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THE AUSTRIAN SOCIETY FOR METALLURGY AND MATERIALS

Morphology control and Electrical characterization of free-standing InSb nanostructures

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Chemical Beam Epitaxy (CBE)

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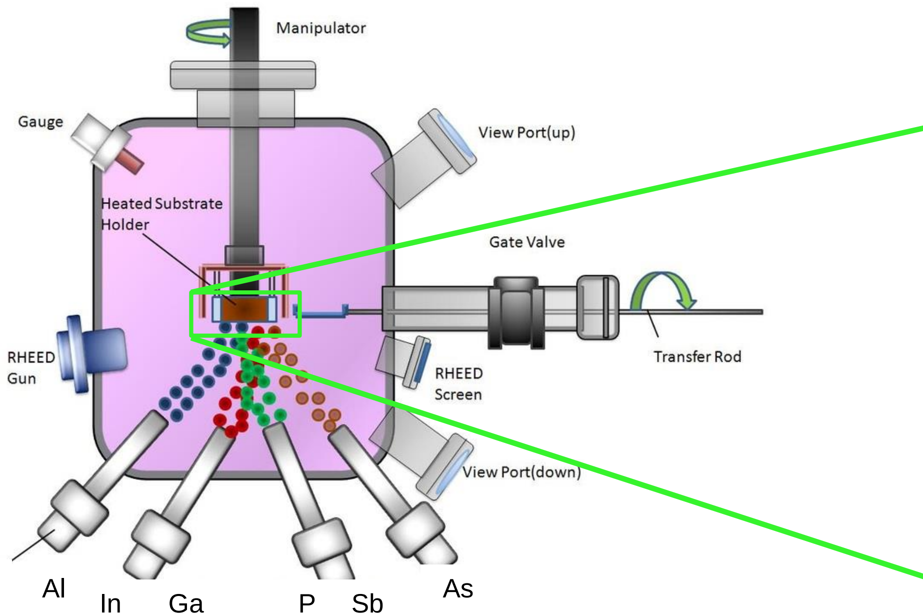
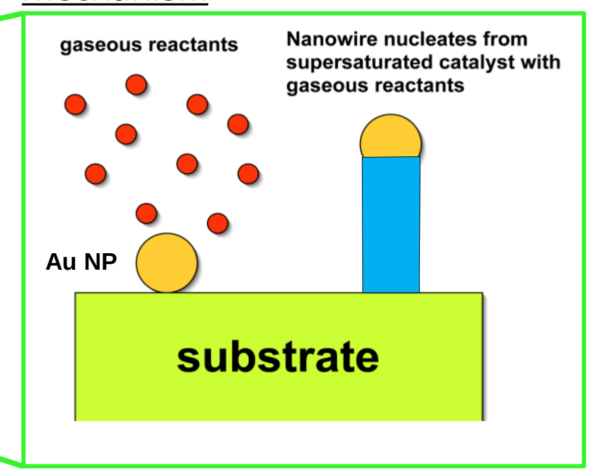
Ultra High Vacuum (UHV) chamber

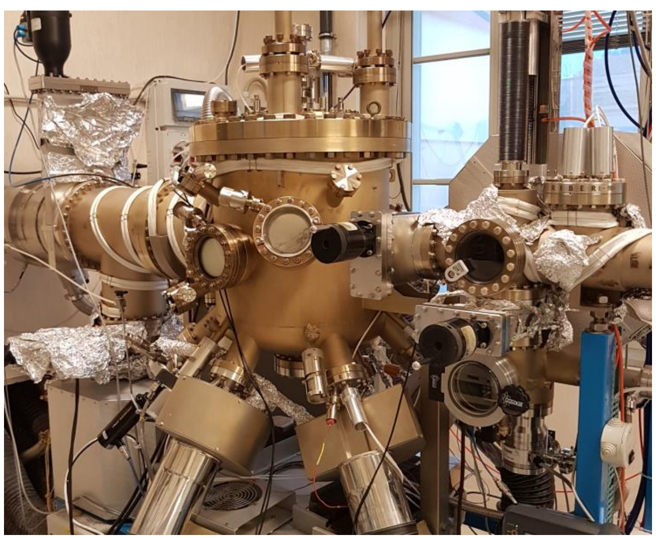
(base pressure: 10^{-9} Torr)



Nanoparticle (NP) assisted vapour-liquid-solid (**VLS**) mechanism



VLS growth occurs when a liquid alloy droplet starting from a metal nanoparticle (NP) becomes supersaturated with material from a gaseous reactant. The material then precipitates from the solid-liquid interface to form a nanowire.



CBE at NEST:

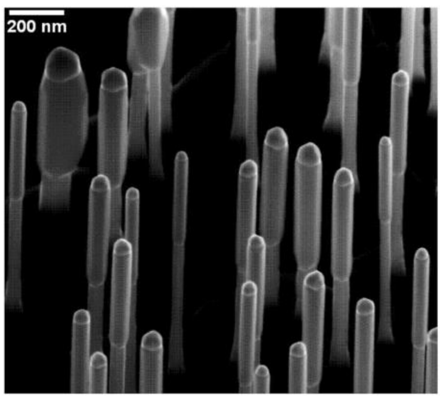
Riber Compact-21 CBE system
Metal-organic precursors:
Group III : TM**In**, TE**Ga**, TM**Al**
Group V : TB**As**, TB**P**, TDMA**Sb**, TM**Sb**
n-doping: TB**Se**

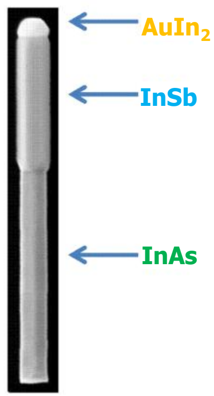
Motivation

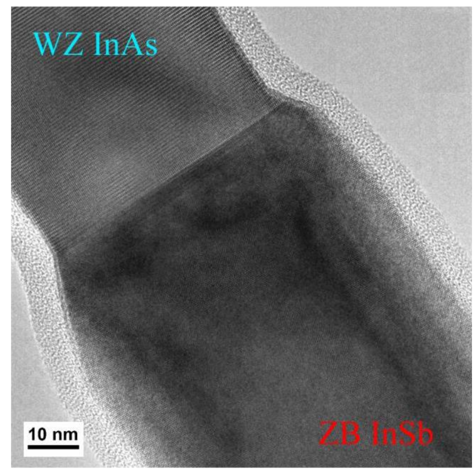
InSb:

