Research Activity

Indium antimonide (InSb), a narrow band gap III–V semiconductor due to strong spin orbit coupling and large Landè g factor is considered a promising material in the field of optoelectronics and quantum computing. In order to exploit these properties it's important to have a better control over the InSb morphology. A two dimensional (2D) nanoflag (NF) morphology is desirable for the purpose as it ease the fabrication process.

Approach 1

During the **second year** of my research in order to achieve InSb NFs were synthesised by **Au-assisted Chemical Beam Epitaxy (CBE)** employing metallorganic (MO) precursors: Trimethylindium (TMIn), Tertiarybutylarsine (TBAs) and Trimethylantimony (TMSb). 30 nm Au colloids (Density ≈ 5 per μm^2) were deposited on InAs (111) B substrates. First InAs stems were grown on the InAs substrate, and then the growth of InSb segments was optimised by changing growth temperature, MO fluxes, and sample rotation to improve the lateral dimensions of the NFs.

First, the transition from **Nanowire** (1D) to **Nanocubes** (3D) and **Nanoflags** (2D) was studied by tuning the growth parameters. It was observed that by keeping the same growth protocol of NWs but by decreasing InSb growth temperature by 10°C, morphology was changed from nanowires to that of nanocubes (NCs) (see scanning electron microscopy (SEM) images in Fig. 1).

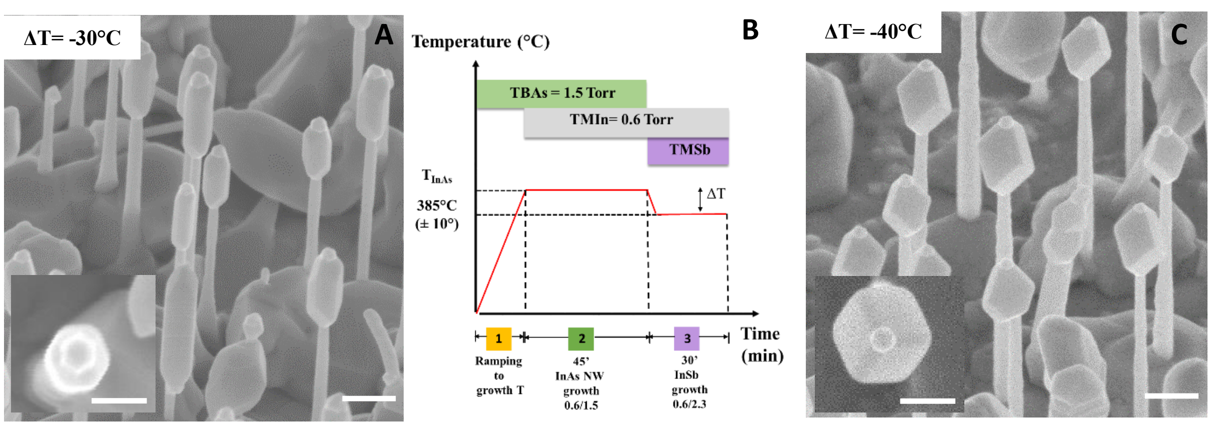

Figure 1: 45° tilt SEM images of nanowires in (A), Growth protocol of NWs and NCs in (B) and NCs in (C) (scale bar: 200 nm). Top views of all the nanostructures are shown in the insets (scale bar: 100 nm).

Furthermore, by stopping the rotation of the NWs, asymmetry is triggered which is crucial for the NF morphology (see Fig. 2).

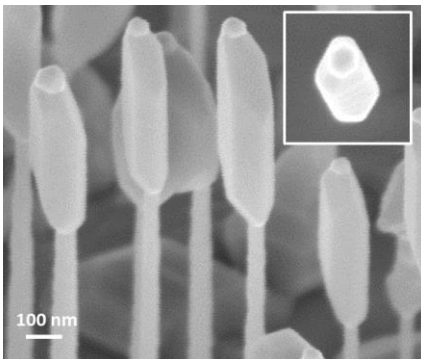

Figure 2: 45° tilt and top view (inset) SEM image of NFs when InSb is grown without rotation.

In order to improve the morphology, the InSb the growth temperature is optimized. ΔT= -10°C seems too high a temperature for the InSb growth and hence only small InSb segments are visible in the SEM image (see Fig 3 c). Decreasing the temperature, the width and the thickness of the InSb NFs increase. Since the goal is to get NFs with higher length and width but lowest possible thickness, the NFs grown at ΔT= -20°C are the best compromise. Hence ΔT= -20°C is the optimized temperature for NF growth (see fig. 3).

