Formation of one dimensional nanostructures in the molecular beam epitaxy of antimony triselenide

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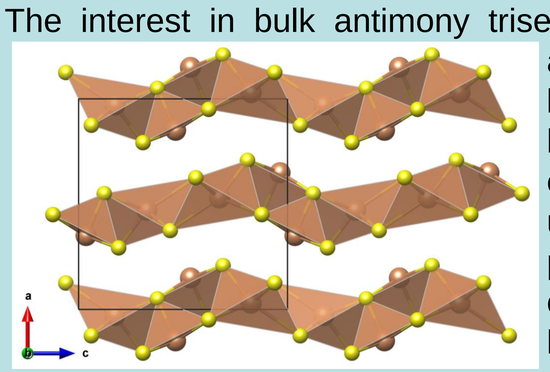
Motivation:

Antimony triselenide belongs to the family of **1D semiconductors**, which could be used for downscaling semiconductor channels in transistors even to the limit of a single atomic chain [1]. Its crystal structure consists of 1D ribbons held together by weak Se-Se van der Waals interactions.

The interest in bulk antimony triselenide has been boasted mainly by its applications in photovoltaic devices leading to the development of Sb2Se3-based solar cells with the efficiency exceeding 10% [2]. The advantages of using antimony triselenide for these purposes are the high absorption coefficient, the appropriate value of the band gap that allows the absorption of the solar spectrum, single-phase structure and low toxicity.



Wikipedia: Antimony_triselenide
Se –yellow, Sb - brown

In this work, the growth of antimony triselenide by **molecular beam epitaxy** on GaAs substrates with various crystalline orientations is reported. It is demonstrated that this semiconductor spontaneously forms **tiny, monocrystalline, highly anisotropic nanostripes** with the areal density of the order of 10^9 cm^{-2} and the cross-section dimensions of the order of a few nanometers.

1] Meng Y, Wang W, Ho JC „One dimensional atomic chains for ultimate scaled electronics „ ACS Nano 2022; 16, 13314

[2] Duan, Z. *et al.* „Sb2Se3 Thin-Film Solar Cells Exceeding 10%...” Adv. Mater. 2022, 34, 2202969

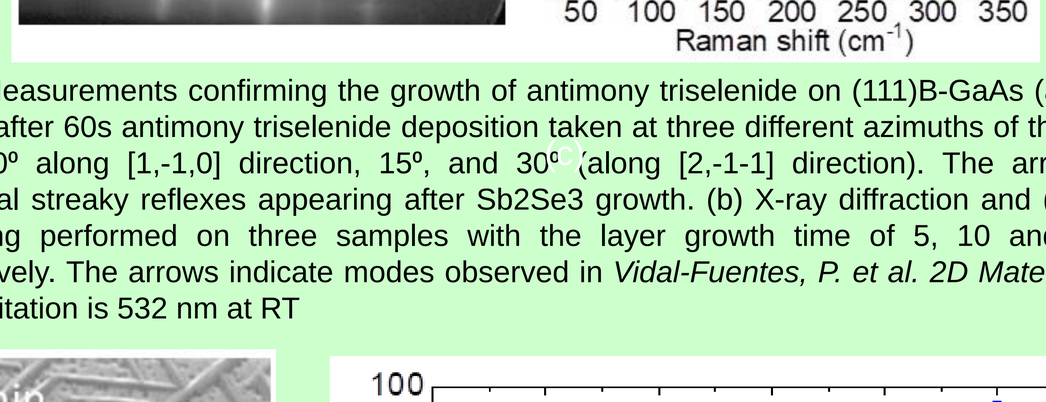


Fig.1 Measurements confirming the growth of antimony triselenide on (111)B-GaAs (a) RHEED pattern after 60s antimony triselenide deposition taken at three different azimuths of the electron beam: 0º along [1,-1,0] direction, 15º, and 30º (along [2,-1-1] direction). The arrows mark additional streaky reflexes appearing after Sb2Se3 growth. (b) X-ray diffraction and (c) Raman scattering performed on three samples with the layer growth time of 5, 10 and 30 min, respectively. The arrows indicate modes observed in *Vidal-Fuentes, P. et al. 2D Materials 2019*. The excitation is 532 nm at RT