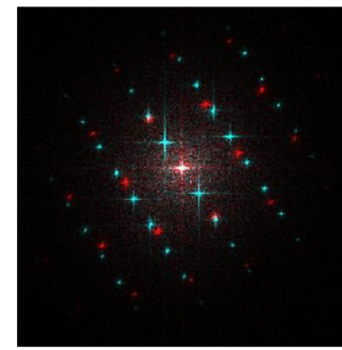
- Small bandgap, low electron effective mass, high electron mobility, high Landè g-factor and strong spin-orbit interaction
  → promising material for optoelectronics, thermoelectrics, spintronics and quantum computing
- Large lattice mismatch with all other III-Vs → difficult integration of defect-free InSb
- Sb acts as an surfactant → difficult to control/tune the InSb morphology during the growth

InAs/InSb axial nanowires grown by CBE

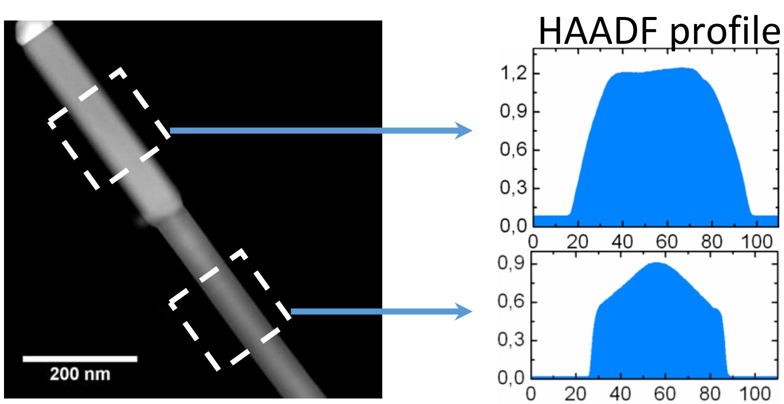


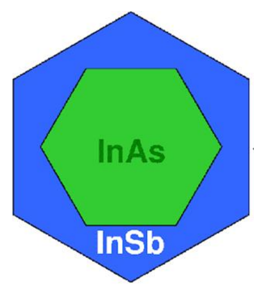






InSb: <110> zone axis
InAs: <2-1-10> zone axis

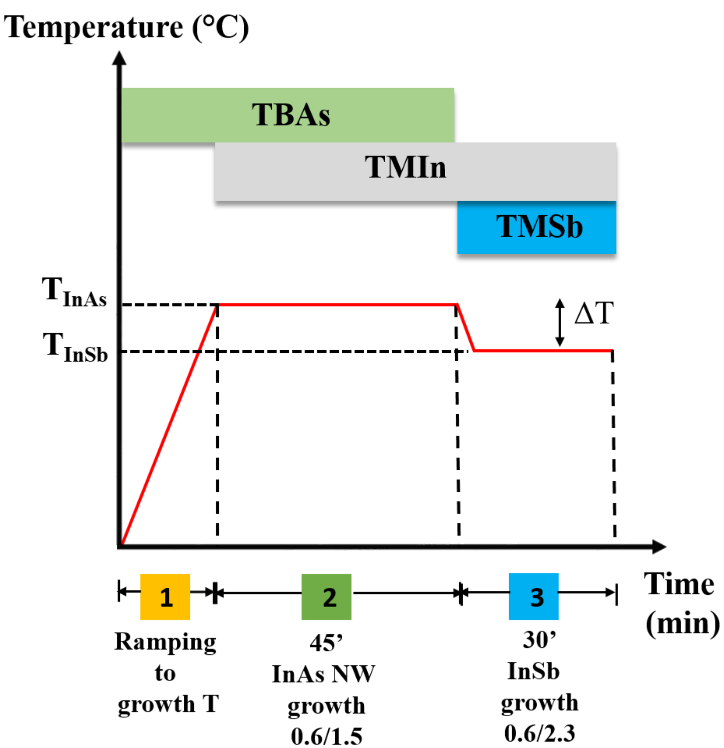




- **InAs NWs have WZ crystal structure with 6 equivalent {112} sidewalls**
- **Axial InSb has ZB crystal structure with 6 equivalent {110} sidewalls**

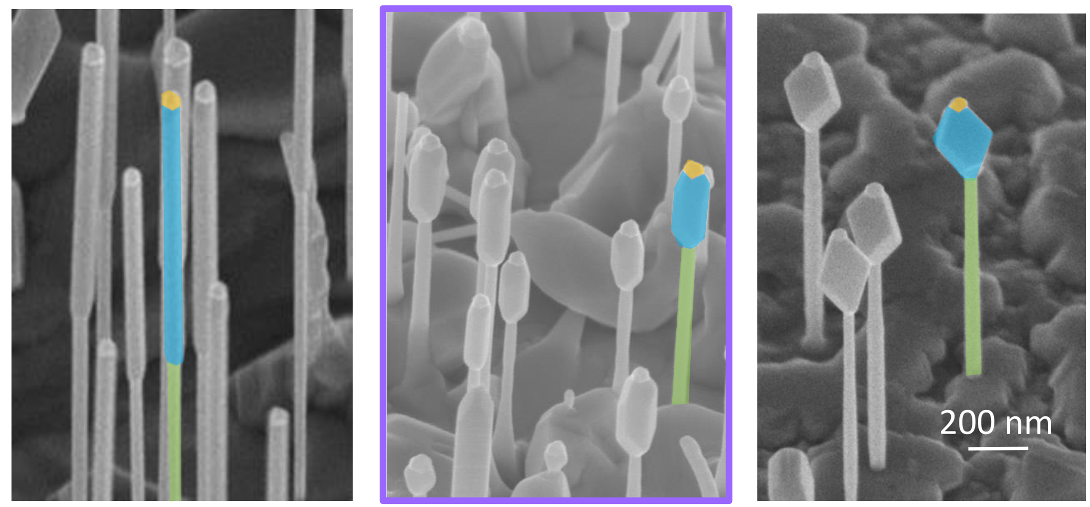
D. Ercolani el al. *Nanotechnology* 20, 505605 (2009)
L. Lugani el al. *Cryst. Growth Des.*, 10, 4038 (2010)

