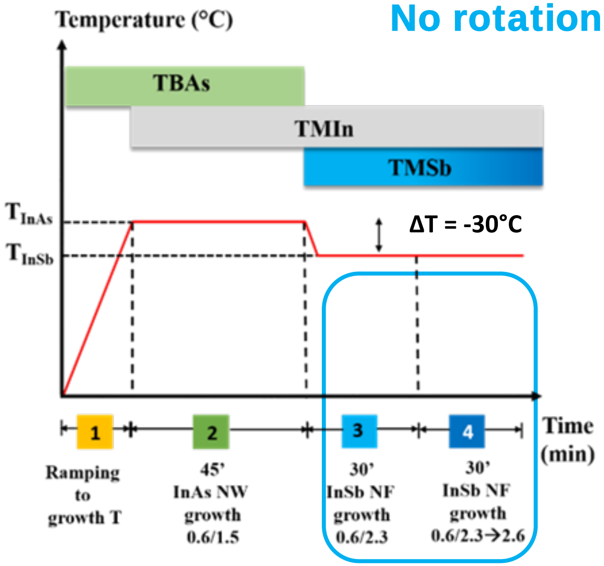
Sb beam projection ⊥ to a {110} sidewall



Sb beam projection ⊥ to a {112} sidewall

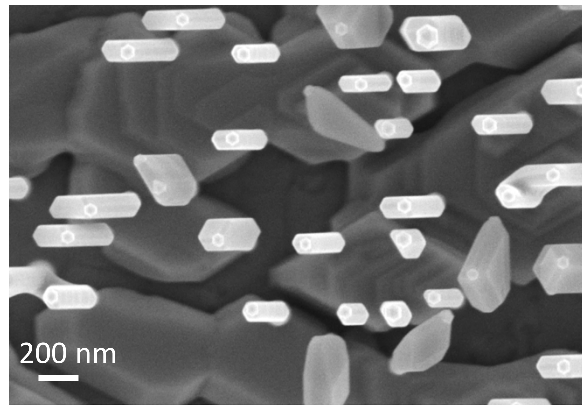


Free-standing InSb nanoflags (NFs)

