MAGNETIC PROPERTIES OF HYBRID Fe/SEMICONDUCTOR STRUCTURES

ABSTRACT

by

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This thesis is devoted to the study of magnetic properties of multilayer structures involving combinations of a ferromagnetic metal with a semiconductor. Understanding such is expected to be relevant for achieving integrated spintronic devices, i.e., applications that depend on electronic and spin effects of the system as a whole. Specifically, we explore structures comprised of ferromagnetic layers of Fe deposited on semiconductors GaAs, ZnSe and Ge fabricated by the method of molecular beam epitaxy. The ability of growing Fe films of high crystalline quality on these semiconductor layers is made possible by a fortuitous between match the body-centered cubic crystal structure of Fe and the face-centered cubic structure of GaAs, ZnSe and Ge. The Fe films so fabricated are capped by Au or Al to protect the film from oxidation after it is taken out of the growth chamber.

In investigating these hybrid magnetic metal/semiconductor structures, we first focus on determining their static magnetic properties by systematic magnetization measurements carried out using a superconducting quantum interference device (SQUID). These studies reveal that the magnetic properties of these highly crystalline Fe films are highly anisotropic, with well-defined easy axes of magnetization. They also reveal a strong dependence of their magnetic anisotropy on the underlying semiconductor materials, as follows. The GaAs/Fe structures show a strong uniaxial magneto-crystalline symmetry in the plane of the film; ZnSe/Fe multilayers show a finite but weak uniaxial anisotropy; and Ge/Fe show a fully cubic symmetry. These

studies are followed by measurements of the ferromagnetic resonance in the semiconductor/Fe systems, which provide the opportunity for a quantitative determination of the magneto-crystalline anisotropy parameters revealed qualitatively in the SQUID measurements. The quality of the FMR spectra further attest to the very high crystalline quality of the Fe films grown on the GaAs, ZnSe and Ge buffer layers.

Having determined their magnetic properties, we then study interactions of the Fe films with their adjacent neighbors. We observed that the GaAs/Fe structures capped by Au show striking exchange bias effects, which we ascribe to the formation of an antiferromagnetic (AFM) layer. While no AFM layer is intentionally deposited on the Fe film, we conclude that penetration of oxygen through the thin capping Au layer leads to the formation of FeO or related oxide, which is an antiferromagnet below room temperature, and is thus likely to lead to exchange bias. The exchange bias studied by SQUID then allows us to quantitatively measure the exchange field arising from the AFM film and acting on the Fe layer. The exchange bias effect is accompanied by highly-asymmetric magnetic hystereses observed when a magnetic field is applied at different angles to the film. The observed hystereses can be satisfactorily fitted by the magnetic free energy modified by including a unidirectional exchange bias term.

We conclude the study of the Fe/semiconductor hybrid structures by investigating the magnetic properties of Fe/GaAs core-shell nanowires. These structures are grown by MBE using catalytic nucleation of GaAs nanowires of about 10 nm diameter and 2000 nm length by gold droplet nucleation. The GaAs nanowires are then coated by Fe (to form in effect Fe tubes), and again by Au to protect them from oxidation after removal from the MBE chamber. Magnetic studies by SQUID and by FMR show that the resulting nanowires are magnetically highly anisotropic. The FMR measurements further reveal that the as-grown ensemble of such nanowires can be described by an entirely new demagnetizing factor, not previously known.