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The Structure, and the Magnetic and Magnetoresistive Characteristics of the Spin Valve Multilayers

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In this paper we report the low and high angle diffraction results, and the magnetic and magnetoresistive characteristics of the spin valve multilayer structure prepared by the sputter machine Emerald II in the Balzers Laboratory. The investigated system consists of a ferromagnetic free layer (7 nm NiFe) and a ferromagnetic pinned layer (7 nm NiFe), separated from each other by a nonmagnetic (2.1 nm Cu) spacer. The NiFe pinned layer is fixed by the exchange coupling with an antiferromagnetic layer (10 nm FeMn). For such system the magnetoresistance ratio $\Delta R/R=3.58\%$, the interlayer exchange coupling $H_c=6.4$ Oe and the field sensitivity 1.15%/Oe were otained.

1. Introduction

The achievement of the 10 Gbit/inch^2 (16 Mbit/mm^2) storage density is possible if the reading part of the recording head uses the magnetoresistivity effect for detection, on the condition that the magnetoresistance ratio of the sensor is higher than that in conventional materials as permalloy ($\Delta R/R=3\%$) [1]. The good candidates as read-heads are multilayers where the giant magnetoresistance (GMR) effect was observed [2] and the spin valve devices are most promising because the switching field in them can often be only of a few Oersted although they suffer from relatively small $\Delta R/R=10\%$ [3]. On the other hand superlattices of Co/Cu can exhibit the room temperature GMR as large as 65% [2] but generally have the disadvantage of large switching (or saturation) fields.

The spin valve structure consists of at least two ferromagnetic layers separated from each other by nonmagnetic layer-spacer. This system is characterized by high resistivity state where magnetizations of ferromagnetic layers are oriented antiparallel to each other and by low resistivity state for parallel configuration. The antiparallel configuration of magnetization could be obtained for ferromagnetic layers with different coercivities [4, 5] and also for the system with antiferromagnetic exchange coupled layers [2, 4]. In such configuration of layers one ferromagnetic film serves as the sense-film with the magnetization along the length of the element. The second layer with magnetization transversally oriented to the length of the element, which is separated from the sense-film by a thin metallic layer (usually Cu) has pinned magnetization by an antiferromagnet. The magnetic field from storage media rotates the magnetization in the sense-layer, and simultaneously changes the relative angle of the magnetizations in the two magnetic layers. The resistance signal of the element is proportional to the cosine of this angle.

In this paper the low- and high-angle X-ray diffraction results, and the magnetic and magnetoresistivity hysteresis loops of spin valve multilayers Si(100)-$Al_2O_3$1600Å/Ta 48Å/$Ni_{80}Fe_{20}$70Å/Cu21Å/$Ni_{80}Fe_{20}$70Å/FeMn100Å/Ta50Å will be discussed.

2. Experimental

The investigated spin valve multilayer was deposited using the EMERALD II sputtering machine in the Balzers Laboratory, described in details elsewhere [6]. EMERALD II consists of two chambers for reactive/non-reactive deposition and six cathode positions are available for sputtering targets. The cathodes are power supplied by RF and DC generators. Six substrates, which are equipped with an aligning magnetic field (0-100 Oe) to induce uniaxial anisotropy, can be placed on the turntable of the EMERALD II. For the deposition of $Ni_{80}Fe_{20}$, Ta and FeMn the RF diode sputtering at Ar pressure 1×10^{-2} mbar was used and for the deposition of Cu the DC magnetron sputtering at Ar 5×10^{-3} mbar pressure was applied. During deposition of $Ni_{80}Fe_{20}$ (free layer) and $Ni_{80}Fe_{20}/Fe_{50}Mn_{50}$ (exchange biased layers) the magnetic field of 100 Oe was applied to induce the mutually perpendicular uniaxial anisotropies. The Si-wafer substrates were

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cleaned by sputter etching before being covered by thick layer of Al_2O_3 using reactive sputtering technique.

The resonance vibration sample magnetometer (R-VSM) [7] was used for determination of the hysteresis loop. The magnetoresistance effect was measured by a dc-current with four-contacts method. The low and high angle diffraction were done by X'Pert MPD diffractometer from Philips.