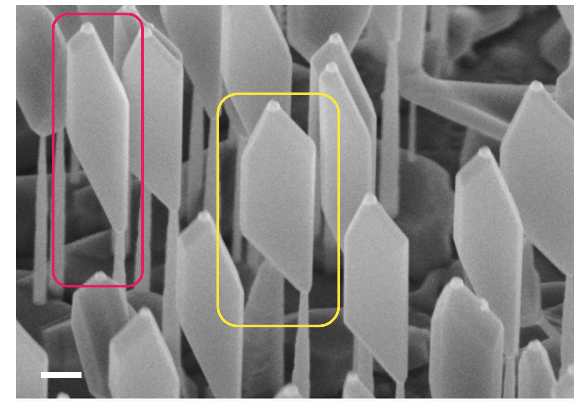


No rotation, alignment, increasing Sb flux → asymmetric growth enhancement

Top-view

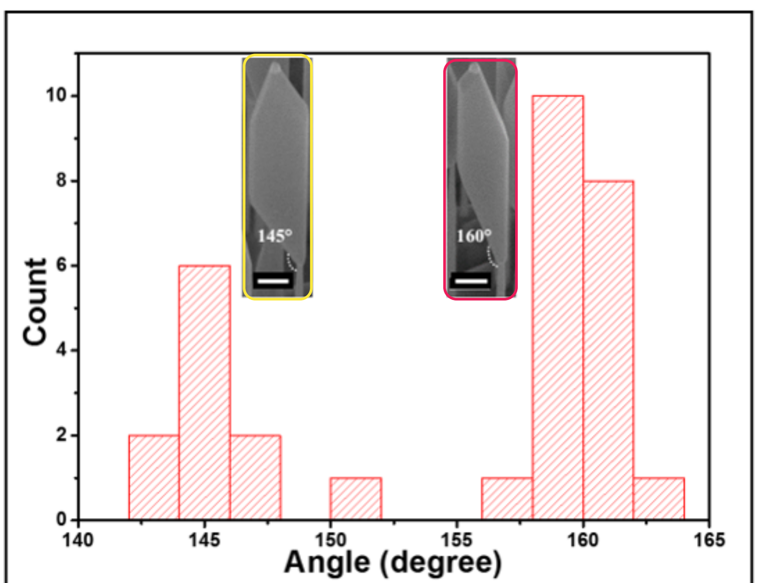


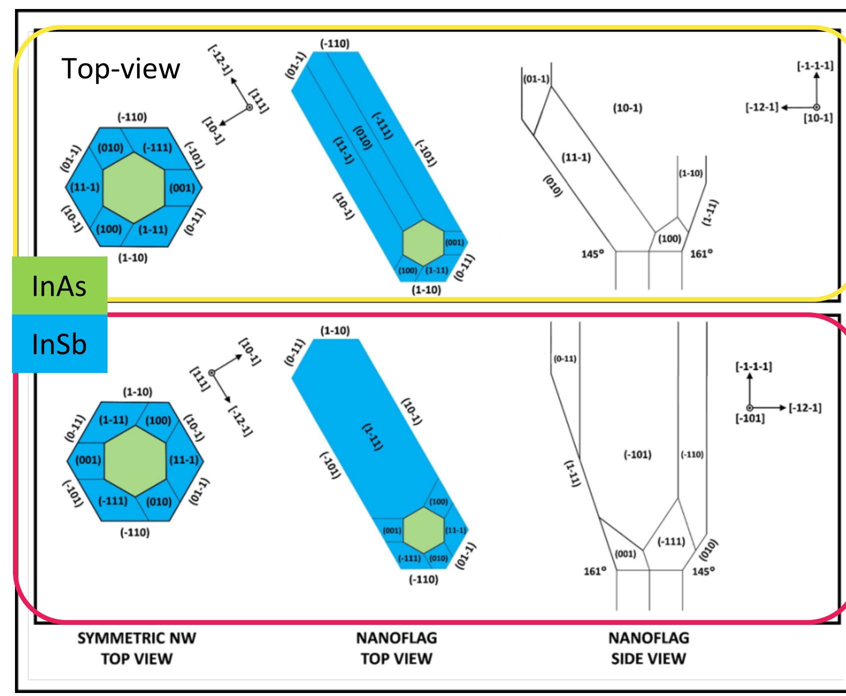
45°-tilted-view



2 different aperture angles: 145° and 160°

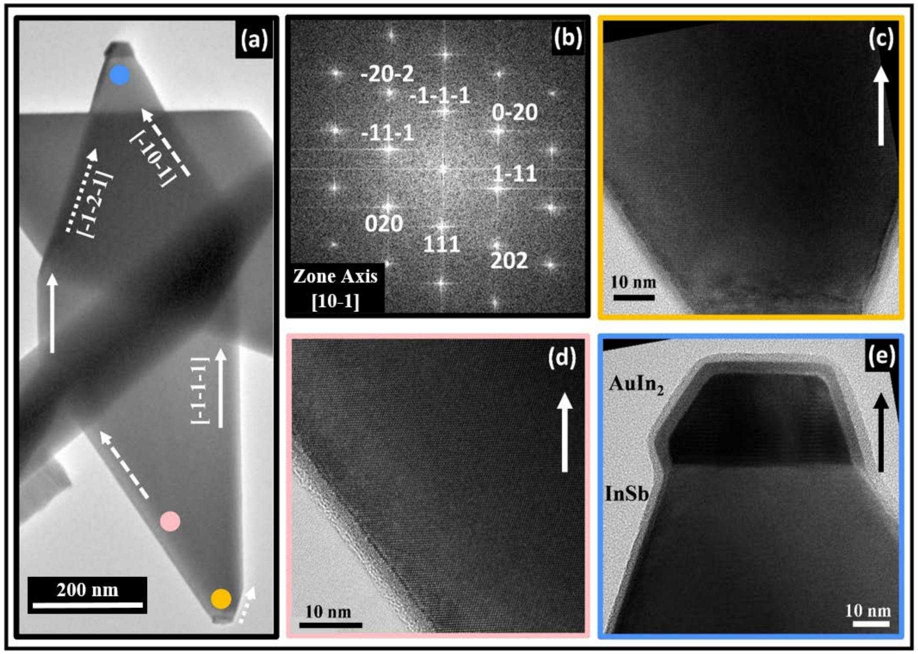
180° rotation around the growth axis of the additional facets at the interface



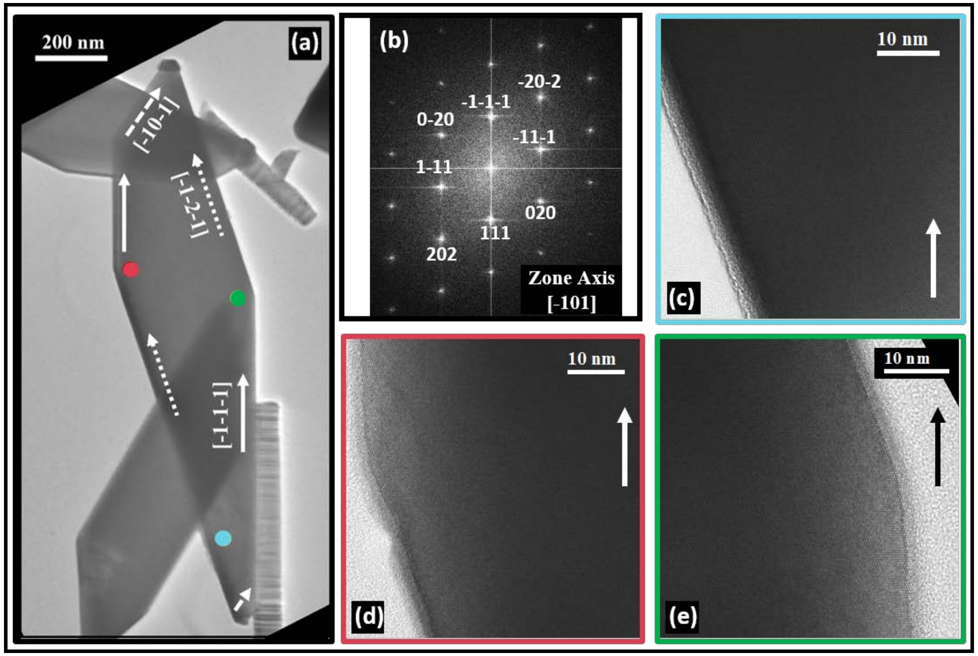


Free-standing InSb nanoflags (NFs)

