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STRUCTURAL PROPERTIES OF Fe/FeN MULTILAYERS

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Discovery of the giant magnetoresistance (GMR) effect at the end of 80s in Fe/Cr multilayers has stimulated a progress in technology and understanding of physical phenomena occurring in magnetic metallic multilayer structures. Studies of a number of magnetic metal/nonmagnetic spacer systems (the spacer may be a metal, a semiconductor or a dielectric) have resulted in application of GMR materials in reading heads of hard disk memories and in creation of a new class of magnetic-field sensors such as spin valves using the giant magnetic tunnelling effect. The next potential application domain of magnetic multilayers are contacts which inject the spin polarised carriers into semiconductors. Such contacts could take advantage of the exchange interlayer coupling between magnetic layers which would permit for switching off and on the spin polarised current by an external magnetic field. It is well known that one can inject polarised spins from iron contact to GaAs (due to a tunnelling through a Schottky barier) [1] or to InAs (by an ohmic contact) [2]. One of candidates for such quantum structure is the Fe/FeN multilayer system. The Fe in-plane lattice parameter for Fe/FeN multilayers matches very well to GaAs and InAs lattice parameters, similar to the pure iron.

Epitaxial iron layers can be grown at room temperature (RT) on (001) oriented GaAs substrates by the sputtering method. Iron nitride is known for its variety of phases with different crystal structures due to different nitrogen content. Such material deposited by sputtering at room temperature (RT) can be crystalline or amorphous, depending on the growth conditions and on the nitrogen content. Its Curie temperature decreases with increasing nitrogen content in the sputtering atmosphere during a layer deposition. For example, this temperature has been reported to drop from 1050 K for pure iron to 70 K if the nitrogen content in the atmosphere has been kept at 37.5% [3].

One can expect that for some thickness of nonmagnetic (at RT) spacer, creation of antiferromagnetic coupling is possible for a Fe/FeN multilayer system. Such a system should work at RT as a spin injector, operated by an external magnetic field.

According to the literature data the proper condition for an observation of the antiferromagnetic coupling in metallic multilayers corresponds to a nonmagnetic spacer thickness close to 10 Å (such values have been reported, *e.g.*, for Fe/Ag and Fe/Mo metallic systems [4,5]). It is also well known from the literature that during the deposition of Fe/FeN multilayers it is very difficult to obtain sharp interfaces because of the nitrogen diffusion [6]. Up to now, successful Fe/FeN multilayer growth has been reported by two groups [6,7]. In both cases, long-period multilayers with a spacer thickness equal at least to 30 Å have been prepared. Our goal is to demonstrate that it is possible to obtain good-quality, short-period Fe/FeN multilayers, for which the antiferromagnetic exchange coupling could occur. In particular, a question appears about the feasibility of reducing the nitrogen diffusion at the interface and of determining the proper conditions for a deposition of structures with sharp interfaces.

The present paper is devoted to the X-ray and neutron characterisation of short-period Fe/FeN multilayers deposited by sputtering on GaAs(001) and Si(111) substrates. In the first case a perfect lattice match between a multilayer and the substrate is obtained, in the second system the lattice mismatch is quite significant. As one can expect, such difference should have an influence on the physical properties of the two sets of samples.

Fe/FeN multilayers were deposited in ultra-high vacuum (UHV) sputtering system at the Institute of Physics of the Polish Academy of Sciences in Warsaw. This system is equipped with four planar magnetrons with targets of 50 mm diameter. During the deposition process, the substrate rotates which makes it possible to obtain uniform samples. Both DC and RF (13.5 MHz) magnetron sputtering modes can be used. Argon, nitrogen and hydrogen can be introduced into the deposition chamber by three independent gas systems. The basic vacuum was 5×10^{-7} Pa. Fe/FeN multilayers were deposited at RT on GaAs(001) and Si(111) substrates (in each case the growth was proceeded in parallel for GaAs and Si substrates). DC magnetron sputtering mode was applied, the growth took place in argon atmosphere with nitrogen supplied periodically during the deposition. Several Fe/FeN multilayers with the nonmagnetic spacer thickness from about 8 Å to 15 Å have been obtained, the number of repetitions varied from 16 to 28.

