Effect of Ir Content and Sputtering Conditions on Unidirectional Anisotropy of Ni-Fe/Mn-Ir Films Fabricated under the Extremely Clean Sputtering Process

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Abstract—**An effect of the Ir content and sputtering conditions of Mn-Ir films on the strength of exchange anisotropy was investigated in Ni-Fe/Mn-Ir layers fabricated under the extremely clean sputtering process. We found that the unidirectional anisotropy constant J_K monotonously increased with increasing the Ir content and decreasing the deposition rate of Mn-Ir films. The change of J_K against the deposition rate of Mn-Ir films is possibly caused by the quite slight changes of the microstructure of Mn-Ir films, which were undetectable with XRD.**

Index Terms—**Exchange anisotropy, Extremely clean sputtering, Ir content, Mn-Ir, Sputtering conditions**

I. INTRODUCTION

In order to satisfy stability and reliability of SpinValve heads against external disturbing fields, it has been strictly required to enhance the exchange biasing of ferromagnetic (F) layers induced by antiferromagnetic (AF) layers. Although Mn-Ir films deposited on Ni-Fe or Co-Fe films are known to induce strong unidirectional anisotropy, there still exist some physical problems concerning dependence of the exchange biasing on the Ir content and sputtering conditions [1][2][3]. The microstructural variance of AF films seems to be one of the main causes of the differences for the physical properties. In the present study, in order to clarify an effect of the Ir content and sputtering conditions of Mn-Ir films on the exchange anisotropy of Ni-Fe/Mn-Ir bilayers, we fabricated bilayers under the extremely clean sputtering process, which suppress the microstructural variance of metallic thin films [4][5].

II. EXPERIMENTAL PROCEDURE

By using a rf-magnetron sputtering method, quadrilayers were fabricated on thermally oxidized Si wafers at room temperature in a sequence of Substrate/Ta 50 Å/Ni-Fe 50 Å/Mn-Ir d_{AF}/Ta 50 Å. A magnetic field of 30 Oe was applied parallel to the film plane during deposition. The base pressure of the sputtering chambers was in the range of 10^{-11} Torr [6][7]. Highly purified (9N) Ar was used as a processing gas. Substrates were separated 200 mm from the 4" ϕ sputtering targets. Mn-Ir targets were 17at% Ir-Mn alloy with 12 Ir chips (size 5×5 mm, purity 99.9 %) which were symmetrically arranged in the eroded area of the target surfaces. The sputtering conditions were fixed for Ni-Fe layers and changed only for Mn-Ir layers by changing Ar pressure (0.75~40 mTorr) and applied power (30~200 W) to the target. Unidirectional anisotropy constant J_K was calculated as $M_s \cdot d_F \cdot H_{ex}$, where $M_s \cdot d_F$ is saturation magnetization of Ni-Fe layers per unit area and H_{ex} is an exchange-coupling field determined as a shift of the center of the M-H loop. M-H loops were measured for as-deposited films with a Vibrating Sample Magnetometer (VSM) at room temperature. The Ir content of Mn-Ir films, x, was determined by X-ray fluorescence analysis. The microstructure of films was analyzed by X-ray diffraction (XRD).

III. RESULTS AND DISCUSSION

A. *DEPENDENCE OF J_K ON Ir CONTENT AND SPUTTERING CONDITIONS OF Mn-Ir FILMS*

Fig. 1 shows dependence of J_K and the Ir content, x, on the sputtering conditions of Mn-Ir films, where d_{AF} was fixed at 100 Å. J_K and x increase with increasing gas pressure (Fig. 1a). In contrast, as power increases, J_K decreases but x

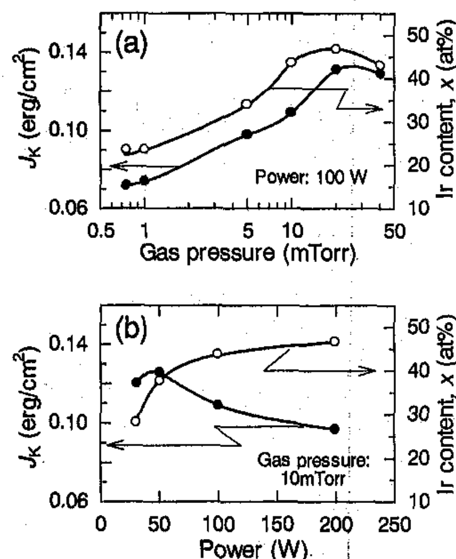

Fig. 1 Dependence of J_k and Ir content, x, on (a) gas pressure and (b) power in sputtering of Mn-Ir films.

