	Experiment title: In operando x-ray imaging of InSb nanocrosses internal electrical fields, composition and local structure	**Experiment number**: HC-4890
Beamline: ID16B	**Date of experiment**: from: 22/06/2022 to: 26/06/2022	**Date of report**: *Received at ESRF:*
Shifts: 15	**Local contact(s)**: Valentina Bonino	

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Report:

The exploitation of topological systems based on the appearance of Majorana zero modes signatures in semiconductor-superconductor systems is one of the current hot topics in the development of quantum computing. Because of its non-Abelian statistics, which also makes logical operations more stable, braiding can occur among these particles. InSb nanowires (NWs) are used as the most promising candidate for Majorana zero modes. InSb has a large Landé *g*-factor ($|g^*| > 30$), a modest effective mass (m_e* 0.0014), and a strong spin-orbital interaction (SOI 0.8 eV). Recent studies on the conductance of InSb NWs found a long-phase coherence length and ballistic transport for high-quality structures [1]. Moreover, in the search for Majorana zero modes, several networks in addition to various materials have been investigated in an effort to create a stable qubit and a controlled exchange mechanism. According to Clarke *et al.*, defects and the chirality of the junction can both influence the Majoranas phase. The changes promoted by the junctions would be transferred to all NWs connected at the crosses, producing different braiding [2].

Here, the InSb nanocrosses networks were grown by in-plane selective area and metalorganic chemical vapor deposition (MOCVD) on an InP(111)B substrate (**Figure 1**) according to the method reported in Ref. [3]. Two types of spider architectures were investigated using a three-fold arrangement of nanowires. The first one is a combination of NWs oriented in the family of directions <210> and the second one is oriented in the <110> one. The three-fold symmetry is important since the III-V NWs morphology is uniform for this configuration. The final network consists of a hexagonal NW arrangement with 1 µm (short NWs) and 3 µm (long NWs) length, and each NWs has a diameter of around 50 nm.

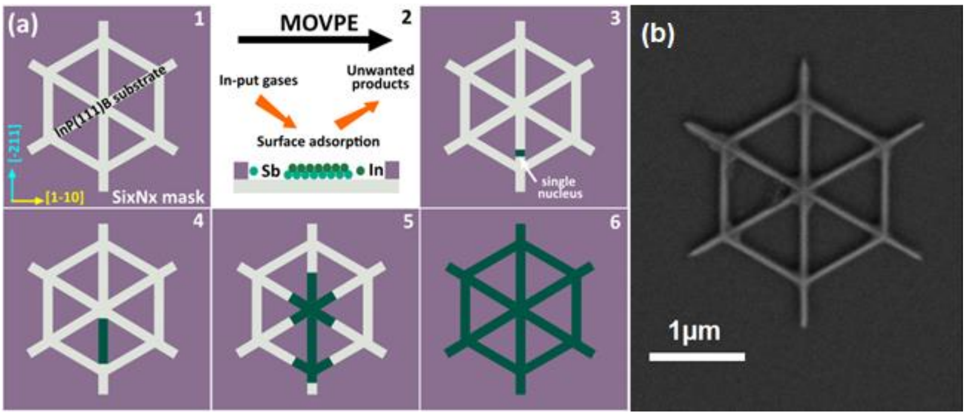

Figure 1 (a) Sketch of the InSb network growth process and (b) SEM image of a representative <211> spider.

A network with incomplete growth was selected in order to investigate if the compositional inhomogeneities play a role in the defective growth of the NWs. The X-ray fluorescence (XRF) experiments were performed with a 62 x 67 nm^2 X-ray nanobeam at 33 keV. The maps were acquired by scanning a sample area of 0.8 x 0.8μm^2 using a step size of 20 nm and 1 second exposure time per point. X-ray absorption near edge structure (XANES) spectra were also acquired around the Sb K-edge (30.49 keV) in XRF mode. The XANES data was measured in an energy range from 30.44 to 30.52 keV for the Sb K-edge. An Sb foil was measured as reference material for the XANES analysis (not shown here for space limitations).