For the structure characterization of multilayers, the X-ray reflectometry and the neutron scattering have been applied. First, X-ray reflectometry and small-angle diffraction measurements were performed in the Institute of Physics using a reflectometric attachment at an X'Pert MPD diffractometer. The Cu Kα radiation (wavelength λ=1.5418 Å) was used for this purpose. Next, selected multilayers were studied in detail by reflectometry at a synchrotron radiation source (Hasylab/DESY, Germany) at W1.1 beamline (λ = 1.54 Å). Finally, the neutron scattering studies were performed at Laboratoire Léon Brillouin (Saclay, France). Both, the small-angle neutron diffraction and the spin-polarized neutron reflectometry with the use of cold neutron beams (corresponding to the wavelength of 4.3 Å), were applied. The X-ray and neutron methods are complementary. For X-ray reflectometry, the results depend on the chemical contrast and do not contain information about the magnetic periodicity for the given multilayer or about the magnetic roughness of its interfaces. On the contrary, because of the lack of the chemical contrast between neutron scattering on iron and nitrogen nuclei, neutron data give purely magnetic information.

An example of reflectivity curve measured at the W1.1 beamline for a sample with Fe/FeN multilayer with 28 repetitions (bilayer thickness about 42 Å) deposited on GaAs(001) substrate is shown in Fig. 1. Preliminary simulation of the X-ray reflectometric curves yielded the thickness of bilayers in the short period Fe/FeN multilayer samples the range 35.5-49.5 Å (29-37.5 Å for Fe layer, 6.5-12 Å for Fe-N layer). The thickness and roughness determined by various techniques are consistent (the chemical period is in agreement with the magnetic one) and they marginally differ from the nominal ones. The roughness was evaluated to vary between 6 and 10 Å at Fe-FeN interface and between 4 and 7 Å for FeN-Fe interface.

The presence of the ferromagnetic order between Fe layers in the studied multilayers was demonstrated by both, neutron diffraction and neutron reflectometry, methods applied. It is noteworthy that the quality of multilayers grown on Si(111) is markedly inferior in respect to those grown on GaAs.

Summary

The obtained results permit to conclude that it is possible to grow high-quality Fe/FeN multilayers on GaAs(001). The nitrogen penetration into the Fe sublayers is weaker than that reported till now in the literature. The neutron scattering and reflectivity experiments show a ferromagnetic ordering in the studied multilayers.

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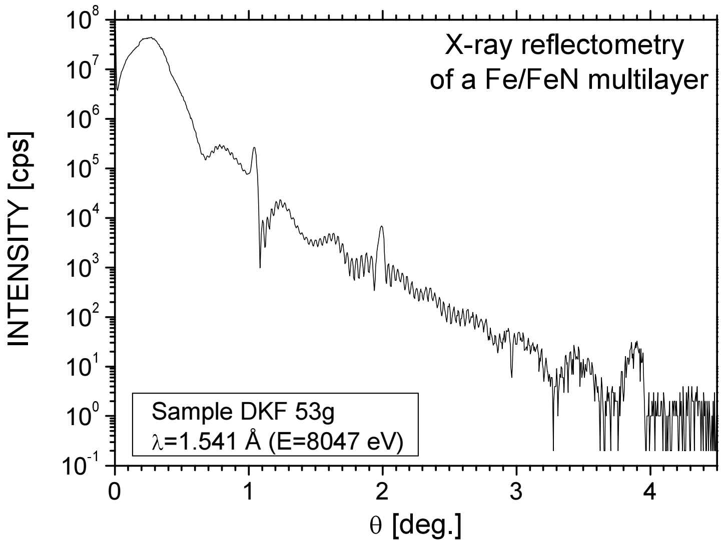

Figure 1.

Example of the reflectivity curve measured at the W1.1 beamline for a sample with Fe/FeN multilayer with 28 repetitions (bilayer thickness about 42 Å) deposited on GaAs(001) substrate.