Morphology control of InSb nanostructures



InSb growth T optimization

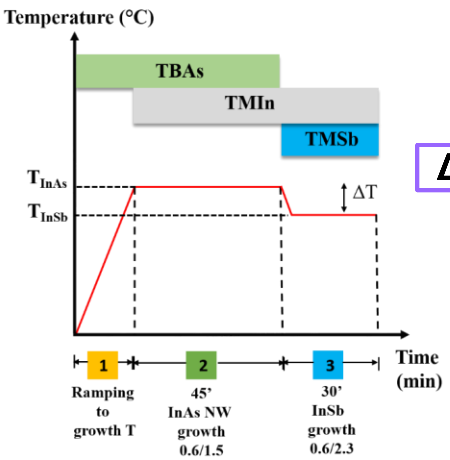
ΔT = -20°C   ΔT = -30°C   ΔT = -40°C



1D-InSb Nanowires   **3D-InSb Nanocubes**

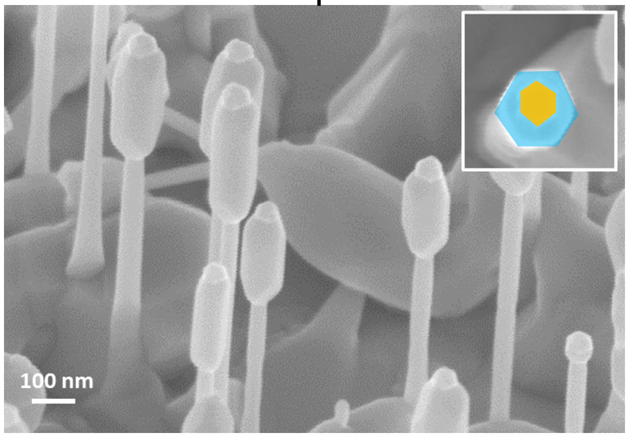
High T enhances the axial growth and reduces the radial growth

Directional InSb growth

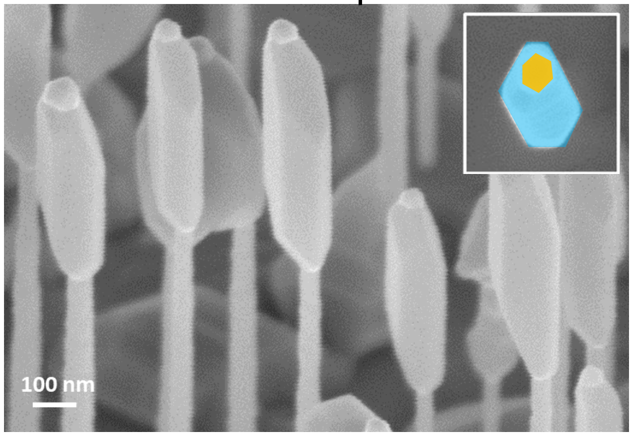


ΔT = -30°C

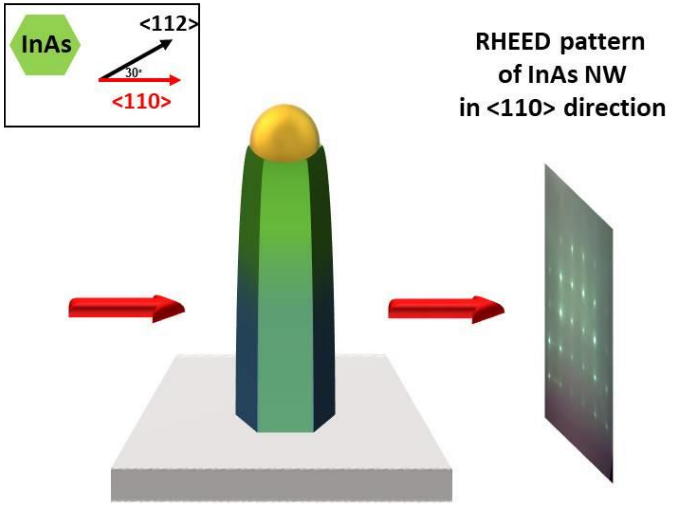
With sample rotation



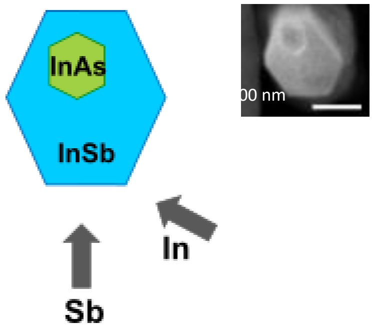
Without sample rotation



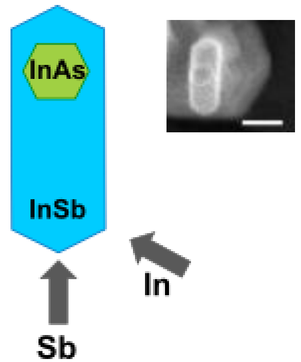
Sample alignment for directional InSb growth:



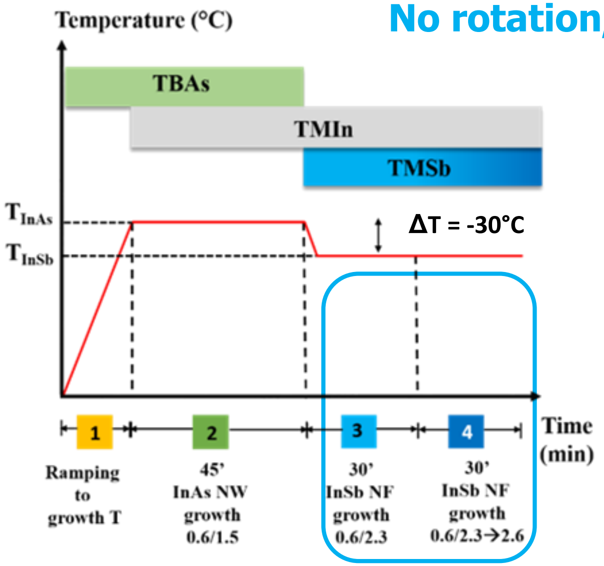
Sb beam projection ⊥ **to a {110} sidewall**