3. Results

The low angle diffraction (scan θ-2θ) in the range $\theta<5°$ presents the reflectivity curve (Fig. 1), which inform us of the quality of the investigated multilayers system. The short period Kiessig fringes allow us to determine the total thickness of the stack Ta/NiFe/Cu/NiFe/FeMn/Ta and a long period oscillation of the thicknesses of particular sublayers (see Table 1). The surface- and interfaces roughness can be determined by the slope of reflectivity curve. In the case of the investigated spin valve system the average roughness was estimated about 5 Å. The deposition of Al_2O_3 buffer layer causes the strong reduction of the substrate roughness which is very important considering exchange coupling between magnetic layers. The best fit of the calculated curve to the experimental one was obtained after the change of the thickness and the density of the top layer which was oxidised due to the contact with atmosphere. It is assumed that the thickness of the top Ta layer increases and density decreases.

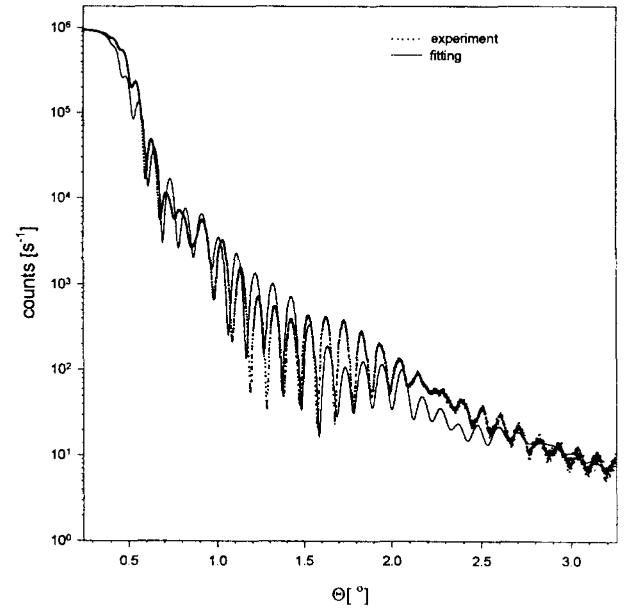

Fig. 1. Low- angle X-ray diffraction pattern (reflectivity curve) of the spin valve Si(100)-$Al_2O_3$1600Å/Ta48Å/$Ni_{80}Fe_{20}$70Å/Cu_{21}Å/$Ni_{80}Fe_{20}$70Å/FeMn100Å/Ta50Å.

Table 1. Fit parameters of the low-angle X-ray diffraction pattern (reflectivity) of the spin valve Si(100)-$Al_2O_3$1600Å/Ta48Å/Ni_{80}-Fe_{20}70Å/Cu21Å/$Ni_{80}Fe_{20}$70Å/FeMn100Å/Ta50Å

Type of the sublayer	Thickness after deposition [Å]	Fitting thickness [Å]	Roughness [Å]	Density [g/cm³]	Fitting density [g/cm³]
Al_2O_3	1600	1600	1	3.96	3.96
Ta	48	55.6	5	16.65	13.6
$Ni_{80}Fe_{20}$	70	70	5	8.68	9
Cu	21	21	5	8.92	8.92
$Ni_{80}Fe_{20}$	70	70	5.5	8.68	8.3
FeMn	100	111.3	5.5	7.63	8.8
Ta	50	77.5	6.9	16.65	12.87

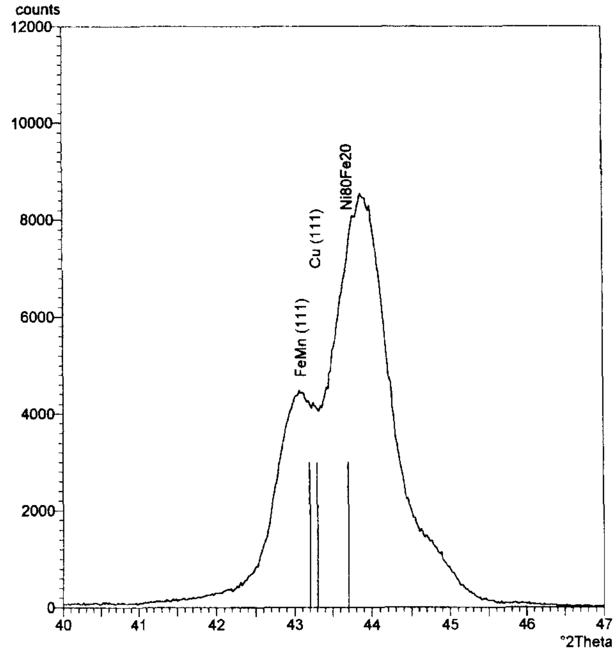

Fig. 2. High-angle X-ray diffraction pattern of the spin valve Si (100)-$Al_2O_3$1600Å/Ta48Å/$Ni_{80}Fe_{20}$70Å/Cu21Å/$Ni_{80}Fe_{20}$70Å/FeMn 100Å/Ta50Å.