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increases (Fig. 1b). To explain the dependence of J_K on the sputtering conditions, we have to take into account other factors besides the Ir content. Fig. 2 shows a contour map of J_K as a function of x and the deposition rate for the quadrilayers with d_{AF} =100 Å. We found J_K increases monotonously with increasing x and with decreasing the deposition rate. J_K, which was 0.068 erg/cm^2 at x = 28.5 at% and the deposition rate of 2.57 Å/s, reaches 0.141 erg/cm^2 at x=41.3 at% and the deposition rate of 0.06 Å/s. Dependence of J_K on sputtering conditions (Fig. 1) is represented as two kinds of dotted lines in Fig. 2. Along the broken line (increasing power), J_K decreases with increasing x. On the other hand, along the one-dot dashed line (increasing gas pressure), J_K increases with increasing x. In the former case, deposition rate increases with increasing x, whereas it decreases in the latter case. Namely Ir content dependence of J_K is variable depending on the behavior of deposition rate. Thus we can say that the chaotic dependence of J_K on x and sputtering conditions of Mn-Ir films previously reported [1][2][3] is due to the lack of considering the deposition rate.

J_K is known to change depending on d_{AF} [8]. In order to clarify the justness of the contour map, d_{AF} dependence of J_K was examined for two typical conditions, which correspond to the maximum and minimum values of J_K in Fig. 2. Fig. 3 shows d_{AF} dependence of J_K and H_c for Ta 50 Å/Ni-Fe 50 Å/Mn-Ir d_{AF}/Ta 50 Å films. J_K arises at around 30Å of d_{AF} and then increases gradually to be saturated at around 50Å of d_{AF} in both conditions. At the same time, H_c takes a peak at around 30 Å of d_{AF} in both conditions. According to Mauri et al. [8], d_{AF} at which J_K arises and H_c takes a peak is defined as the critical thickness, below which the exchange anisotropy vanishes. Fixed d_{AF} of 100 Å in the present study

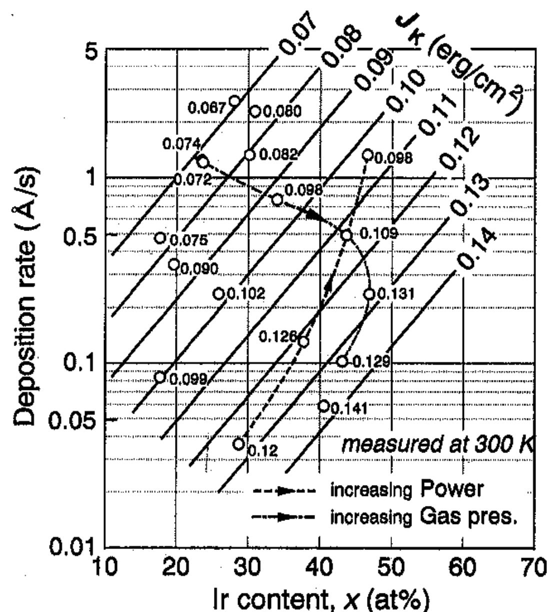

Fig. 2 A contour map of J_k as a function of Ir content and the deposition rate of Mn-Ir films