Sb beam projection ⊥ **to a {112} sidewall**

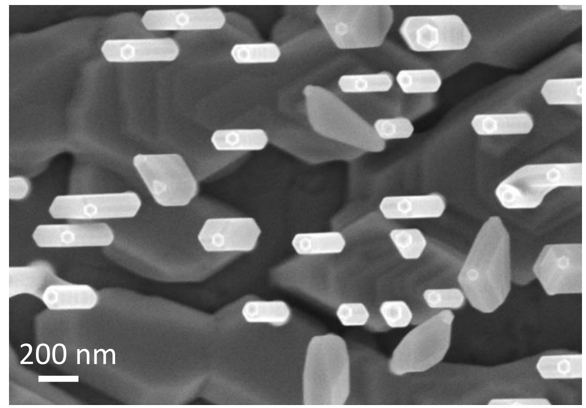


Free-standing InSb nanoflags (NFs)

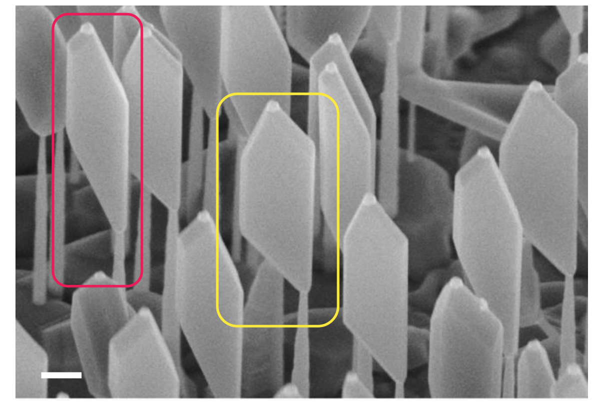


No rotation, alignment, increasing Sb flux → asymmetric growth enhancement

Top-view

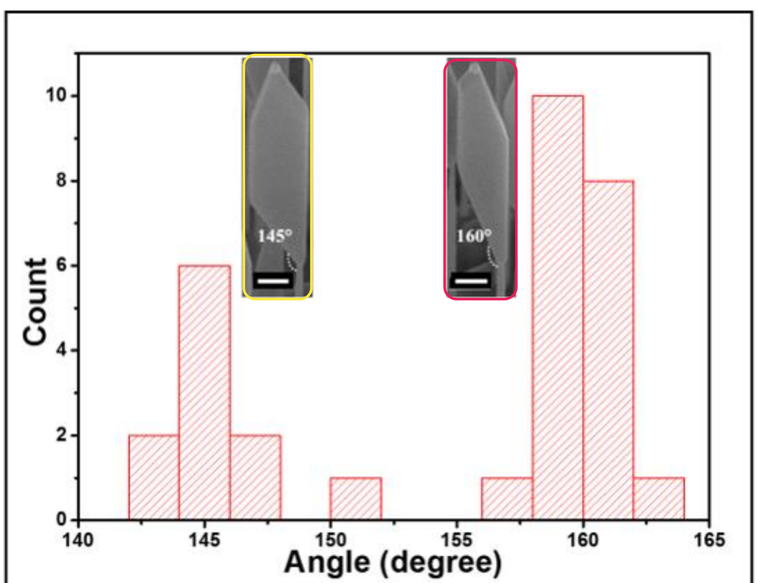