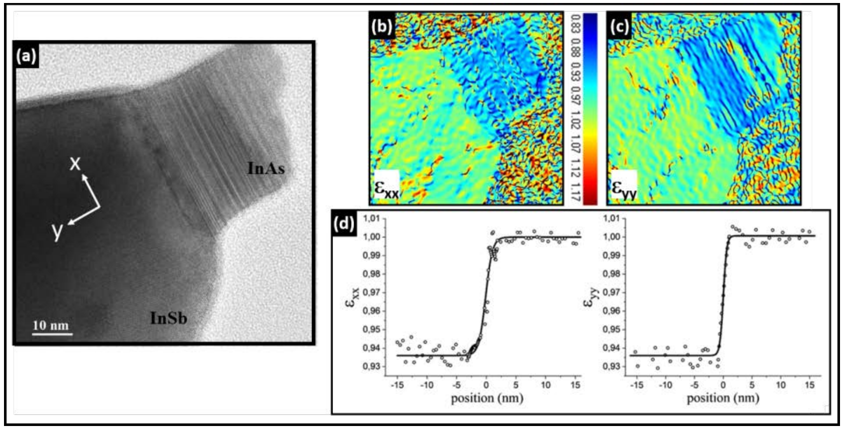
145° aperture angle



160° aperture angle



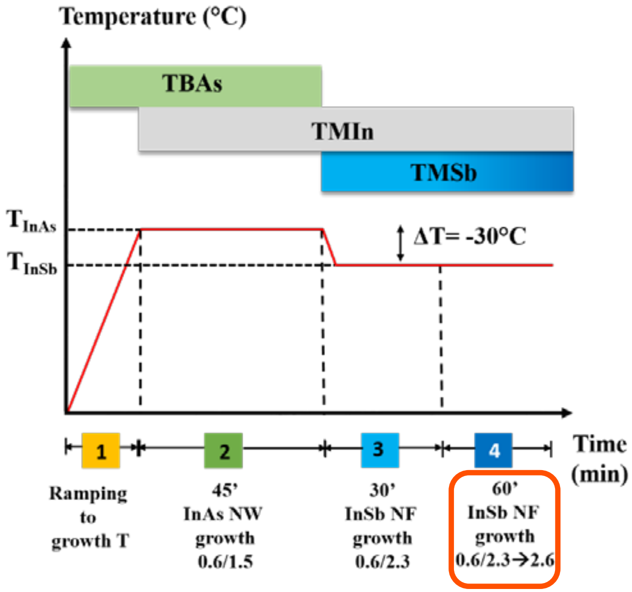
GPA

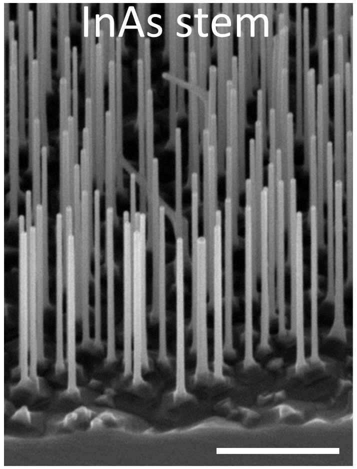


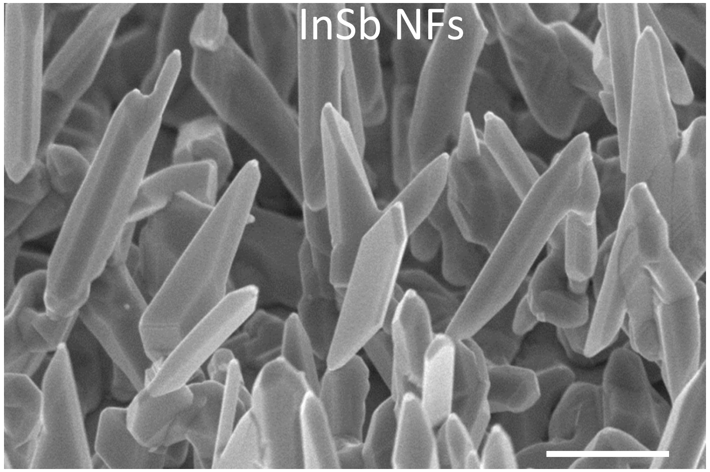
- Defect-free ZB crystal structure
- Stoichiometric composition
- Relaxed lattice parameter

Verma *et al*, *Nanotechnology* **31** 384002 (2020)