The bottom Ta (50 Å) layer induces the (111) texture in magnetic and Cu sublayers (Fig. 2), which is known to be stronger with increasing the thickness of Cu [8]. For 20 Å thick Cu interlayer the separate (111) peaks for $Fe_{50}Mn_{50}$ and Cu (2θ=43.2° and 43.3° respectively) and $Ni_{80}Fe_{20}$ (2θ= 43.7°) can be distinguished, implying that the layers are strongly textured. Additionally, owing to high resistivity of Ta the sense current of spin valve element flows mostly through magnetoresistively active part of the spin valve NiFe/Cu/NiFe/FeMn.

The hysteresis loops of magnetization ($M(H)$) (Fig. 3a) and magnetoresistivity ($R(H)$) (Fig. 3b) consist of low and high magnetic field loops because the bottom NiFe (free layer) and the top NiFe (pinned layer) have mutually perpendicular oriented uniaxial anisotropies which cause reversal magnetization in different fields. The top NiFe (pinned layer) has unidirectional, uniaxial anisotropy due to the coupling with antiferromagnetic FeMn layers and the bottom NiFe has perpendicular uniaxial anisotropy to the former. The magnetic field oriented in the direction of the hard axis of free NiFe layer rotates the magnetization in response to low field signal while the pinned layer

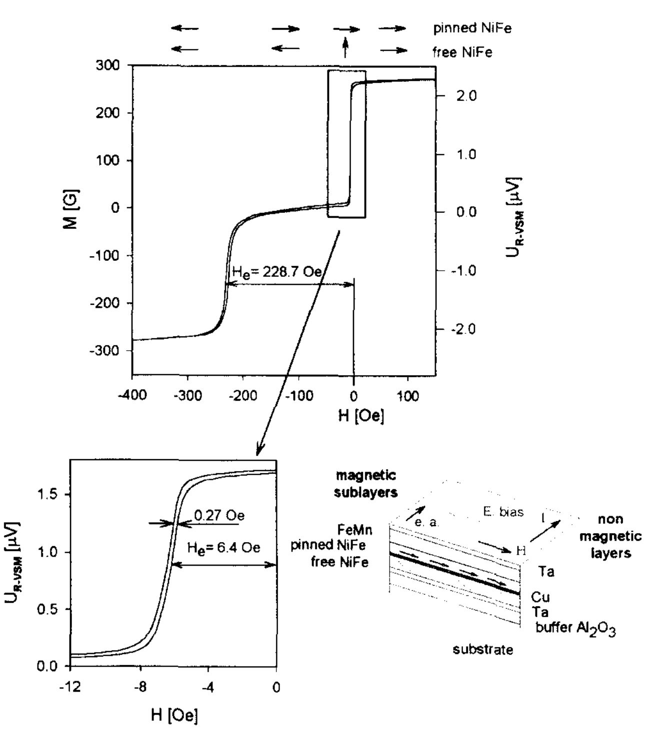

Fig. 3a. Magnetic hysteresis loop of the spin valve Si(100)-$Al_2O_3$1600Å/Ta48Å/$Ni_{80}Fe_{20}$70Å/Cu21Å/$Ni_{80}Fe_{20}$70Å/FeMn100Å/Ta50Å. abbreviations: e.a.-easy axis of free NiFe layer, E. bias-exchange bias axis of unidirectional, uniaxial anisotropy of pinned NiFe layer.

