doi:10.1017/S1431927618008590
Microsc. Microanal. 24 (Suppl 1), 2018

Surface-Interface Quality of Mn_5Ge_3 Thin Films on Ge(001): Reactive Deposition Epitaxy vs. Solid Phase Epitaxy

Adriana Alvídrez-Lechuga, José T. Holguín-Momaca, Óscar O. Solís-Canto, Carlos R. Santillán-Rodríguez, José A. Matutes-Aquino and Sion F. Olive-Méndez

Centro de Investigación en Materiales Avanzados, S.C. (CIMAV), Chihuahua, Chih., Mexico.

The study of ferromagnetic (FM) compounds, which can be epitaxially grown on semiconductor substrates is especially interesting as they can be ideal candidates for the development of spintronic devices that take advantage not only of the electron charge but also of the electron spin considered as an additional degree of freedom. Spintronic devices promise the fabrication of faster, lower consumption and non-volatile storage devices. Among several spintronic devices, the spin field-effect transistor (FET) [1] where the source and drain, usually elaborated of non-magnetic materials, are replaced by FM electrodes, can store information due to the magnetic orientation of the FM electrodes. The major challenge in the design of these devices is to achieve spin injection from a FM thin film into a semiconductor at room temperature. Spin injection is achieved via tunnel effect through the Schottky barrier at the semiconductor/FM interface, without needing an AlO_x or MgO oxide barrier [2].

The phase diagram of the Mn-Ge system contains 12 phases. Among these phases, Mn_5Ge_3 is interesting since it is FM with a Curie temperature (T_C) of 296 K [3]. Mn_5Ge_3 has a hexagonal crystal structure $P6_3$/mcm, and lattice parameters a = 7.184 Å and c = 5.053 Å. The hexagonal crystal structure of Mn_5Ge_3 matches the hexagonal surface of Ge(111) within a lattice mismatch of 3.7% [4]. Furthermore, the T_C can be enhanced up to 450 K by the incorporation of a small amount of carbon in the formula $Mn_5Ge_3C_x$ with $x = 0.6 – 1.5$. In this work, we present the results concerning two different approaches for the growth of the thin film: reactive deposition epitaxy (RDE) and solid phase epitaxy (SPE). The first method, RDE, consists on the co-deposition of Mn and Ge at a substrate temperature (T_s) of 250 °C allowing the reaction between Mn and Ge adatoms at the time they reach the substrate surface. On the other hand, SPE method consists on the deposition of Mn at room temperature followed by thermal annealing at a T_s = 250 °C to induce Ge diffusion into the Mn layer to form the Mn_5Ge_3 compound. The growth of the thin films was achieved using magnetron-sputtering technique and radio frequency power sources.

The interface quality of the films grown by RDE and SPE are shown in the fast Fourier transform filtered micrographs in Figs. 1(a) and 1(b), respectively. The interface is abrupt at the atomic scale along a few atomic layers. In both cases, the films are complete monocrystalline and perfectly epitaxial with the Ge(001) substrate. The interface quality depends only on the preparation of the Ge(001) substrate as a 2×1 surface reconstruction is obtained after the removal of the GeO_2 native oxide. The epitaxial relationship is Ge(001)[110]‖Mn_5Ge_3(001)[110] with the c-axis of the Mn_5Ge_3 unit cell forming an angle of 45° with the plane of the substrate surface. The results of the atomic force microscopy (AFM) analyses show a rough surface for the sample grown by RDE with a root mean square roughness of 9.7 nm, compared to that grown by SPE of 1 nm. This 10-times reduction is attributed to the surface diffusion of the adatoms of Mn and Ge during the RDE growth method. Atoms may segregate to reduce the total surface free energy. In the case of the growth by SPE, as the growth of the Mn thin film is performed at room temperature, Mn adatoms cannot diffuse along the surface thus leading to the formation of a continuous thin film. In the second step as T_s is increased to 250 °C, Ge atoms from the substrate diffuse towards the Mn layer to form the Mn_5Ge_3 compound. In this case, only vertical diffusion takes place [5].

References:

[1] J. C. Egues, G. Burkard and D. Loss, Appl. Phys. Lett. **82** (2003), p. 2658.
[2] J.J. Zhu and Ch. Park, Materials today **9** (2006), p. 36.
[3] C. Zeng, *et al*, Appl. Phys. Lett. **83** (2003), p. 5002.
[4] S. Olive-Méndez, *et al*, Thin Solid Films **517** (2008), p.191.
[5] Authors thank the financial support obtained from Ciencia-Básica SEP-CONACYT grant No. 157559 and Fondo Mixto Chihuahua FOMIX grant No. CHIH-2011-C03-168831.

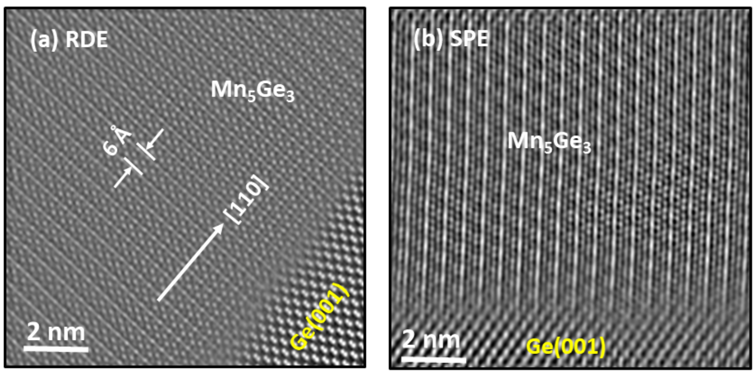

Figure 1. HR-TEM micrographs of 30-nm thick films grown at 250 °C, (a) by RDE method and (b) by SPE method.

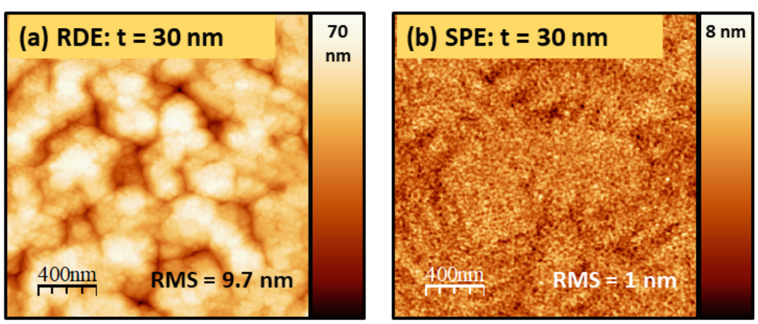

Figure 2. AFM micrographs of the films grown at 250 °C following the (a) RDE method, and (b) the SPE method.

https://doi.org/10.1017/S1431927618008590 Published online by Cambridge University Press