Epitaxial Ferromagnet on Ge(111)

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The difficulty of injecting spin-polarized electrons into a semiconductor is a major bottleneck in spintronics research. There are two ways to realize spin injection. One of these is to fabricate a ferromagnetic- metal/semiconductor heterostructure; the other is to use a dilute magnetic semiconductor as the spin aligner. The former method does not work well because chemical intermixing and/or lattice mismatch at the interface usually results in a significant loss of spin polarization. The large "conductivity mismatch" between the ferromagnetic metal and semiconductor furthermore limits the spin injection efficiency. The latter method of using a dilute magnetic semiconductor is limited by the low Curie temperature, T_c.

We have developed a novel interface with good potential for spin injection, namely an epitaxial ferromagnetic Mn_5Ge_3 film on Ge(111). The Mn_5Ge_3 films are fabricated by depositing 40 nm Mn onto Ge(111) and subsequent annealing at 150°C for several minutes. The lattice mismatch between Mn_5Ge_3(100) and Ge(111) is only 3.7%, so we expect Mn_5Ge_3(100)//Ge(111). Scanning tunneling microscope (STM) images display large terraces with a $(\sqrt{3}\times\sqrt{3})R30°$ honeycomb structure, which perfectly agrees with the theoretical image of the Mn terminated Mn_5Ge_3 (100) surface, using first-principles Density Functional Theory; see Fig. 1(a). X-ray diffraction θ-2θ scans show Mn_5Ge_3 (200) and (400) reflections besides the Ge (111) and (333) reflections, which confirms the Mn_5Ge_3(100)//Ge(111) epitaxial relationship. Rutherford Backscattering Spectrometry and ion-channeling experiments confirmed the stoichiometry and epitaxy of the film.

Magnetic properties were measured with a SQUID magnetometer. Fig. 1(b) shows the temperature-dependent remanent magnetization. It reveals a T_c of about 295 K. Hysteresis loops at T = 5 K with in-plane and out-of-plane field orientations are shown in the inset. The easy axis is in-plane which is most likely due to the shape anisotropy. The multiplet splitting of the Mn 3*s* core level in X-ray photoelectron spectroscopy indicates an average magnetic moment of $2.7\mu_B$ per Mn atom, which is in almost perfect agreement with the spin-resolved band structure calculations and SQUID measurements. This research was sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725

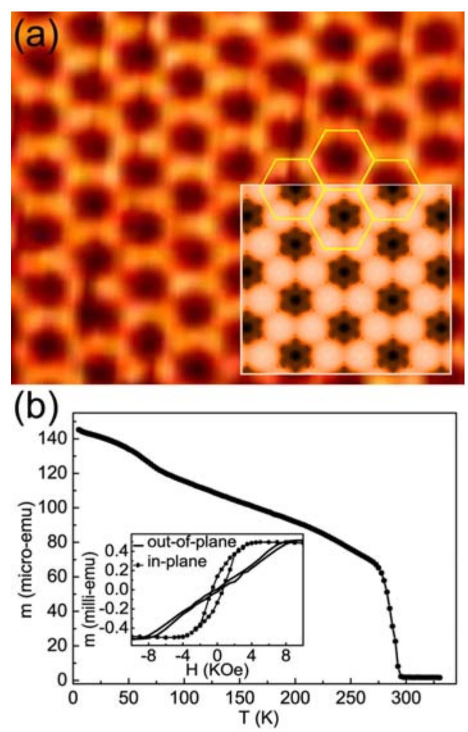

Fig. 1: *(a) Filled-state STM image of Mn_5Ge_3 films on Ge(111). The inset is the simulated result. (b) Magnetic measurements of the Mn_5Ge_3 films on Ge(111).*