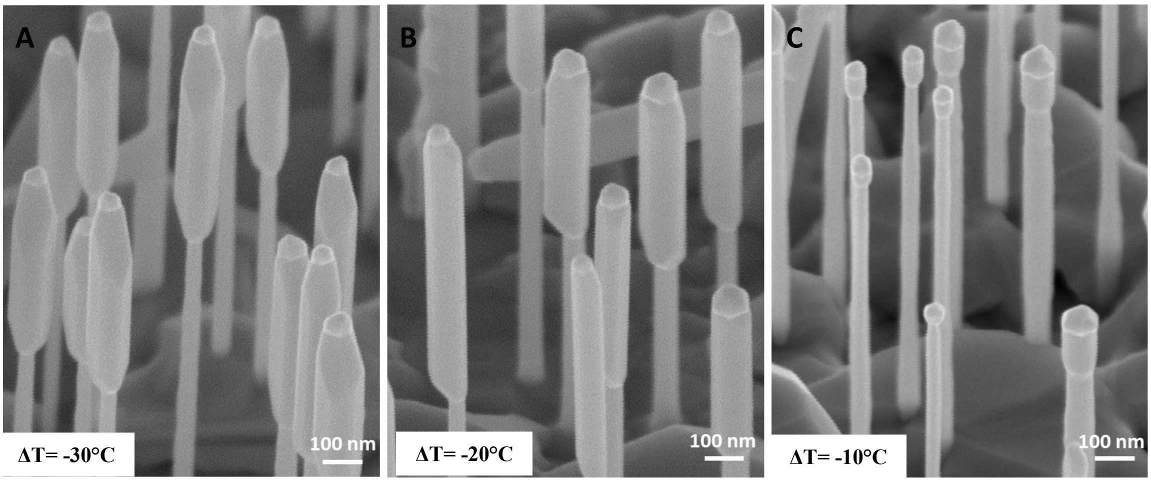

Figure 3: InSb morphology variation with changing temperature A) at ΔT=-30°C B) at ΔT=-20°C and C) at ΔT=-10°C.

Another crucial parameter that drives the change in the InSb morphology is the Sb flux. In particular, an additional step to increase the lateral growth was added to the growth procedure by increasing Sb flux from 2.3 Torr to 2.6 Torr while keeping the Influx constant at 0.6 Torr. The morphology of the resulting InSb NFs, measured by scanning electron microscopy, is reported in Fig. 4.

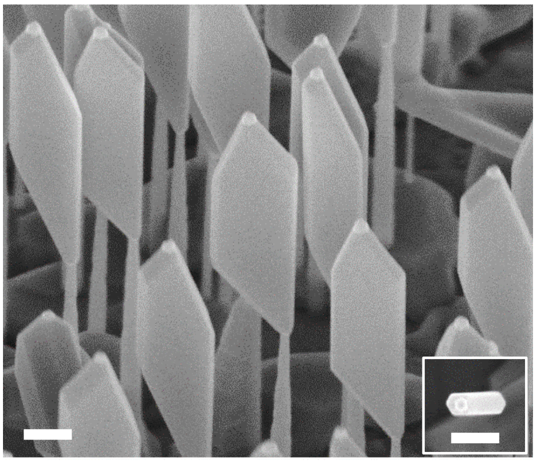

Figure 4: 45° tilt and top view (inset) SEM image of InSb NFs grown via Au assisted Chemical beam epitaxy. The scale bar is 200 nm.

The dimensions of the optimized InSb NFs are: **length = 1.3 ± 0.1 µm, width = 282 ± 86 nm, and thickness=104 ± 17 nm**. By further increasing the growth time we have very small increase of the length and width while only the thickness increases. **This work was presented at 3rd Nanowire week 2019 at Pisa, Italy.**

I started my training to perform low temperature electrical measurements on these as grown InSb NFs at **Magneto-Transport Lab at NEST**. To assess the electronic quality of the as grown InSb NFs, electrical measurements were performed in the Hall bar configuration (see Fig.5) at low temperature (T = 4.2 K). We observed that there is a mixing of the V_{XX} and V_{XY} components due to the reduced size of the NF, and hence correct value of electron carrier and mobility cannot be determined. **This work was presented at 20th Euro MBE conference 2019 at Lenggries, Germany**.

