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Different Types of Bismuth Selenide Nanostructures for Targeted Applications: Synthesis and Properties

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Abstract : Bismuth selenide (Bi_2Se_3) is known as a narrow band gap semiconductor with pronounced thermoelectric (TE) and topological insulator (TI) properties. Unique TI properties offer exciting possibilities for fundamental research as observing the exciton condensate and Majorana fermions, as well as practical application in spintronic and quantum information. In turn, TE properties of this material can be applied for wide range of thermoelectric applications, as well as for broadband photodetectors and near-infrared sensors. Nanostructuring of this material results in improvement of TI properties due to suppression of the bulk conductivity, and enhancement of TE properties because of increased phonon scattering at the nanoscale grains and interfaces. Regarding TE properties, crystallographic growth direction, as well as orientation of the nanostructures relative to the growth substrate, play significant role in improvement of TE performance of nanostructured material. For instance, Bi_2Se_3 layers consisting of randomly oriented nanostructures and/or of combination of them with planar nanostructures show significantly enhanced in comparison with bulk and only planar Bi_2Se_3 nanostructures TE properties. In this work, a catalyst-free vapour-solid deposition technique was applied for controlled obtaining of different types of Bi_2Se_3 nanostructures and continuous nanostructured layers for targeted applications. For example, separated Bi_2Se_3 nanoplates, nanobelts and nanowires can be used for investigations of TI properties; consisting from merged planar and/or randomly oriented nanostructures Bi_2Se_3 layers are useful for applications in heat-to-power conversion devices and infrared detectors. The vapour-solid deposition was carried out using quartz tube furnace (MTI Corp), equipped with an inert gas supply and pressure/temperature control system. Bi_2Se_3 nanostructures/nanostructured layers of desired type were obtained by adjustment of synthesis parameters (process temperature, deposition time, pressure, carrier gas flow) and selection of deposition substrate (glass, quartz, mica, indium-tin-oxide, graphene and carbon nanotubes). Morphology, structure and composition of obtained Bi_2Se_3 nanostructures and nanostructured layers were inspected using SEM, AFM, EDX and HRTEM techniques, as well as home-build experimental setup for thermoelectric measurements. It was found that introducing of temporary carrier gas flow into the process tube during the synthesis and deposition substrate choice significantly influence nanostructures formation mechanism. Electrical, thermoelectric, and topological insulator properties of different types of deposited Bi_2Se_3 nanostructures and nanostructured coatings are characterized as a function of thickness and discussed.

Keywords : bismuth seleinde, nanostructures, topological insulator, vapour-solid deposition
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