In **Figure 2** the spectrum acquired in the analysis of the <211> spider is shown. Using the PyMca software we can identify the elements detected at 33 keV. The main peak observed in the spectrum corresponds to In, which is present in the networks and in the substrate (InP). Since the emission lines of Sb are close to the In one, a partial superposition of the Sb and In peaks occur. This imposes some limits on the XRF maps, as the nanocrosses can only be discriminated from the substrate by the Sb peak. Other elements are identified as impurities in the systems, such as Fe and Ta. Mo signals are related to the multielement silicon drift detectors. By appropriate fitting, it is possible to observe the distribution of Sb along the networks. As observed in **Figure 3**, in both cases, the Sb is well distributed through the NWs and the junctions in the network. Even in defective networks, the NWs present high homogeneity which discards the hypothesis of incomplete growth by loss of stoichiometry. Due to the low content of Sb compared to the InP substrate, the signal of Sb was overlapped by In signal from the InP substrate. To increase the statistic of the absorption process in InSb, the photon flux was increased, exploiting the potential of the extremely brilliant source (EBS). An ion chamber was used to detect the transmitted beam and this signal was also used to normalize the XANES spectra. The XANES results are still under interpretation and additional reference XANES spectra will be calculated by *ab initio* simulations and included in further in-depth analysis. Due to serious experimental issues with the electrical contacts in the NWs networks, the complementary measurement of XBIC for energy scans required for Sb K-edges, the in-operando experiments were not carried put. However, based on the experience acquired in this study, a complementary proposal will be written to conclude the experiment as initially proposed.

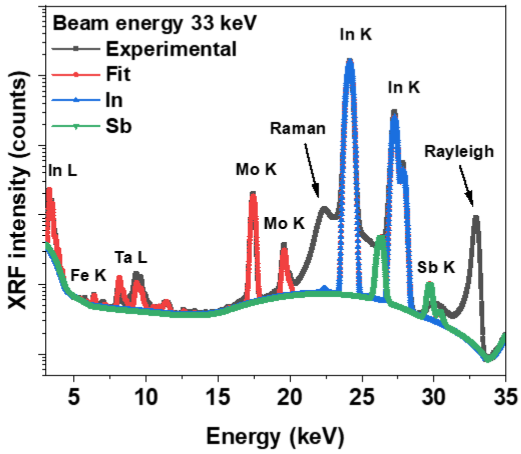

Figure 2 - XRF spectrum of spider network <211>.

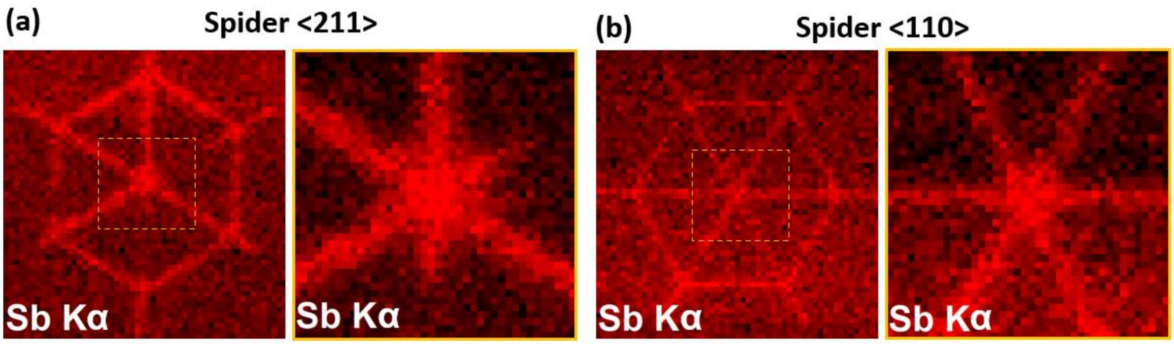

Figure 3 - Sb distribution maps in the spider networks (**a**) <211> and (**b**) <110>.

[1] Khan, S. A. *et al.* Advanced Materials **33**, 2100078 (2021).
[2] Clarke, D. J., Sau, J. D. & Tewari, S. Physical Review B **84**, 35120 (2011).
[3] Op Het Veld, R. L. M. *et. al.* Nature Communications, **59**, 3, (2020).