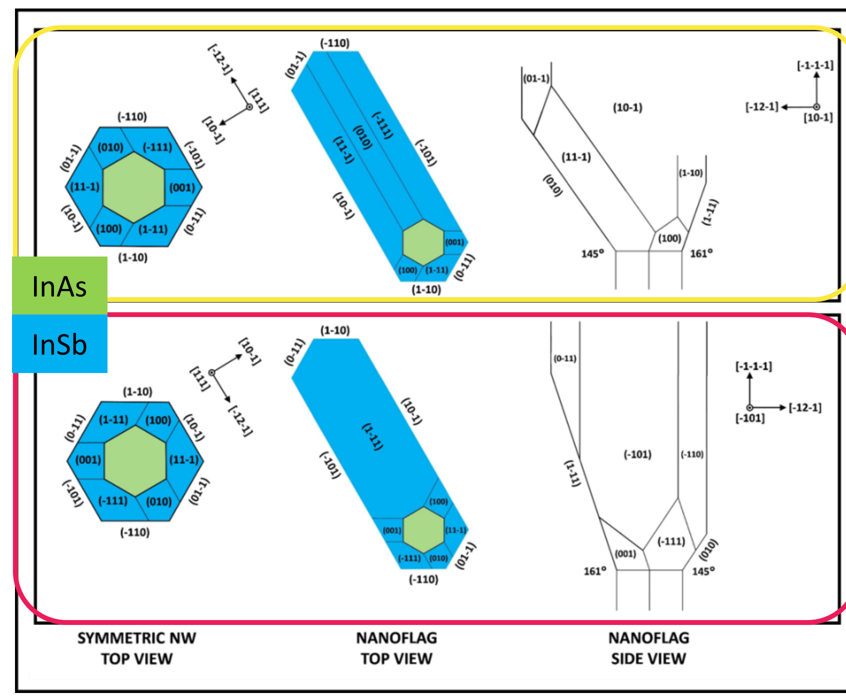
45°-tilted-view



2 different aperture angles: 145° and 160°

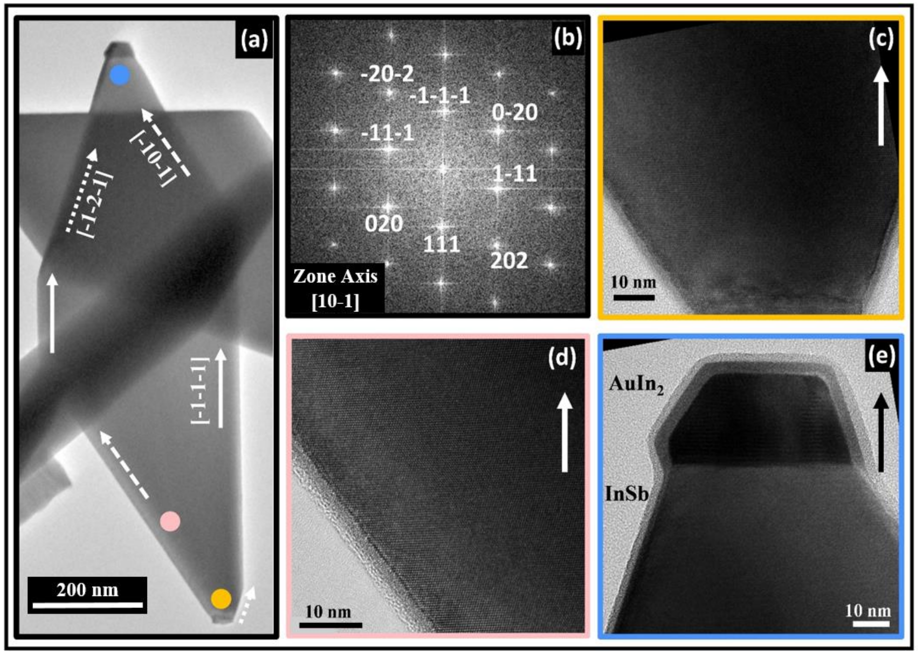
180° rotation around the growth axis of the additional facets at the interface



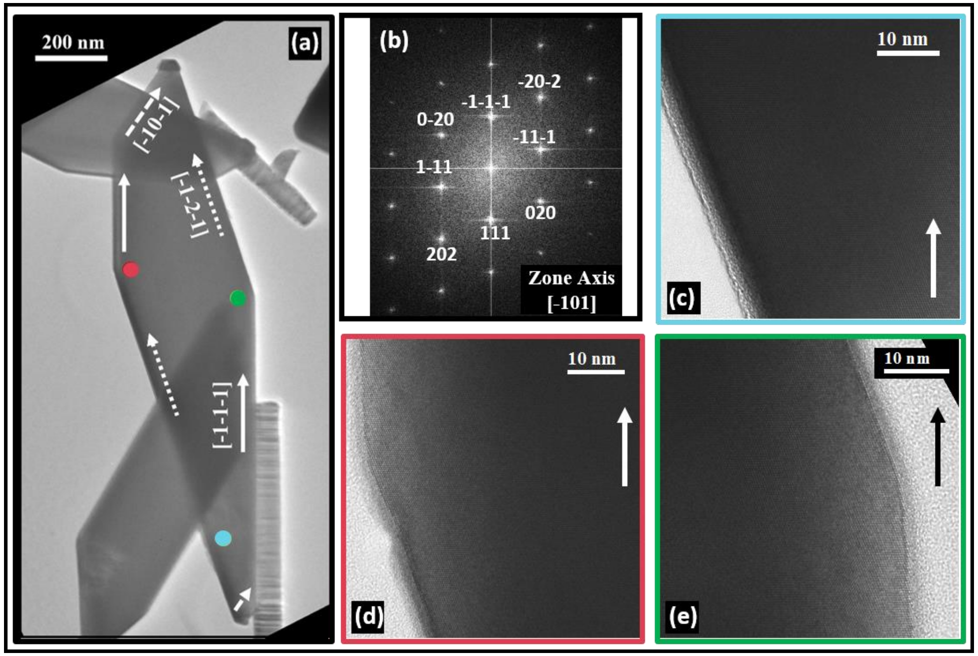


Free-standing InSb nanoflags (NFs)

