Directional growth of antimony triselenide by molecular beam epitaxy

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Antimony triselenide is a semiconductor which crystallizes in the stibnite (orthorhombic) crystalline structure which consists of one dimensional ribbons held together by weak Se-Se van der Waals interactions. It belongs, therefore, to the family of one dimensional materials which attract the research interest due to the possibility of downscaling semiconducting channels in transistors even down to the one atomic chain limit [1]. The interest in bulk antimony triselenide is risen mostly due to its application in photovoltaic devices [2] leading to the development of Sb_2Se_3 based solar cells with the efficiency with the efficiency exceeding 10% [3]. The advantage of using antimony triselenide is the high absorption coefficient typical for this semiconductor, the proper value of the band gap for the absorption of the solar spectrum, single phase structure and its low toxicity.

In this work, we demonstrate the growth of antimony triselenide by molecular beam epitaxy. We find that depending on the choice of the substrate, one can obtain either one-dimensional nano-stripes or thin epilayers composed of antimony triselenide. The substrate of the choice is GaAs since one of the lattice constants of Sb_2Se_3 amounts to 3.976 Å, which fits quite well to the interatomic distance of (111)-oriented GaAs (3.997 Å). The growth temperature used in our study is in the range 300 - 350ºC. Se and Sb atomic fluxes are given by the beam equivalent pressure equal to 5.5 10^{-7} and 1.5 10^{-7}, respectively.

Particularly interesting are the initial stages of the growth. When starting the growth on (111)B oriented GaAs we find that Sb_2Se_3 forms highly asymmetric, one dimensional nano-stripes which is, most likely, the result of its highly anisotropic crystal lattice. When increasing the deposition time, all three dimensions of the stripes: the length, the height and the thickness, increase simultaneously, whereas the length/thickness and length/height ratio amount always to about 10. After the growth process, the structures are characterized by means of atomic force microscopy, scanning and transmission electron microscopy, X-ray diffraction, Raman scattering and low temperature photoluminescence. Most importantly, it is found that the nano-stripes are Sb_2Se_3 monocrystals oriented in three different directions given by the substrate lattice orientation. When performing the growth on (110)-GaAs, antimony triselenide starts the growth epitaxially. It is possible to deposit at least a few well-oriented Sb_2Se_3 layers before crystals with other orientations appear.

References

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

[2] Shen, K. et al. Mechanisms and modification of nonlinear shunt leakage in Sb2Se3 thin film solar cells. Sol. Energy Mater. Sol. Cells 2018; 186, 58

[3] 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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