A Thesis for the Degree of Ph.D. in Engineering

Magnetic properties of single crystalline Mn_5Ge_3 films grown on Ge(111) substrates

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Thesis abstract

The field of spintronics has increasingly become an interest because of the possibility to manipulate magnetic properties with electric current and to produce spin currents. Spin currents are less energy-consuming than charge currents and they can be generated in a semiconductor material by a process called spin injection, using a ferromagnet as a spin polarizer. Due to the fact ferromagnets are usually metallic, the efficiency of spin injection is affected by the difference of conductivity between the ferromagnet and the semiconductor. In order to prevent such conductivity mismatch, the creation of ferromagnetic semiconductors was proposed. Semiconductors doped with magnetic atoms (diluted magnetic semiconductors) are excellent candidates as spin polarizers due to their conductivity matching. They are however difficult to fabricate and suffer from low Curie temperatures. Increasing the spin injection efficiency of ferromagnetic metals, that can be grown epitaxially on doped semiconductors, represents a reasonable alternate choice as long as the properties at the ferromagnet/semiconductor interface can be controlled. Mn_5Ge_3 has the advantage to be grown coherently on Ge(111) with a relatively high Curie temperature and spin polarization.

The present thesis demonstrate a successful characterization of the interface between epitaxial Mn_5Ge_3 thin films and their Ge substrate. The evidenced interfacial spin-glass state is a promising result towards elucidating the interactions between ferromagnets and spin-glasses, which could open new prospects for spintronics applications. This thesis is composed of six chapters. Chapter 1 explains the motivations of this thesis. Chapter 2 gives a general background about epitaxial growth and deals with the structural characterization of the Mn_5Ge_3 thin films used in this work. Chapter 3 introduces the magnetic properties that are relevant to this work. Chapter 4 provides a detailed characterization of the magnetocrystalline anisotropy in Mn_5Ge_3 by using the ferromagnetic resonance technique. It is revealed that, despite being weak, a perpendicular anisotropy exists in such Mn_5Ge_3 thin films and its temperature dependence is successfully determined not to follow the Callen-Callen law. By comparing the perpendicular anisotropy with the shape anisotropy, this chapter concludes that the weak perpendicular anisotropy does not affect the magnetization hysteresis at low temperature. Chapter 5 explains the presence of a thermal irreversibility in the in-plane magnetization of Mn_5Ge_3 thin films. A spin-glass-like state arising at the interface between Mn_5Ge_3 and Ge considerably changes the magnetic properties of the ferromagnetic Mn_5Ge_3 by introducing a slow magnetization dynamics below the Curie temperature. It is also observed that the spin-glass-like state clearly depends on the growth conditions. Chapter 6 concludes the results of this work.