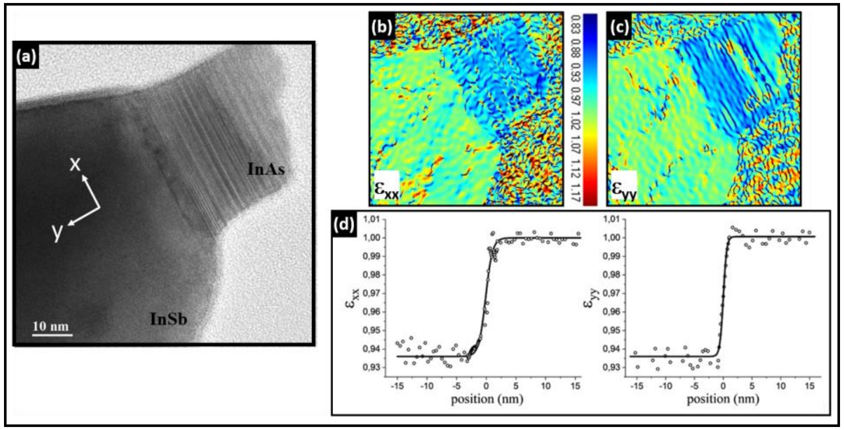
145° aperture angle



160° aperture angle



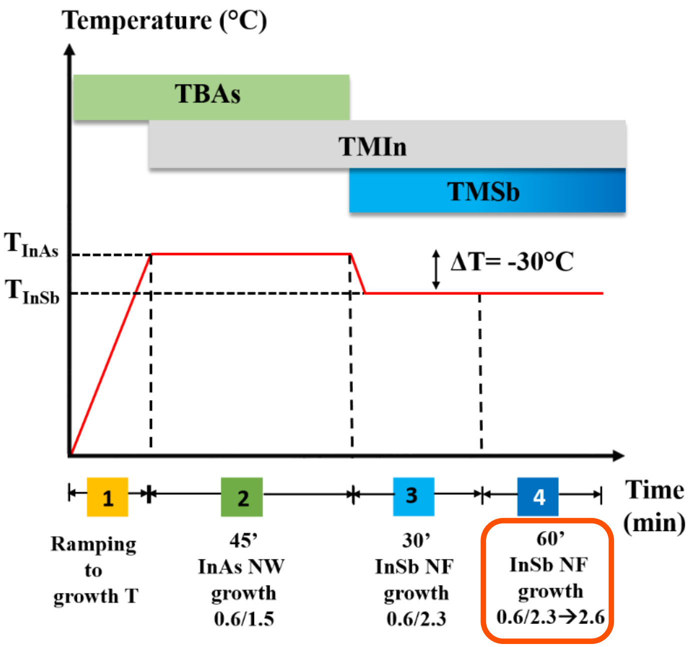
GPA



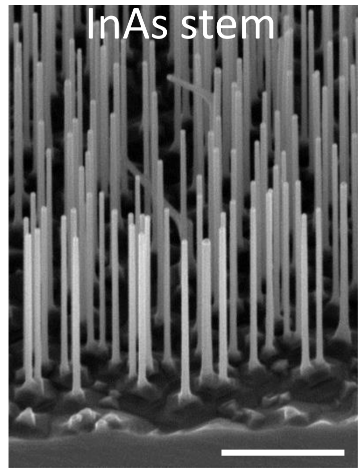
- Defect-free ZB crystal structure
- Stoichiometric composition
- Relaxed lattice parameter

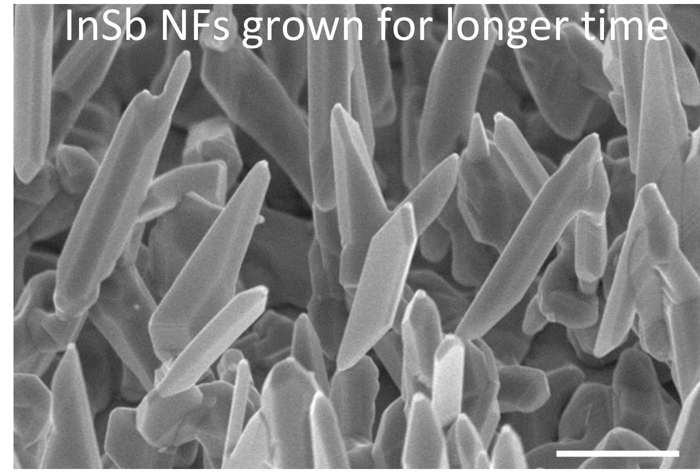
Verma *et al, Nanotechnology* **31** 384002 (2020)

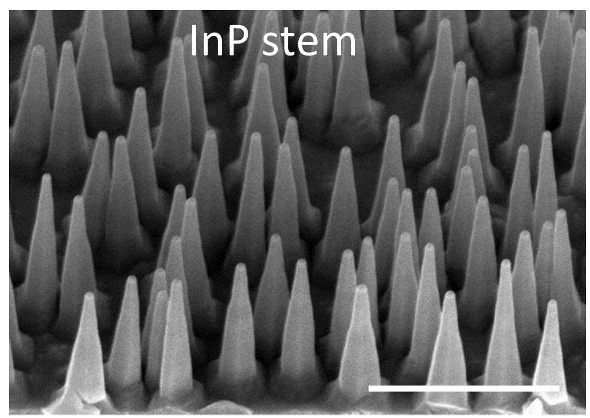
Free-standing InSb nanoflags (NFs)

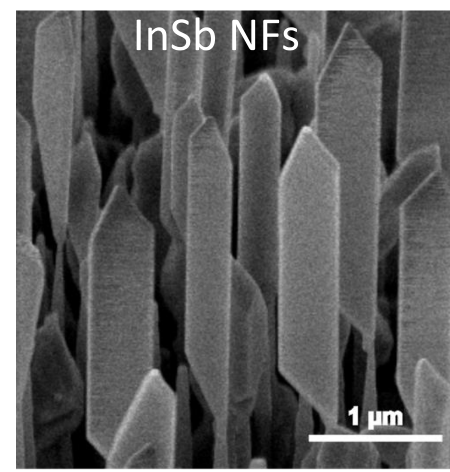


Increasing InSb growth time







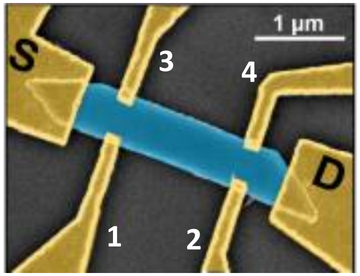


InSb NFs dimension
Length= 2.8 ± 0.2 µm
Width= 470 ± 80 nm
Thickness= 105 ± 20 nm

Using tapered and more robust InP NW stems, we could achieve bigger InSb NFs – easy device fabrication