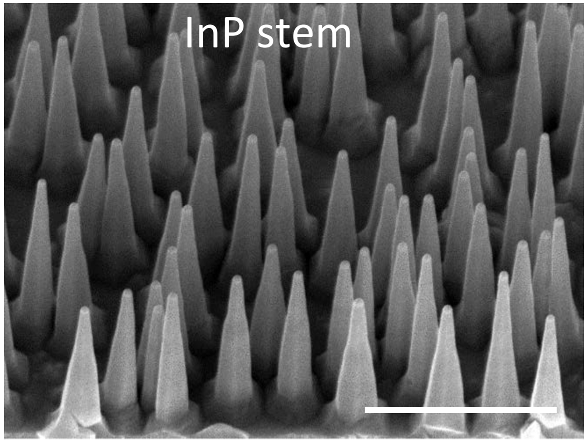
Longer InSb growth time

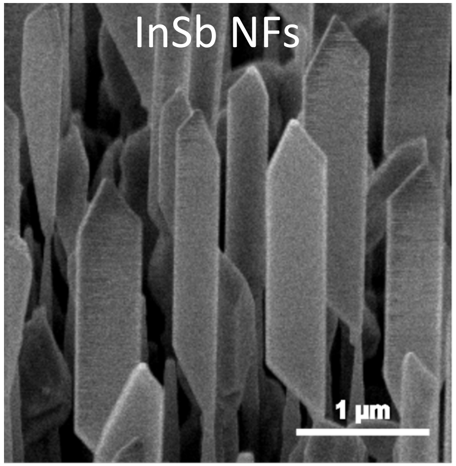






Increasing InSb growth time





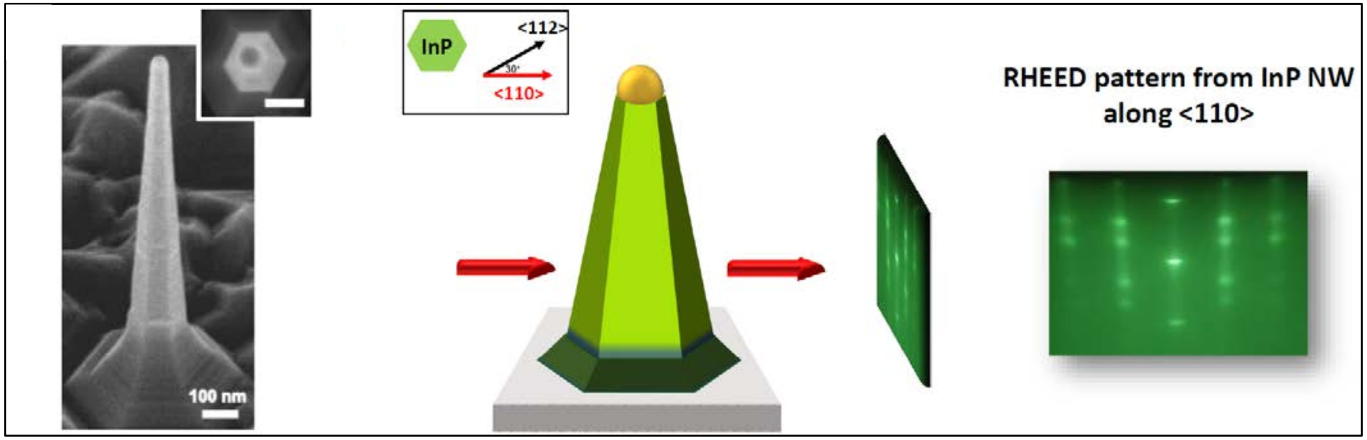
InSb NFs dimension
Length= 2.8 ± 0.2 µm
Width= 470 ± 80 nm
Thickness= 105 ± 20 nm

Using **tapered and more robust InP NW stems**, we could achieve bigger InSb NFs

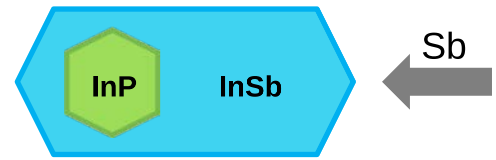
Verma *et al, ACS Appl. Nano Mater* **4** 5825 (2021)