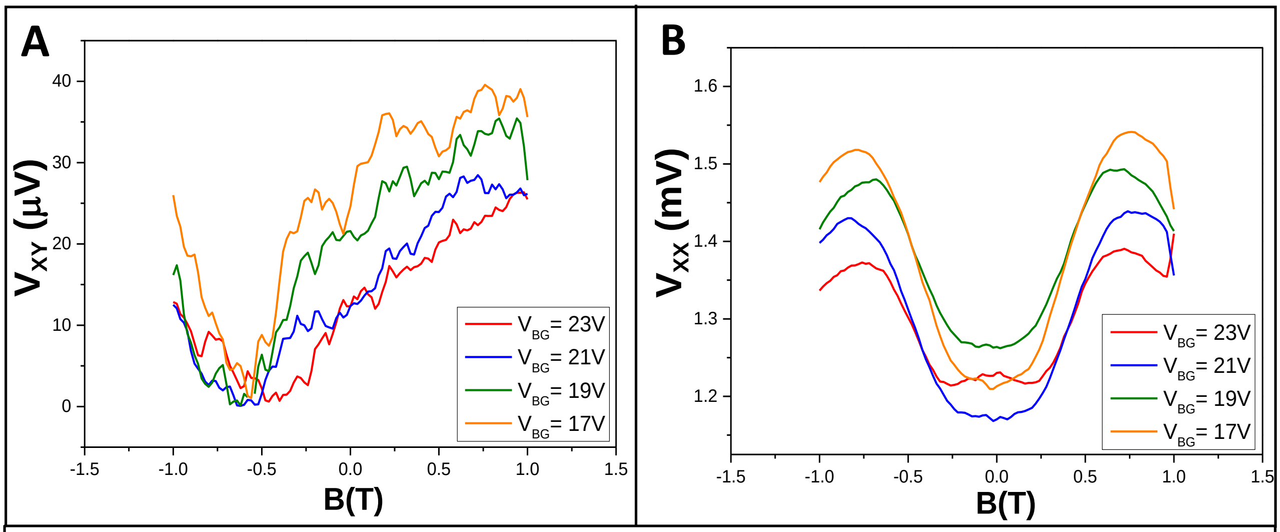

Figure 5: Hall measurements at 4K. A) V_{XY} vs B and B) V_{XX} vs B at different back gate voltage V_{BG}

Approach 2

In order to improve the morphology of the InSb NFs, and in particular to limit the flag thickness, I had to switch to the growth procedure called **Selective Area Epitaxy (SAE)**. This method, due to the presence of an oxide mask, should in principle limit the thickness of the flags. A 30 nm thick masking layer of **sputtered SiO_2** is deposited on InSb (111) B substrates. The patterns are defined by **electron beam lithography (EBL)** and formed by **reactive ion etching** followed by a **dip in HF solution** and a final rinse in deionized water. The patterns formed are slits which are 5 μm long and 60 nm wide. They are oriented in different crystallographic directions (see Fig. 6 (a)) to determine the well faceted direction of InSb NF (Ref. 1). The InSb slabs realised along {211} and {110} directions are well faceted (see Fig. 6 (b)). Preliminary tests have produced InSb slabs with height and thickness of about 280 nm and 110 nm, respectively. In order to improve the axial growth versus lateral growth we have to optimize the fluxes and pattern geometry (by adjusting inter-line distance and slit width), activity which is in progress. Some delay of the NF production is due to the complexity of the fabrication process.

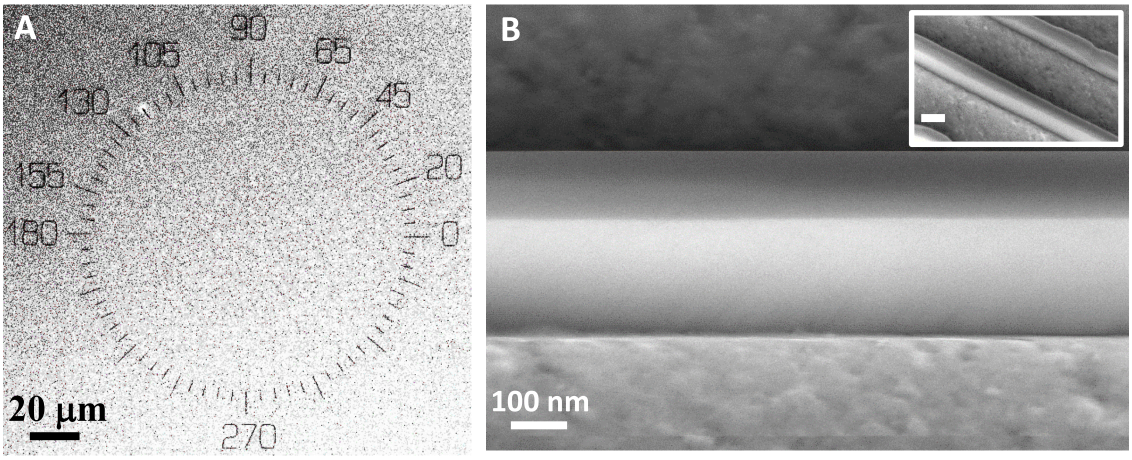

Figure 6: A) SEM image of EBL patterned InSb (111) B before growth to determine the direction of well faceted InSb NF. B) 45° tilt SEM image of an InSb slab along {211}. Inset: Top view SEM image.

References

[1] J. S. Lee, S. Choi , M. Pendharkar, D. J. Pennachio, B. Markman, M. Seas, S. Koelling, M. A. Verheijen, L. Casparis, K. D. Petersson, I. Petkovic, V. Schaller, M. J.W. Rodwell, C. M. Marcus, P. Krogstrup, L. P. Kouwenhoven, E. P.A.M. Bakkers, and C. J. Palmstrøm, Phys. Rev. Materials 3, 084606 (2019).