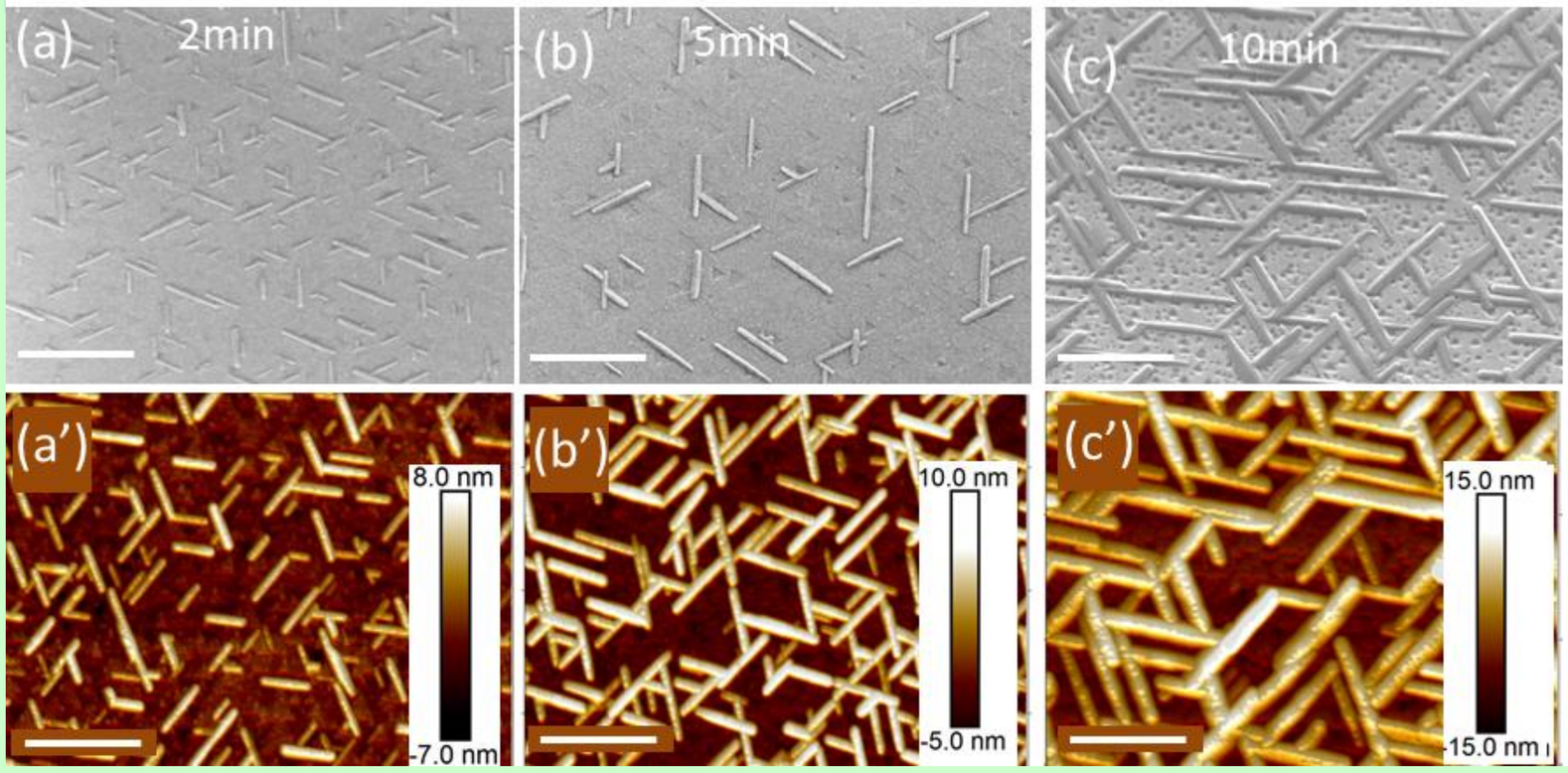


Fig. 2 Microscopy study of antimony triselenide nanostructures grown on (111)B oriented GaAs substrates. The growth times are (a) 2 min (b) 5 min (c) 10 min. The upper panel represents scanning electron microscopy taken at an acceleration voltage of 5 keV and a probe current of 500 pA. The lower panel shows a comprehensive atomic force microscopy study of the same samples. All scale bars correspond to 500 nm.