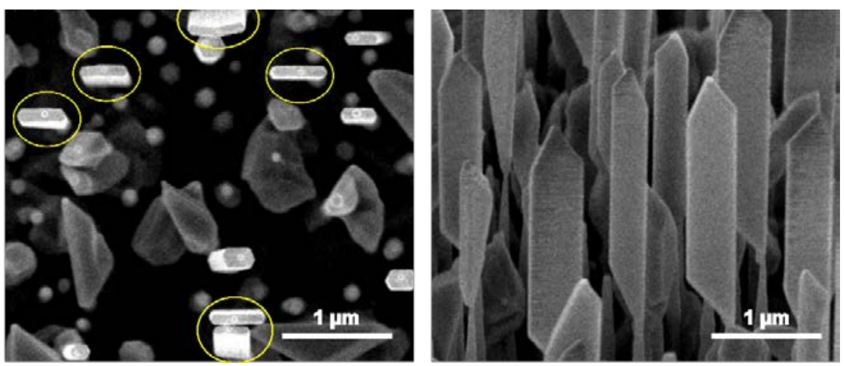
Larger InSb nanoflags

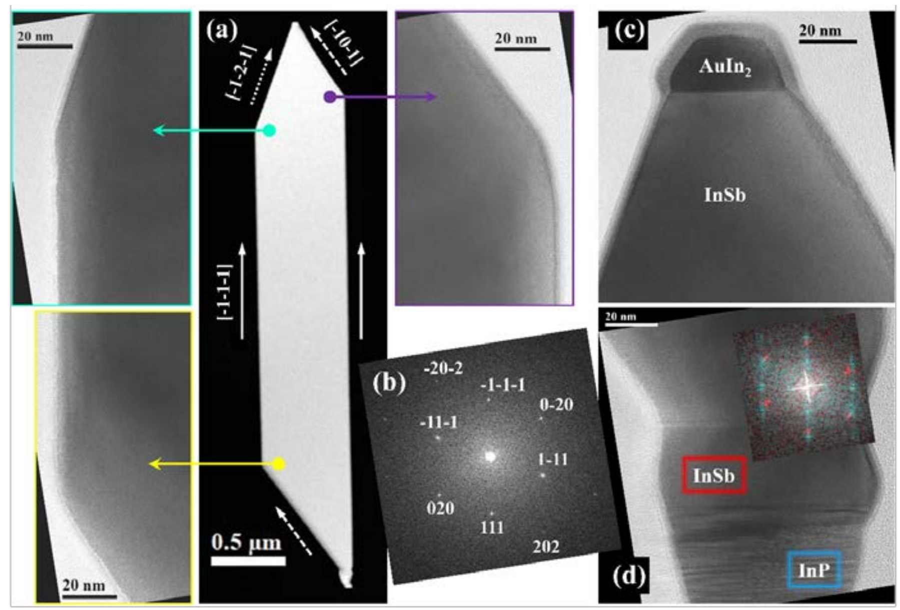
InP NWs have mixed WZ/ZB crystal structure, but still <112> sidewalls



Sb beam projection ⊥ to a {112} sidewall

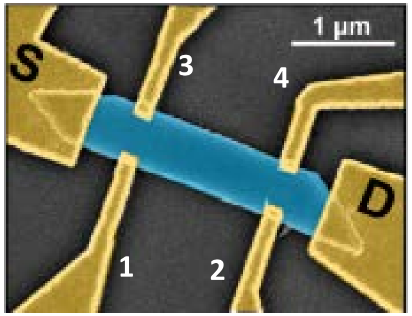






STEM-HAADF image and corresponding HRTEM images show **defect-free InSb ZB crystal structure**.

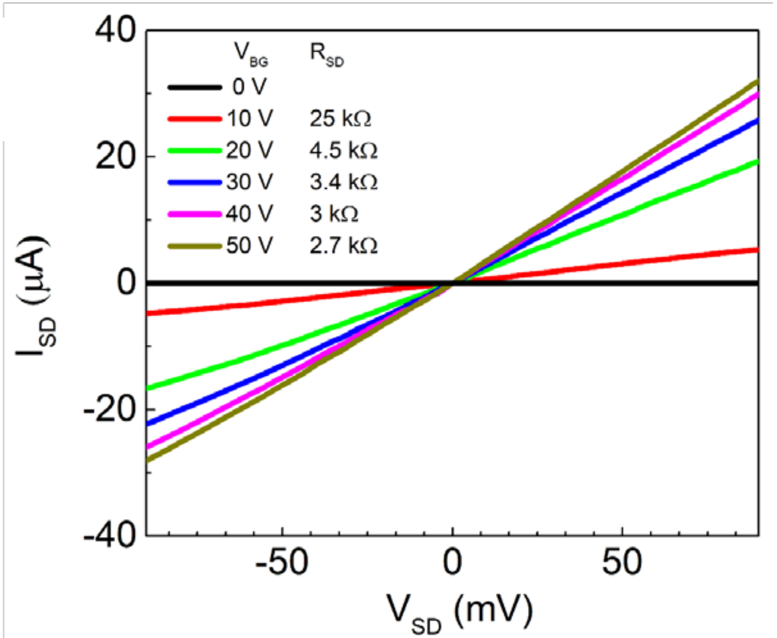
Transport measurements



Hall-bar device

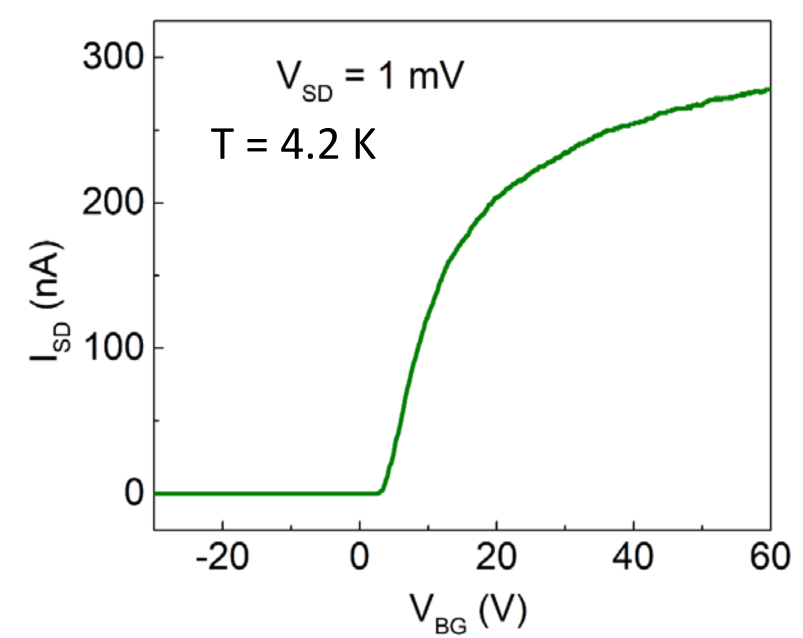
Channel width (width between contacts 1-3 and 2-4)=325 nm
Channel length (1-2 and 3-4)=1.5 μm. The NF thickness is ~100 nm.
Contacts: 10 nm Ti/190 nm Au
Substrate: Si/SiO_2

