Ferromagnetic resonance in nanometric epitaxial Fe_3Si films on (111)Ge

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The epitaxial growth of ferromagnetic thin films on semiconductor substrates is the base of a new technology applied to the spintronic devices. The ferromagnetic silicide Fe3Si is a promising material for a spin injector. Usually the Fe3Si thin films are grown on (001) substrates (GaAs, MgO). However, it has recently been shown that the low-temperature molecular beam epitaxy (MBE) growth of Fe_3Si on (111)Ge provides atomically flat interfaces and good magnetic properties, e.g., Curie temperature as high as 840 K [1]. Furthermore, an unexpected uniaxial magnetic anisotropy was observed in the film plane, and the direction of the uniaxial easy axis was different for each of the as-grown samples. By postgrowth annealing, surprisingly, the random orientation of the uniaxial easy axis was aligned to a direction along about [0−11]. An enhancement of the ordering of the magnetic DO3 phase was suggested. In the present work, we apply the ferromagnetic resonance (FMR) spectroscopy to further study this in-plane anisotropy.

Fe_3Si epilayers were grown on n-type (111)Ge substrates by low-temperature (130ºC) MBE. The thickness of the epilayers was about 50 and 100 nm. The post-growth annealing was carried out at temperatures up to 375ºC for 30−120 min. FMR spectra were obtained using an X-band spectrometer (~9.8 GHz). Measurements of the angular dependences of the FMR signal were performed at room temperature for the in-plane and out-of-plane field orientations. The angular dependences of the FMR line position were analyzed in the framework of the well-established theory [2]. In order to analyze the angular dependence of the linewidth, a phenomenological model considering intrinsic (homogeneous) and inhomogeneous contributions was adopted [3].

We have observed a very strong difference of the FMR linewidth for the 100 nm and 50 nm thick as-grown samples. The lines in the latter are several times narrower. Simulations of the angular dependence of the line width indicated an effective magnetization dispersion $\Delta(4\pi M_{eff})$ = 390 G in the 100 nm thick and 60 G in the 50 nm thick samples. This means a much higher homogeneity of the thinner films. Thus, in the follow-up work we investigated only the latter ones. In the as-grown sample, the simulations give a Gilbert damping factor α = 0.004 and the dispersion of the effective magnetization orientation $\Delta\theta_H$ = 0.1°. There is very weak uniaxial in-plane anisotropy of the resonance line position. Annealing at 350ºC enhances this anisotropy without significantly changing the linewidth parameters. This means, there is probably no ordering of the DO3 magnetic phase. After increasing the anneal temperature to 375ºC, we observed the appearance of a six-fold anisotropy, as expected for the (111) plane of the DO3-type Fe_3Si, still superimposed with a uniaxial anisotropy. Our results confirm that no second phase is formed as a result of the annealing at temperatures up to 375ºC, as no additional FMR line appears in the samples. The annealing-induced changes of the magnetic anisotropy parameters are discussed in detail.

References:

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