Structural Effect of Carbon on Mn$_5$Ge$_3$ Thin Films Grown on Ge(001) Substrates by Solid Phase Epitaxy

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Spintronic devices take advantage of the electron spin, considered as an additional degree of freedom. One of the challenges on the design of spintronic devices, as the spin-field effect transistor, is the achievement of spin injection into IV-group semiconductors via a Schottky barrier at room temperature (RT) [1]. Mn$_5$Ge$_3$ compound is the only FM phase with a Curie temperature (TC) of 296 K, has been found that TC increases with carbon doping [2]. Mn$_5$Ge$_3$ has a hexagonal crystal structure P63/mcm and lattice constants $a = 7.184$ Å and $c = 5.053$ Å, these characteristics allow the growth on Ge(111) substrates within a lattice mismatch of 3.7% [3]. However, Ge(111) is not compatible with the Si(001) technology, while Ge(001)/Mn$_5$Ge$_3$ heterostructures offer a good possibility for the design of spintronic devices. In this work, we present the growth of Ge(001)/Mn$_5$Ge$_3$ thin films using the solid phase epitaxy (SPE) method, samples doped with carbon atoms and without carbon were grown by magnetron-sputtering technique. Carbon doping has been found to affect the arrangement of the atomic structure. The SPE method consists of the deposition of Mn or co-deposition of Mn and Ge at room temperature (RT) followed by thermal annealing at $T_s = 250$ °C to induce Ge diffusion into the Mn layer to form the Mn$_5$Ge$_3$ layer.

Figure 1 shows the bi-dimensional grazing incidence x-ray diffraction (2D-GIXRD) pattern collected for a sample doped with carbon. The pattern shows discontinuous Debye rings that are associated with the texture, there are observed four peaks at 20.4, 28.3, 35.0, and 40.5° corresponding to the (102), (4-21), (5-21), and (5-12) reflections from the Mn$_5$Ge$_3$ compound. The reflection Ge(311) corresponds to the substrate. The indexation was based on the ICSD #156103 crystallographic datasheet. Figure 2(a) shows the HRTEM micrograph for the sample without carbon, the c-axis of the Mn$_5$Ge$_3$ unit cell is normal to the Ge(001) plane of the substrate. The interface is relatively abrupt at the atomic scale along with a few atomic layers. The sample doped with carbon, figure 2(b), shows two stages of epitaxial growth: first, an Mn deposition, where the c-axis is normal to the Ge(001) plane, but the atomic arrangement is different from that in figure 2(a). In the Mn and Ge co-deposition stage, the c-axis of the Mn$_5$Ge$_3$ unit cell forms an angle with the plane of the substrate surface.

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Figure 1. 2D-GIXRD for a simple with carbon, where the indexed Debye rings belong to the Mn$_5$Ge$_3$.

Figure 2. HR-TEM micrographs of Mn$_5$Ge$_3$ samples: (a) without carbon and (b) with carbon.

References