R_{SD}(RT, VBG=0 V) = 11 KΩ
R_{SD}(4.2K, VBG=50 V) = 2.7 KΩ



Good Ohmic contacts, no Schottky barrier

Injected current VS BG voltage @ 4.2 K

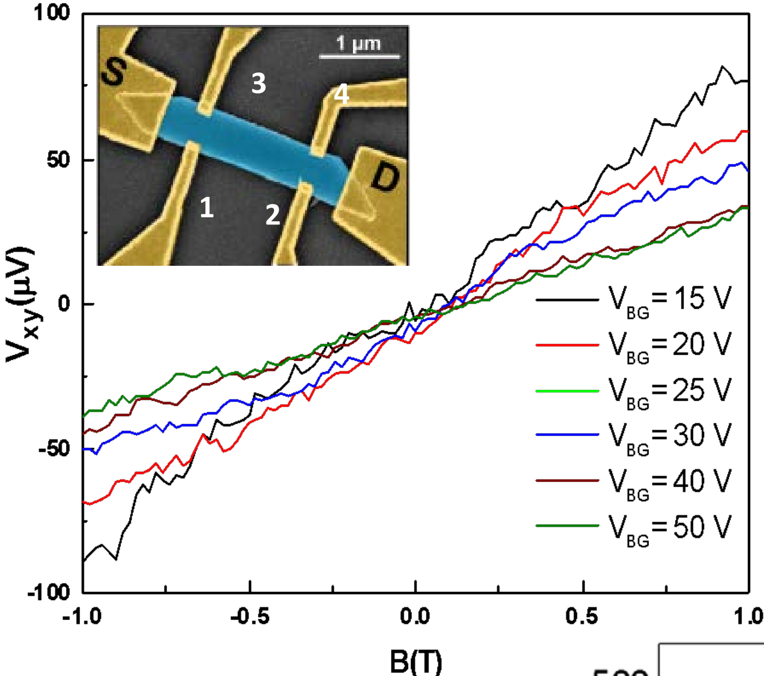


Four-probe field-effect mobility: 28000 $cm^2V^{-1}s^{-1}$
Nanoflags are n-type

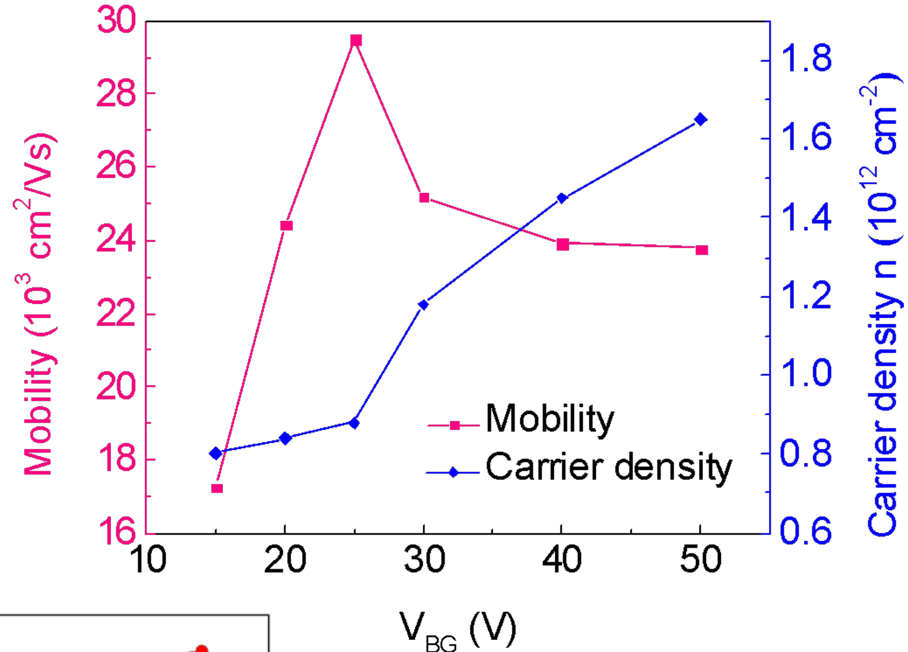
n- type characteristics of InSb NFs under BG modulation