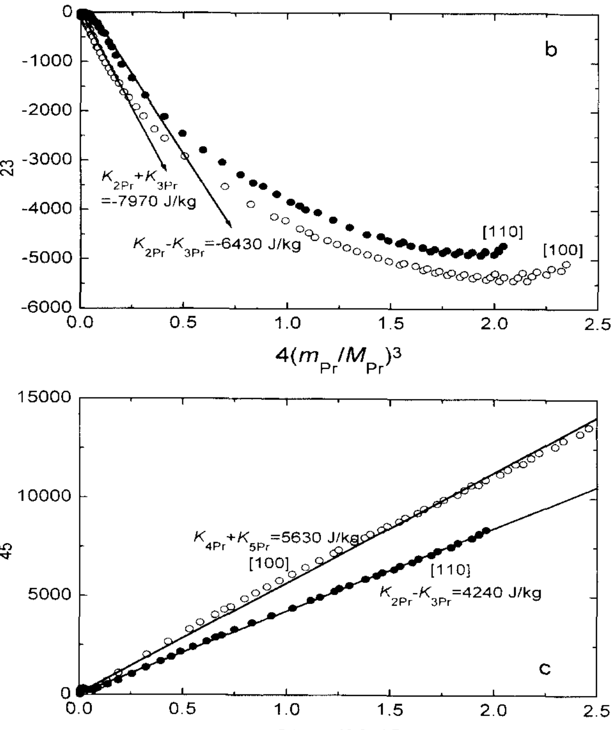

Fig. 3b. Magnetoresitivity hysteresis loop of the spin valve Si (100)-$Al_2O_3$1600Å/Ta48Å/$Ni_{80}Fe_{20}$70Å/Cu21Å/$Ni_{80}Fe_{20}$70Å/FeMn 100Å/Ta50Å.

exhibits hysteresis loop shifted to high field. Exchange coupling fields (indicated on (Fig. 3a)) between FeMn and pinned NiFe layer and free NiFe are H_{e1}=228.7 Oe and H_{e2} =6.4 Oe respectively. Exchange coupling field between FeMn and free NiFe from the application point of view should be as smallest as possible which can be achieved by the optimization of the thickness of Cu spacer.

The resistance of NiFe/Cu/NiFe system depends on orientations of magnetization angle and is described by equation

$$R=R_0+(\Delta R/2)\ [1-\cos(\theta_1-\theta_2)] \qquad (1)$$

where R_0 is the resistance when magnetizations of NiFe layers are parallel to each other and perpendicular to the current I, $\Delta R=R_{\uparrow\downarrow}-R_{\uparrow\uparrow}$, where $R_{\uparrow\downarrow}$, $R_{\uparrow\uparrow}$ are the resistances when magnetizations of pinned and free NiFe layers are oriented antiparallel and parallel, respectively, and θ_1 and θ_2 are magnetization angles of two NiFe layers relatively to the magnetic field.

The low magnetic field response signal of spin valve is linear as a function of magnetic field (Fig. 3b) in contrast to the parabolic signal response of conventional magnetoresistivity sensors, which what makes advantage for optimisation of high density recording heads.

4. Conclusions

The low-angle X-ray diffraction measurements of the investigated spin valve system demonstrate that the thicknesses of particular sublayers determined from reflectivity curve agree very well with thicknesses assumed in the process of deposition. The high angle diffraction experiments show that the magnetoresistively active layers NiFe/Cu/NiFe/FeMn have mostly (111) texture. The spin valve parameters determined from our measurements: magnetoresistance ratio $\Delta R/R$=3.58%, interlayer exchange coupling H_e=6.4 Oe and field sensitivity 1.15%/Oe are similar to the results obtained by other authors [3, 8].

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References

[1] J. A. Burg, L. Tran, M. Bhattacharrya, J. H. Nickel, T. C. Anthony, A. Jander, J. Appl. Phys. **79**, 4491 (1996).
[2] S. S. P. Parkin, Ann. Rev. Mater. Sci. **25**, 357 (1995).
[3] Ching Tsang, Robert E. Fontana, Tsann Lin, D. E. Heim, Virgil S. Speriosu, Bruce A. Gurney, and Mason L. Williams, IEEE Trans. Magn. **30**, 3801 (1994).
[4] B. Dieny, V. S. Speriosu, B. A. Gurney, S. S. P. Parkin, D. R.

Wilhoit, K. P. Roche S. Metin, D. T. Peterson and S. Nadimi, J. Magn. Magn. Mat. **93**, 101 (1991).

[5] T. W. Ko, J. H. Lee, B. K. Park, K. Rhie, P. W. Jang, D. G. Hwang, S. S. Lee, M. Y. Kim, J. R. Rhee, Electron Technology **31**, 70 (1998).

[6] W. Maass, B. Ocker, M. Scherer, N. Klind, Ch. Loch, Layers **6**, (1997).

[7] J. Wrona, B. Gob, M. Czapkiewicz, T. Stobiecki, Resonance Vibration Sample Magnetometer for Thin Films, Conf. Proc. ELTE' 97, vol. 2, p.574 (in polish).

[8] Th. G. S. M. Rijks, R. Coehoorn, J. T. F. Daemon and W. J. M. de Jonge, J. Appl. Phys. **76**, 1092 (1994).