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High-Temperature Growth of $Mn_5Ge_3C_x$ Thin Films on Ge (001) Substrates: Reactive Deposition Epitaxy vs. Solid Deposition Epitaxy

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The need for electronic devices with a greater data storage capacity, faster data processing and lower power consumption, forces to reduce the size of electronic components. Spintronic devices, such as the spin-field effect transistor, require spin injection into IV-group semiconductors via a Schottky barrier at room temperature (RT). Mn_5Ge_3 is a ferromagnetic phase with a Curie temperature (T_C) of ~ 296 K, and spin polarization above 42%. It has been found that T_C increases with carbon doping up to 445 K [1]. Mn_5Ge_3 has a hexagonal crystal structure $P6_3/mcm$ and lattice constants a = 7.184 Å and c = 5.053 Å, allowing epitaxial growth on Ge(111) substrates within a lattice mismatch of 3.7% [2]. On the other hand, Mn_5Ge_3/Ge (001) heterostructures are compatible with the Si(001) technology [3]. In this work, we present the growth of Mn_5Ge_3/Ge (001) thin films by the solid phase epitaxy (SPE) and reactive deposition epitaxy (RDE) methods, using the magnetron-sputtering technique. The RDE method consists on the co-deposition of Mn and C at a substrate temperature (T_s) of 750 °C. The SPE method consists on the co-deposition of Mn and C at room temperature followed by thermal annealing at a T_s = 750 °C.

Figures 1(a) and 1(b) show the atomic force microscopy (AFM) images, which reveal the surface topography of the C-doped samples. The sample obtained by the SPE method shows a RMS roughness of 4 nm. Figure 1(c) shows the line profile of the AFM micrograph for the RDE sample, which obeys a Volmer-Weber (VW) growth mode. The diagram describing the VW growth is shown in figure 1(e), and figure 1(g) shows the scanning electron micrograph of a cross-section of the sample, which confirms an island-like growth [3]. On the other hand, figure 1(d) shows the line profile for the SPE sample, and figure 1(f) shows a close-packed arrangement of the grains describing a Frank-van der Merwe (FM) growth mode. Finally, figure 1(h) shows the scanning electron micrograph of a cross-section of the SPE sample revealing layer-by-layer growth. Figure 2 shows the magnetization vs. temperature (M-T) curves, it can be observed that the RDE sample presents a T_C of 390 K compared to ~330 K for the SPE sample. The saturation magnetization obtained in this sample, M_s = 250 kAm^{-1}, is much lower than that of the sample grown by SPE, M_s = 415 kAm^{-1}.

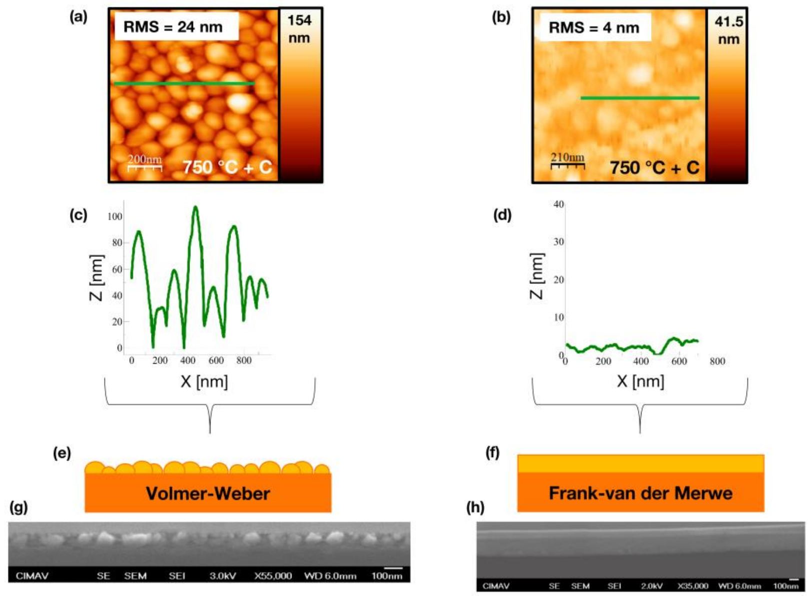

Figure 1. (a) and (b) AFM images of the C-doped samples grown at 750 °C. (c) and (d) Line profiles. (e) The VW growth mode representation for the RDE sample, and (f) the FM growth mode for the SPE sample. SEM cross-section for (g) the RDE sample and (h) the SPE sample.

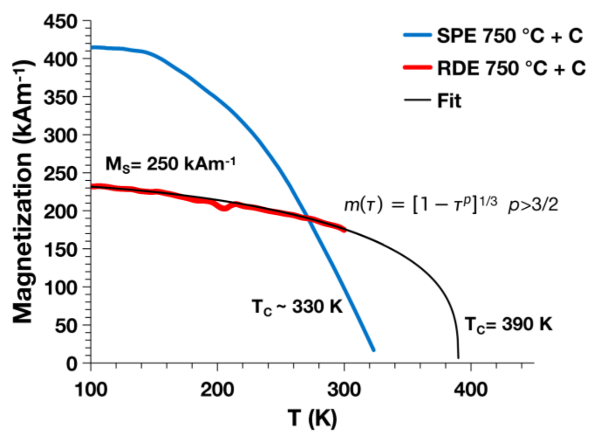

Figure 2. *M*-*T* curves. The T_C was obtained using equation $m(\tau) = [1- \tau^p]^{1/3}$, $p>3/2$. The RDE sample shows a T_C of 390 K compared to ~330 K for the SPE sample, and a M_s = 250 kAm^{-1}.

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