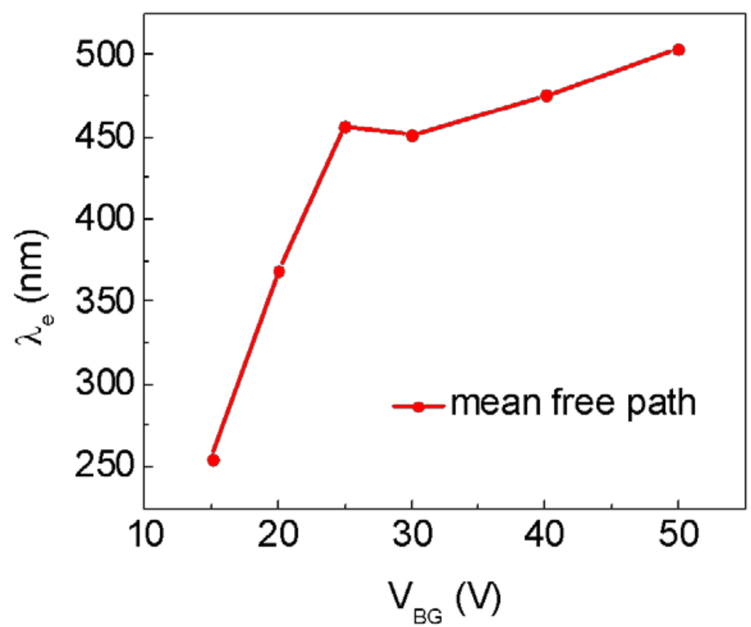
Transport measurements

Hall effect vs BG bias @ 4.2K



Electron Hall mobility = 29500 $cm^2V^{-1}s^{-1}$

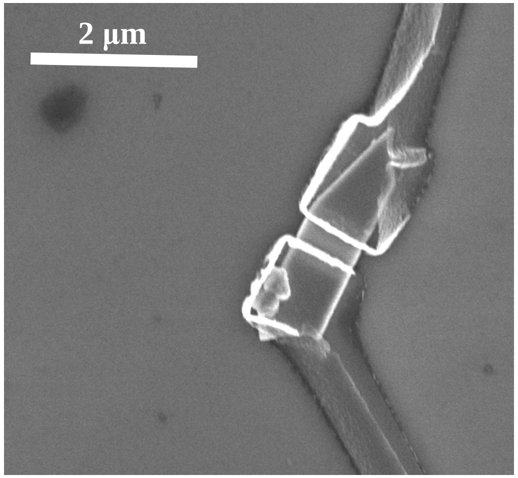




Mean free path λ_e up to 500 nm

$$\lambda_e = (\hbar\mu/e)(2\pi n)^{1/2}$$

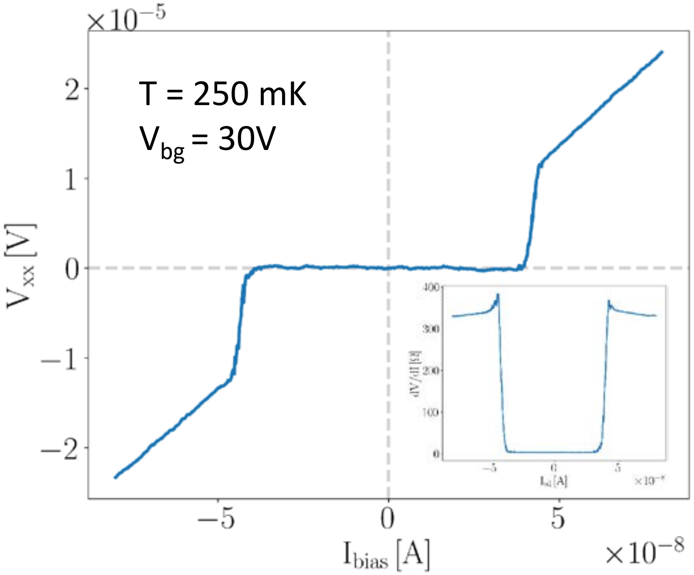
Ballistic InSb NFs-based Josephson junction devices



10 nm Ti/150 nm Nb
Substrate: Si/SiO_2

L = 200 nm
W = 700 nm
d = 100 nm

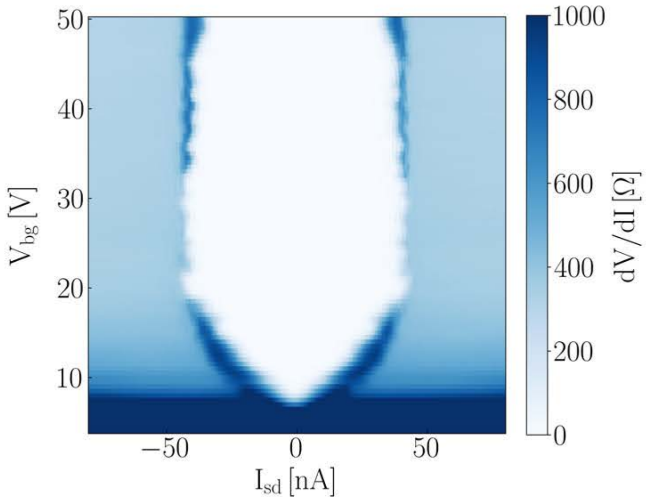
T_c = 8.44 K
$\Delta = 1.76\, k_B T_c = 1.28$ meV

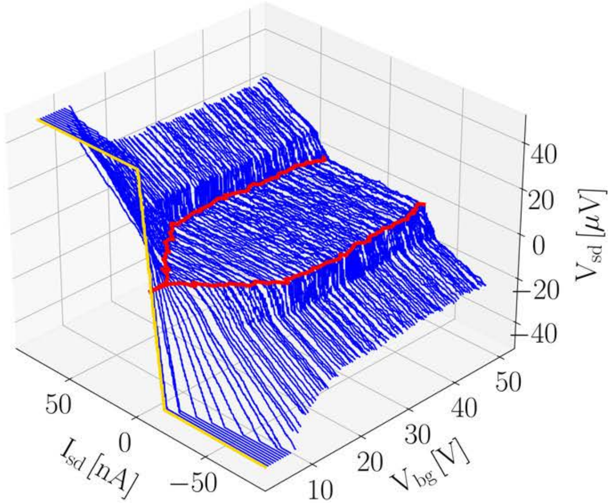


Ballistic regime! Mean free path λ_e > length L of the junction, $\lambda_e > L$.