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

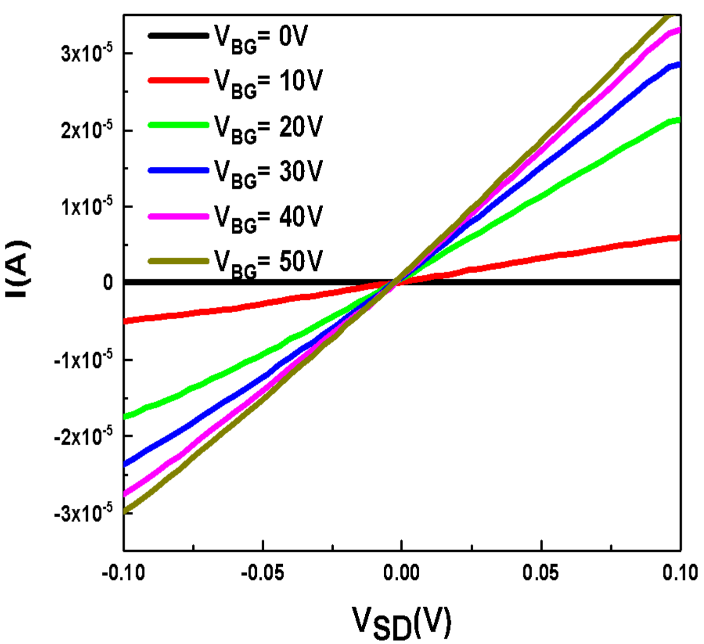
Transport measurements



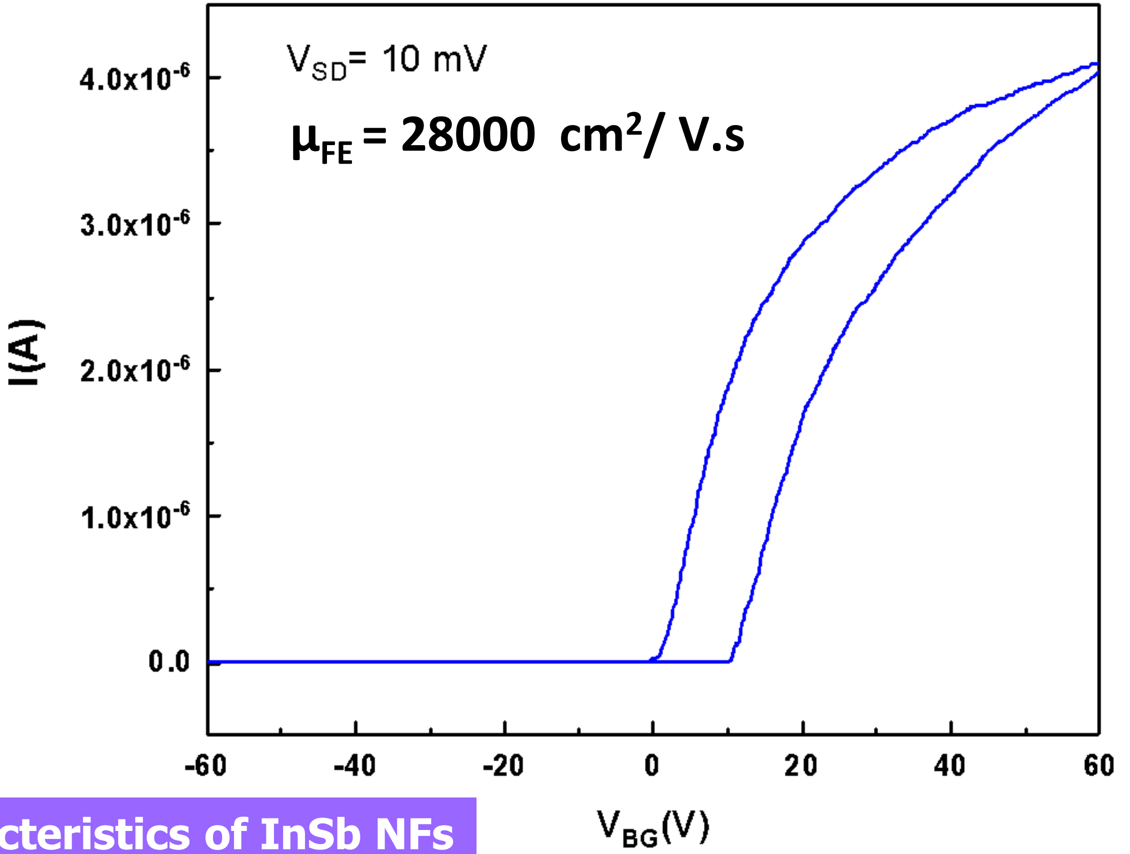
Hall-bar device

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.

R_{SD}(RT, VBG=0 V) = 11 KΩ
R_{SD}(4.2K, VBG=50 V) = 2.5 KΩ



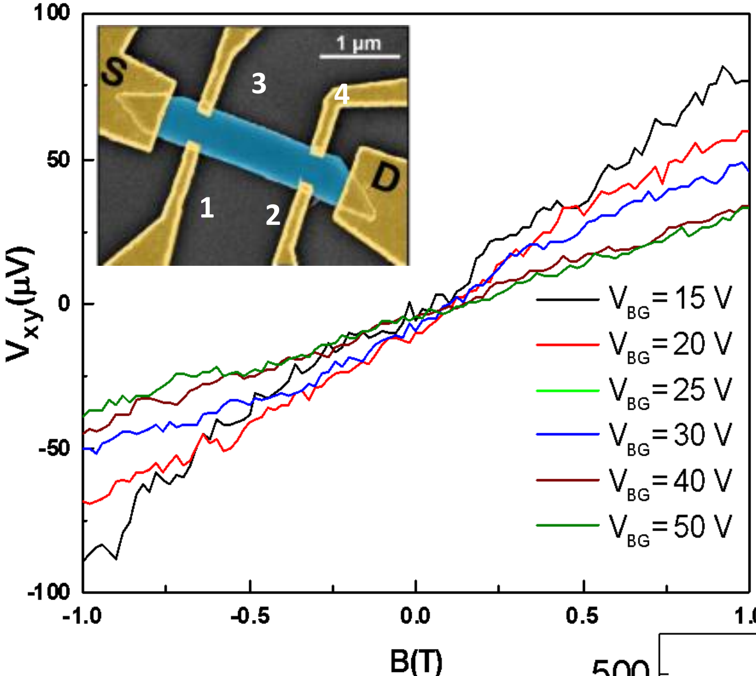
Four-probe configuration @ 4.2 K



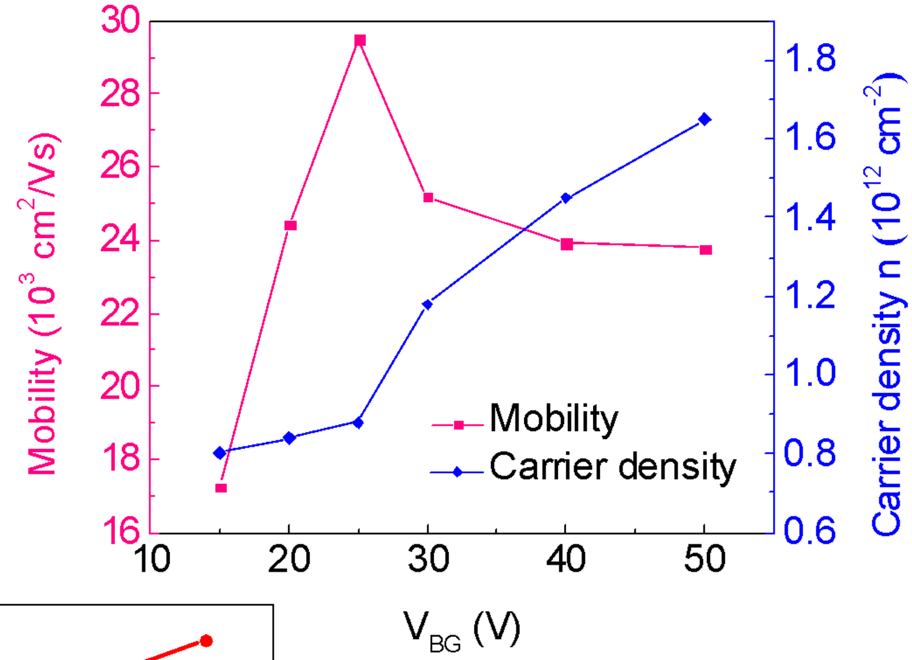
n- type characteristics of InSb NFs under BG modulation

