Abstract

Bismuth chalcogenides have been well studied for both excellent thermoelectric properties [1], and topologically protected surface states [2]. These surface states are most relevant when the ratio of surface conductivity to bulk conductivity is high. This is due to the high surface area-to-volume ratio. Therefore, bismuth chalcogenide nanostructures are of particular interest [3]. In addition, theoretical investigations suggest that specific geometries of nanostructures can improve the properties of these materials, e.g. perforating structures of Bi_2Se_3 can exhibit improved thermoelectric properties [4, 5]; Bi_2Se_3 wires can be used as efficient connections in integrated circuits [6]; heterostructures of bismuth chalcogenide and superconductor may allow the control of Majorana fermions and other topological phenomena, potentially supporting the development of quantum computing [7, 8, 9]. Changing the thickness of nanostructures may also allow to control the electronic transport properties [10, 11]. However, implementing these ideas is challenging because most growth methods do not produce nanostructures of controlled sizes and shapes in the same process. This limits the ability to build devices to exact specifications and also limits the future scalability of devices. One way to overcome these problems is to use structurization methods to fabricate nanostructures with precise shapes and sizes. There are many such etching processes. One that allows the achieving of object sizes below 10 nm is focused ion beam (FIB) cutting of the material, using a beam of accelerated charged atoms to selectively remove material from the sample.

The doctoral thesis focused on the use of milling by means of a focused beam of Ga+ ions, as well as the use of an innovative approach using Xe+ ions. FIB milling uses Ga+ ions to mill the target material and can be used for both shape forming [12, 13] and defect introduction [12, 14]. FIB has shown the potential application in producing devices based on bismuth chalcogenides that retain their surface states [15, 16]. However, the results of electron transport studies at low temperatures indicated that the crystal structure of Bi_2Se_3 nanowires was partially changed by FIB [15]. Although these results do not encourage the use of FIB as a method of fabricating nano-devices, they do not fully take into account possible changes in the structure of the material. Therefore, in order to better understand the effect of FIB modifications on the atomic and electronic structure of bismuth chalcogenides, in this PhD thesis, independent research methods were used to analyze changes in the material under the influence of high-energy ion milling. The work combines device fabrication methods (such as photolithography, electron beam lithography, and FIB), analytical methods (scanning electron microscopy, transmission electron microscopy, X-ray absorption spectroscopy, and electron transport measurements at ultra-low temperatures), as well as a theoretical approach based on density functional theory.

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