Proximity induced superconductivity
50 nA supercurrent

Gate tunable supercurrent



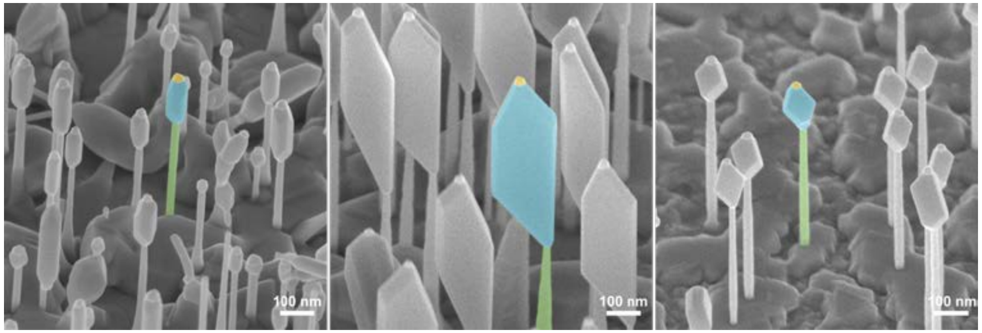


Further info:

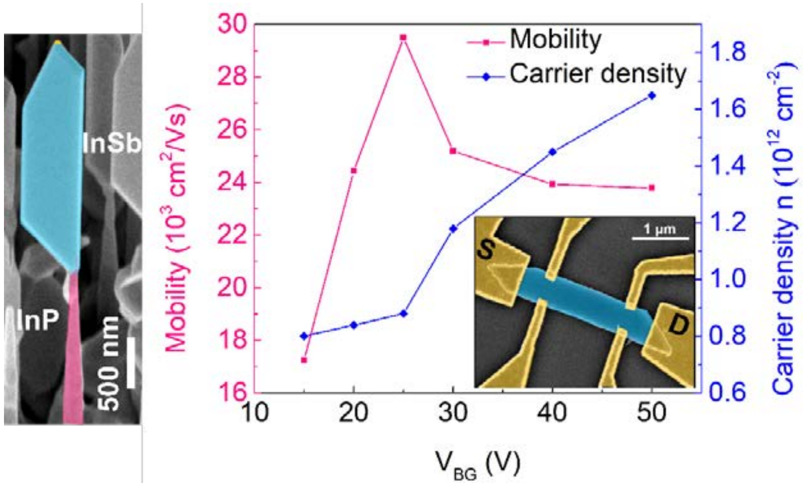
S. Salimian et al. "Gate-controlled supercurrent in ballistic InSb nanoflag Josephson junctions" *Appl. Phys. Lett.*, 119, no. 21, 2021 doi: 10.1063/5.0071218

Decreasing V_{bg} below 20 V the supercurrent decreases and it disappears at 5 V

Conclusions

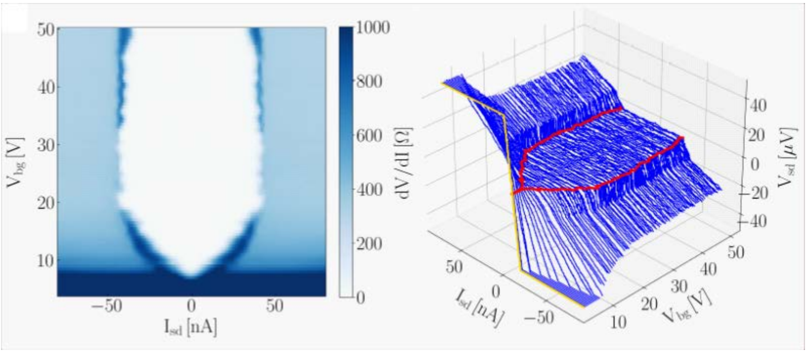


- Finding the parameters that affect axial and radial growth is important for controlling and tuning the InSb nanostructure morphology



- Using tapered NW stem and precise orientation (RHEED pattern) allow to achieve uniformly thin and large NFs

- Electron Hall mobility of about 29500 cm^2/Vs Mean free path up to 500 nm.



- NFs-based Josephson junction devices showed gate tunable supercurrent

- InSb NFs: versatile and convenient 2D platform for advanced quantum technologies.

Thanks to...

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Lucia Sorba

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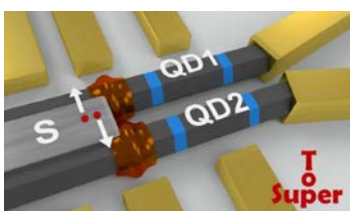
Francesca Rossi

Transport Measurements

Sedighe Salimian

Stefan Heun



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AndQC

Thank you for your attention!