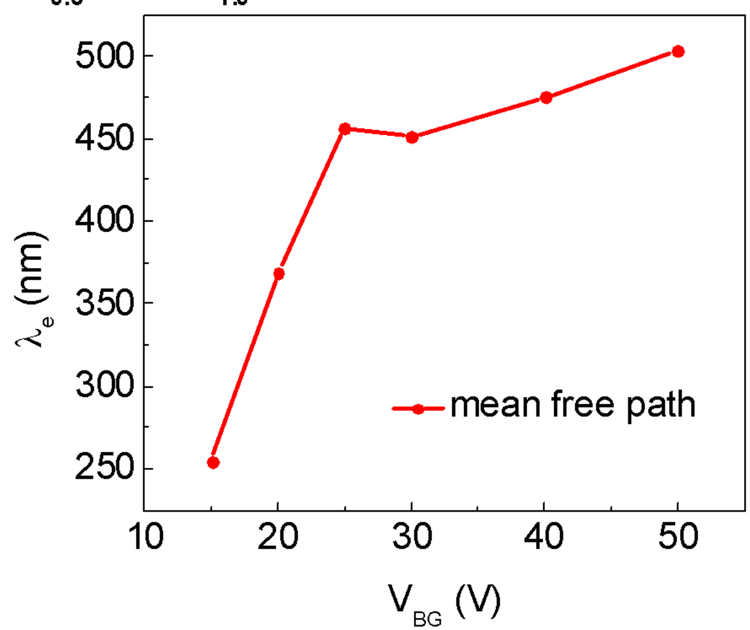
Transport measurements

Hall effect vs BG bias @ 4.2K



Electron Hall mobility = 29500 cm²/ V.s

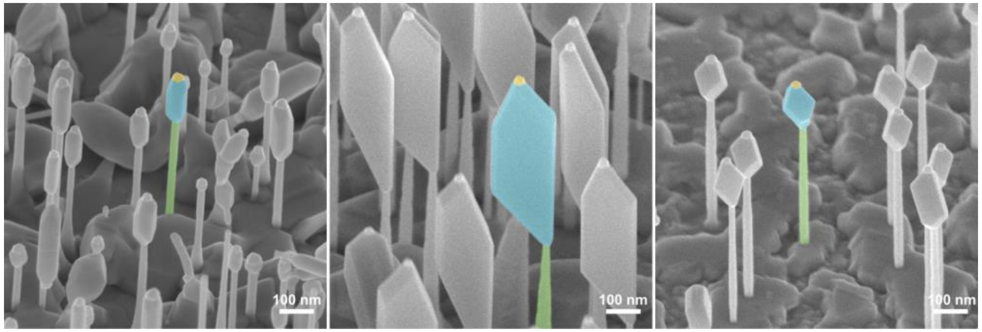




Mean free path l_e up to 500 nm

Conclusions

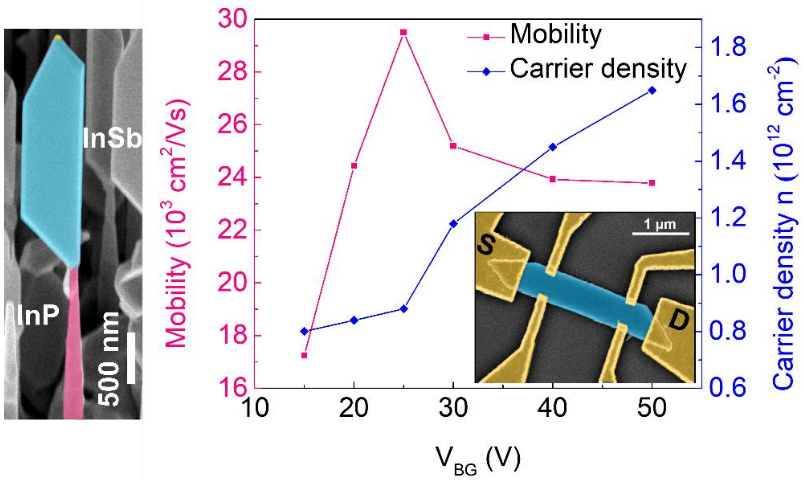
- Finding the parameters that affect axial and radial growth is important for controlling and tuning the nanostructure morphology



- More robust NW stem for longer growth time and sustenance of orientation

- Electron Hall mobility of about 29500 $cm^2/V.s$ reported for Free-standing InSb NF. Mean free path upto 500 nm.

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



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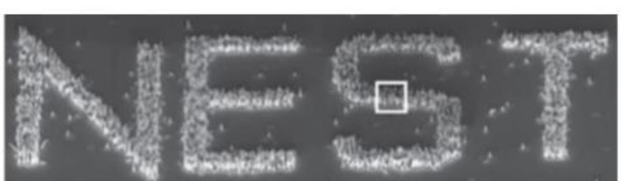

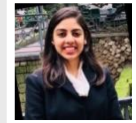

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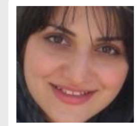

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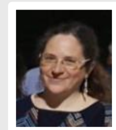

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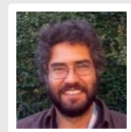

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