ERD Analysis of Reactively Sputtered NiO Films for Spin-Valve Structures

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The coupling between an antiferromagnetic (AFM) and a ferromagnetic (FM) film can lead to a shift of the hysteresis loop by an amount H_{eb} from zero field. This effect is called exchange bias (EB) or exchange anisotropy [1]. In spin-valve structures [2] the EB is used to achieve an antiparallel magnetization of two FM layers separated by a spacer layer. The antiparallel alignment has an up to 20 % higher resistance than the parallel alignment due to an increased electron scattering probability at the layer interfaces. The Giant Magnetoresistance (GMR) effect finds its application in read heads for high-density magnetic recording or future magnetic random access memory (MRAM) devices.

Oxides like NiO are favored materials as AFM layers in spin-valves, because of their high corrosion resistance and their insulating character. Reactive sputtering is a common method to form the oxide films, but the EB will be mainly determined by the terms of preparation. Applications require high values of H_{eb} and thermal stability of the EB.

We investigated the influence of the oxygen supply during the reactive NiO deposition on the chemical composition of the grown films and how the thermal stability of the EB to an adjacent NiFe layer is affected. The chemical compositions of NiO single layers were evaluated by elastic recoil detection analysis (ERD) which is a suitable method to measure quantitative concentrations of heavy and light elements like oxygen [3]. An incident beam of 170 MeV ^{127}I was used. Temperature dependent magnetic measurements on NiO(50 nm)/NiFe(5 nm) bilayers were performed in a vibrating sample magnetometer.

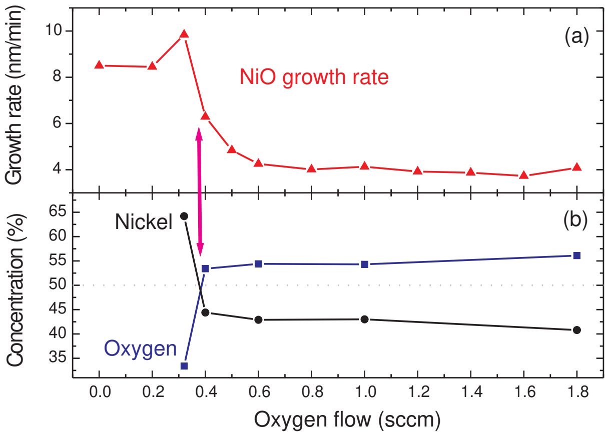

Fig. 1: (a) Growth rate of NiO in dependence on the oxygen supply. (b) Chemical compositions of 100 nm NiO films measured by ERD.

All films were prepared on thin glass substrates by rf-diode sputtering [4]. The oxygen flow to the sputtering chamber was varied during the reactive NiO deposition. After preparation the NiO/NiFe bilayers were annealed and cooled down to room temperature in a magnetic field to improve the stability of the EB [4].

The growth rate of the NiO depends on the oxygen flow [Fig. 1(a)]. When the flow exceeds a critical value (≈ 0.35 sccm) the target surface oxidizes and the sputtering yield drops down. The chemical composition of the NiO films as obtained by ERD is shown in Fig. 1(b). An abrupt phase transition from oxygen poor to oxygen rich NiO takes place between 0.3 and 0.4 sccm O_2 which corresponds to the transition from metallic to compound sputtering mode (arrow in Fig. 1). With further increasing oxygen flow the surplus oxygen in the NiO raises from 3 to 6 %. Additional x-ray diffraction showed an increasing NiO lattice parameter from 4.265 to 4.311 Å. However, oxygen poor NiO did not lead to an EB in NiO/NiFe bilayers even though the NiO phase was present.

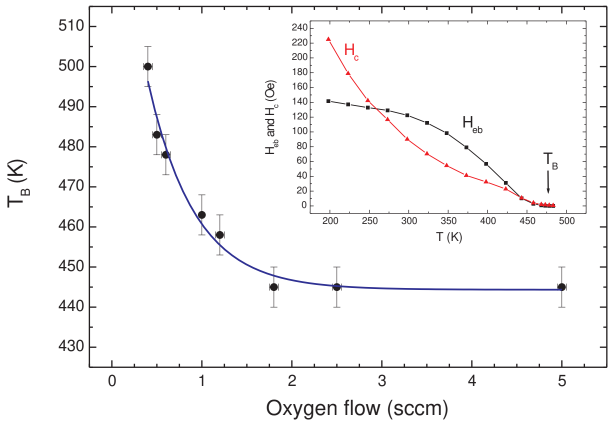

Fig. 2: In NiO/NiFe bilayers the blocking temperature T_{B} decreases exponentially with increasing O_2 flow during NiO deposition. The inset shows the temperature dependence of H_{eb} and H_{c} of such a bilayer. H_{eb} becomes zero at $T = T_{\mathrm{B}}$.

With increasing temperatures H_{eb} decreases (inset of Fig. 2) and vanishes completely when the 'blocking temperature' T_{B} is reached. Thus, T_{B} is a measure for the thermal stability of the EB. In NiO/NiFe bilayers T_{B} decays exponentially with increasing oxygen flow during NiO deposition and reaches a saturation level of $T_{\mathrm{B}} \approx 445$ K at 2 sccm O_2.

Comparing the magnetic measurements (Fig. 2) with the ERD results (Fig. 1) lets us believe that the surplus oxygen stretches the crystal lattice and increases the defect density within the NiO. The exponential decay of T_{B} seems to be the result of the increasing perturbation of the NiO lattice. Our experiments point out that the chemical composition of the NiO determines the thermal stability of the EB in NiO/NiFe bilayers.

References

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