ELECTROCHEMICAL DEPOSITION OF FERROMAGNETIC METALS ON GAAS

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The direct integration of thin films of ferromagnetic metals or alloys with semiconductors has recently raised interest due to the possibility of coupling spin-dependent transport phenomena with conventional electronics, potentially yielding devices characterized by increased speed and density, and decreased power consumption [1].

In this respect, electrodeposition presents unique advantages due to (*i*) its capability to grow epitaxial films, (*ii*) the possibility to form sharp interfaces as a consequence of the low temperature of the growth process, and (*iii*) its unique selectivity, which allows purely additive micro- and nanofabrication by through-mask plating [2].

We have grown 3d ferromagnetic FM metals Fe, Co and Ni and some of their alloys by electrodeposition at room temperature on n^+-doped GaAs with (100) or (110) orientation and investigated the growth, structure and magnetic properties of the films (thickness 5 – 100 nm), as well as the electrical properties of the resulting FM/GaAs junctions.

Ni films on GaAs(100) are extremely flat, as shown in the X-ray reflectivity spectrum in Fig. 1, and exhibit roughness below 1 nm , slowly increasing with thickness. Angle dependent XPS shows that interdiffusion of Ga and As into the Ni film is limited while more pronounced for As. Film resistivity as function of thickness (Fig. 2) follows Fuchs' model down to 5 nm, confirming limited intermixing at the interface. The films form mosaic structures on GaAs, with the two following approximate epitaxial orientations: Ni(001)[100]//GaAs(001)[100] and Ni(011)[111]/GaAs(001)[110] (Fig. 3).

The relative percentage of the two orientations was studied by measuring the in-plane remanent magnetization as a function of field/substrate orientation and was found to depend on solution pH.

Ni films on GaAs(110) grow according to the approximate epitaxial relation (Fig. 4): Ni(111)[110]//GaAs(011)[110]. They show a well-defined uniaxial anisotropy that can be explained by magnetostrictive effects induced by lattice deformation.

Co films grow on GaAs as a FCC-HCP mixture, the relative fraction of the two phases depending on the pH of the electrolyte used. No definite preferred orientations are observed, however the Co films on GaAs(110) exhibit a uniaxial anisotropy in the direction perpendicular to that exhibited by the Ni films.

Fe films must be electrodeposited from electrolytes including reducing agents, to avoid formation on the GaAs substrates of $Fe(OH)_x$ precipitates. The resulting films do not exhibit any anisotropy when electroplated onto GaAs(100), while they show a uniaxial anisotropy similar to Co when plated onto GaAs(110). No definite crystallographic orientation is observed in either case.

References
[1] S. Wolf et al., *Science* **294**, 1488 (2001).
[2] L.T. Romankiw, *Electrochimica Acta* **42**, 2985 (1997).

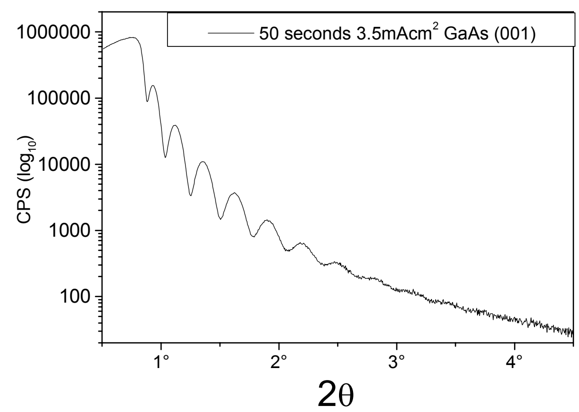

Fig 1. X-ray reflectivity spectrum of a 30 nm thick Ni film on GaAs(001).

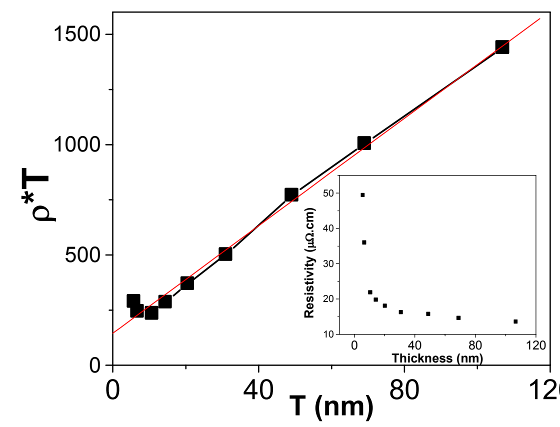

Fig. 2. The product resistivityxthickness (in the inset, the resistivity) of a series of Ni films on GaAs(001). The line indicates the ideal behavior predicted by the Fuchs' model.

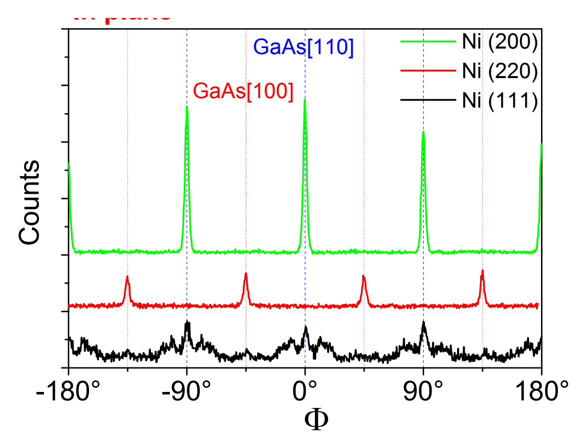

Fig. 3. In-plane XRD spectra of Ni films on GaAs (100) indicating the epitaxial orientations discussed in the text.

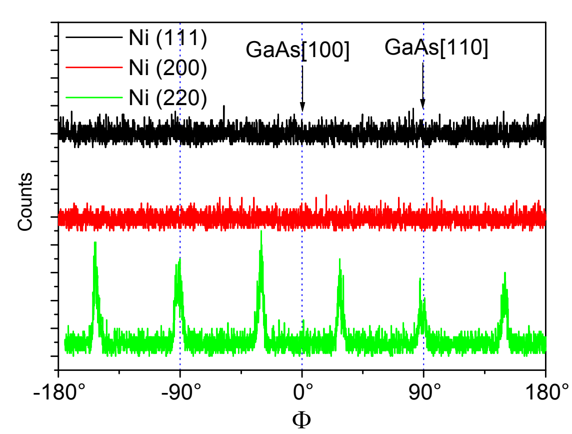

Fig. 4. In-plane XRD spectra of Ni films on GaAs (110) indicating the epitaxial orientations discussed in the text.