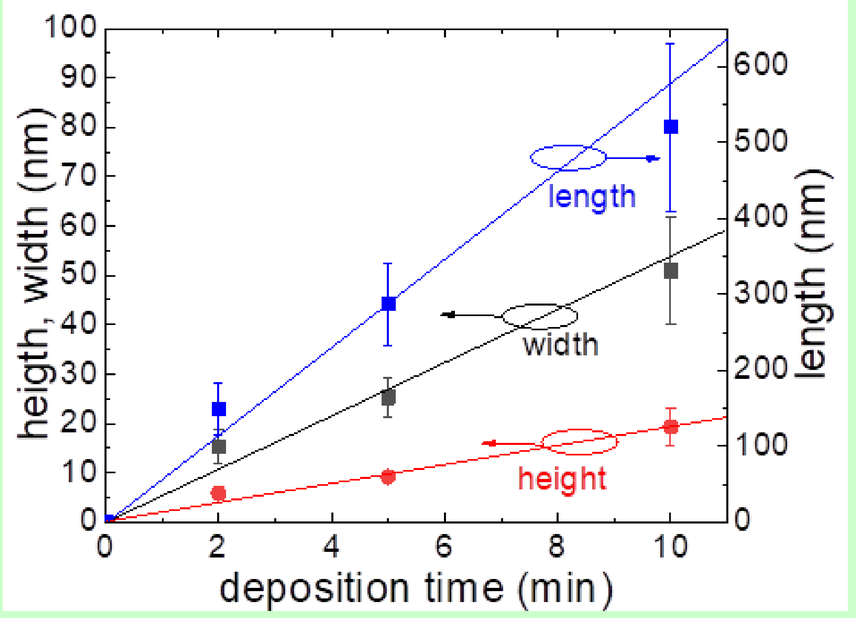


Fig.3 Average values of length, width and height for various growth times of Sb2Se3 determined by scanning electron microscopy and atomic force microscopy. Solid lines represent fits with a linear function indicating a linear increase of these parameters with a constant length-to-width ratio of 11 and a length-to-height ratio of 30.

