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

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Antimony triselenide belongs to the family of one-dimensional 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 one dimensional 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 Sb_2Se_3-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.

In this work, the growth of antimony triselenide by molecular beam epitaxy on GaAs substrates with various crystalline orientations is reported [3]. It is demonstrated that this semiconductor spontaneously forms tiny, monocrystalline, highly anisotropic Sb_2Se_3 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 implying a significant contribution of the quantum confinement to their electronic landscape. They lie always in the surface plane and their orientation corresponds to one of <1-10> azimuths of the substrate, Figure 1. With increasing deposition time all three dimensions: the length, the width and the height of these nanostructures increase simultaneously, with the length usually one order of magnitude larger than the two other parameters. The monocrystalline nature of Sb_2Se_3 lattice within a single nanostructure is demonstrated by transmission electron microscopy. Raman scattering and X-ray diffraction confirm its high crystalline quality.

To confirm that there is an epitaxial relationship between the substrate and the nanostripes, and thus the crystalline orientation of the substrate is an important parameter that directly affects the orientation of the nanostripes' growth direction, antimony triselenide is grown on three differently oriented GaAs substrates. It is found that in the case of (111)B oriented GaAs substrate three equivalent growth directions of the nanostripes are preferred corresponding to [1-10], [10-1] and [01-1] crystallographic directions of the substrate. In the case of (100) oriented GaAs substrate, there are only two equivalent growth directions: the [011] and [01-1] directions, while in the case of (110) oriented GaAs substrate, there is only one preferred orientation of the nanostripes: the [1-10] direction.

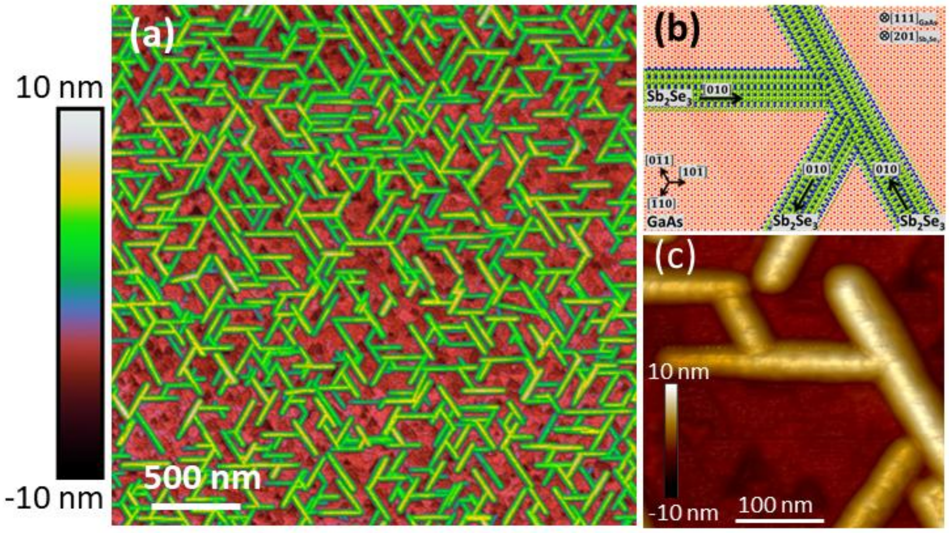

Figure 1 (a) Antimony triselenide nanostructures on (111)B GaAs substrate measured by atomic force microscope (AFM). (b) Crystallographic model illustrating three possible Sb_2Se_3 orientations on (111)B GaAs substrate. One dimensional nano-stripes grow always along $\langle 0\bar{1}1 \rangle$ directions of GaAs substrate (c) Close-up of a AFM image showing the orientation of the nanostripes.

References

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[2] Duan, Z. *et al. Sb2Se3 Thin-Film Solar Cells Exceeding 10% Power Conversion Efficiency Enabled by Injection Vapor Deposition Technology* Adv. Mater. 2022, **34**, 2202969

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Fig. 1: Logo of EUROMBE 2025

Table I: Important dates

Date	Event
November 28, 2024	Registration open
December 06, 2024	Abstract submission deadline
January 10, 2025	Registration deadline
March 9–13, 2025	ICMBE 2025