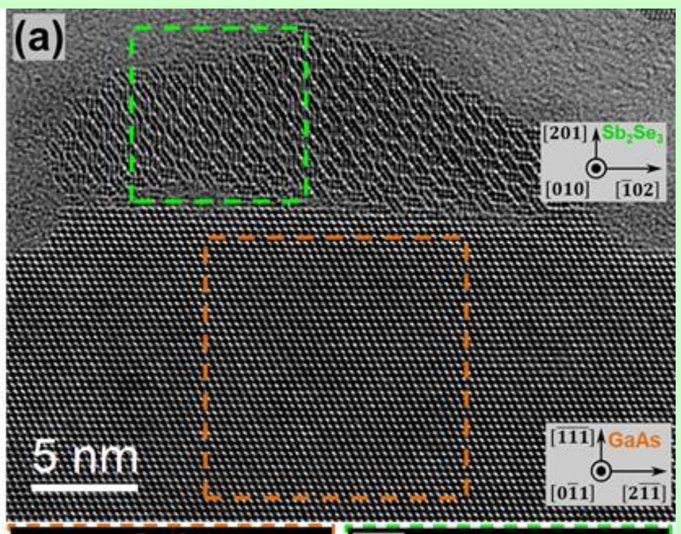


Fig. 4 (a) Cross section of a typical antimony triselenide nanostripe grown on GaAs substrate for 10 min, revealed by high-resolution transmission electron microscopy (HR-TEM); (b) Fast Fourier Transform (FFT) calculated from orange square in panel (a) with corresponding orange GaAs diffraction pattern in [0-11] zone axis (ZA), confirming substrate (111)B-orientation; (c) FFT calculated from green square in panel (a) with matching green Sb2Se3 diffraction pattern in [010] ZA;

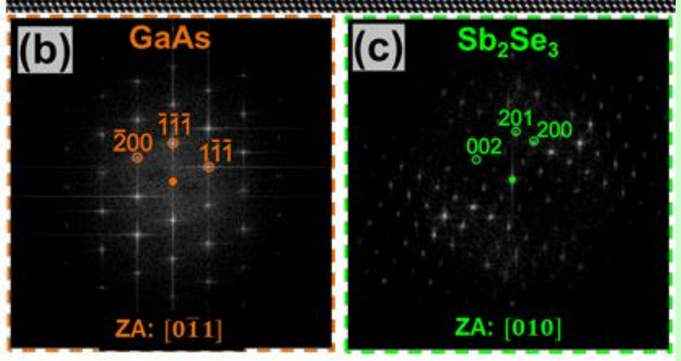
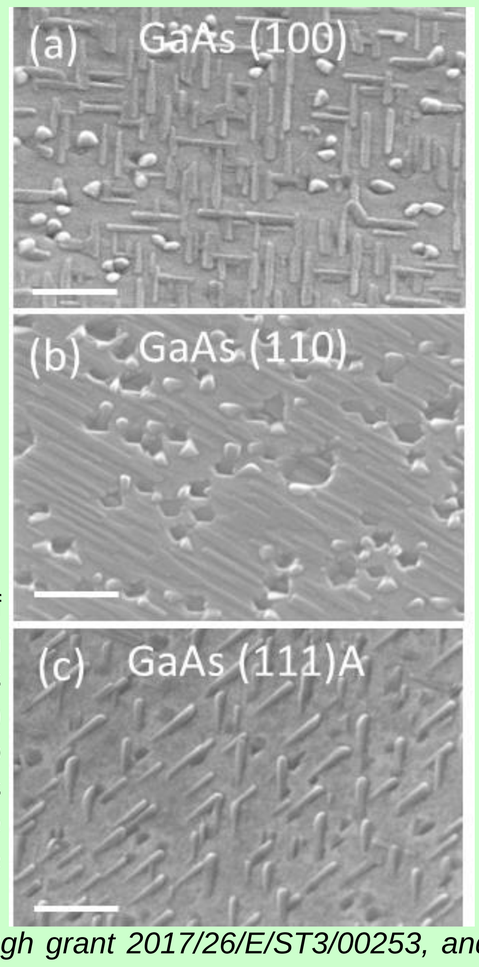


Fig.3 Scanning electron microscopy of antimony triselenide nanostripes grown on differently oriented GaAs substrates: (a) (100) (b) (110) (c) (111)A. All scale bars correspond to 200 nm. Data is collected with Zeiss Auriga scanning electron microscope operating at 5 keV with the probe current of 500 pA..



Summary

✓ Sb_2Se_3 grows in form of monocrystalline 1D nanostripes by MBE

✓All dimensions: width, length, height of the nanostripes increase simultaneosly

✓Raman scattering and XRD confirm that, indeed, Sb2Se3 is grown

✓Transmission electron microscopy reveals monocrystaline nature of antimony triselenide

✓Epitaxial relation between the substrate and the nanostripes is preserved

Plans

✓Activation of the optical emission:

- Other substrate: ZnSe, InSe or dielectric
- Cap layer

✓Transport and photocurrent measurements

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