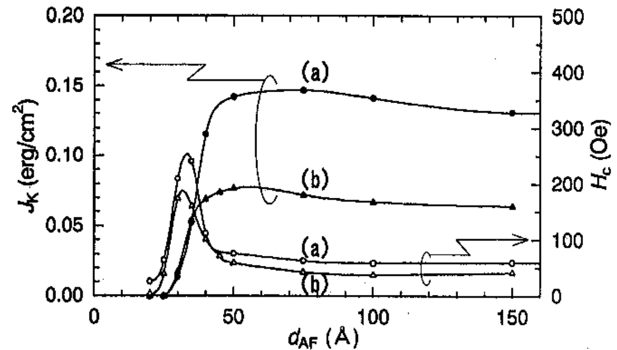

Fig. 3 Dependence of J_k and H_c on d_{AF} for Ni-Fe 50Å/Mn-Ir d_{AF} films. Ir content and sputtering rate of Mn-Ir films are (a) 41.3 at%, 0.06 Å/s, and (b) 28.5 at%, 2.57 Å/s.

is sufficiently larger than the critical thickness; thus each J_K shown in Fig. 2 is regarded as a saturated value.

The change of J_K against Ir content, x, is naturally thought to be caused by the changes of intrinsic physical quantities of Mn-Ir, such as Neel temperature [9], magnetic anisotropy energy, exchange-coupling J at the F/AF interfaces, etc. However the changes of J_K against the deposition rate are not simply attributed to the intrinsic physical properties of Mn-Ir. In order to examine the correlation between the change of J_K and the microstructure of AF films against the deposition rate, structural analysis was carried out by XRD.

B. STRUCTURAL ANALYSIS

Fig. 4 shows the changes of XRD profiles of Ta 50 Å/Ni-Fe 50 Å/$Mn_{1-x}Ir_x$ 100 Å/Ta 50 Å films as a function of Ir content x, measured (a) and calculated (b) by using a step model [10][11]. For the calculation, the preferred orientations in each layer were assumed to be (002) for Ta (β-phase), (111) for Ni-Fe (disordered fcc), and (111) for Mn-Ir (disordered fcc), respectively. Lattice spacings used for the calculation were determined from the experimental values for respective thick films: 2.658 Å for Ta, 2.055 Å for Ni-Fe, and 2.134+0.1345 x Å for $Mn_{1-x}Ir_x$. The measured profiles qualitatively agreed with the calculated ones, meaning that films prepared in the present study have almost ideal crystal structures like those assumed in the calculations. Although the effect of interference of diffracted X-ray from the very thin layers appears in the profile, we can clearly recognize a diffraction peak from Mn-Ir (111) planes at around 48 ~ 49 degrees of 2θ. From these profiles, peak intensity, I, lattice spacing, d, and grain size, D, were determined and shown in Fig. 5 for Mn-Ir as a function of x. d was calculated from 2θ values of Mn-Ir (111) peaks, and D was calculated from FWHM of diffracted peaks using Scherrer's formula [12]. In Fig. 5, we can see qualitative agreement between the measurement and the calculation for the above three characteristics. The discrepancy in d and D is possibly caused by the interference of X-rays diffracted by very thin films. With increasing x, I and d increase, while D decreases. The important point to be noticed in Fig. 5 is little

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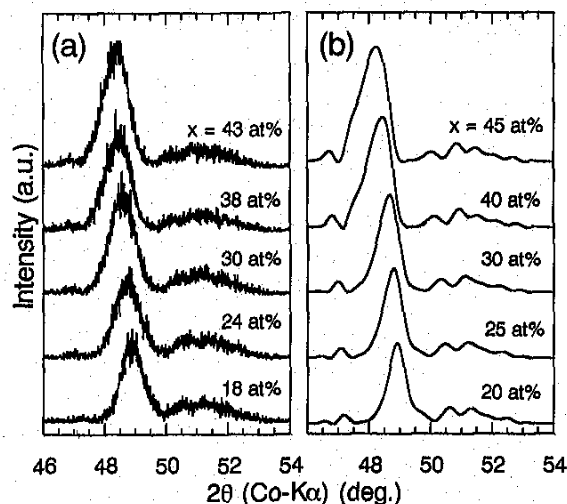

Fig. 4 Changes of (a) measured and (b) calculated XRD profiles of Ta 50 Å/Ni-Fe 50 Å/$Mn_{1-x}Ir_x$ 100 Å/Ta 50 Å films as a function of Ir content x.

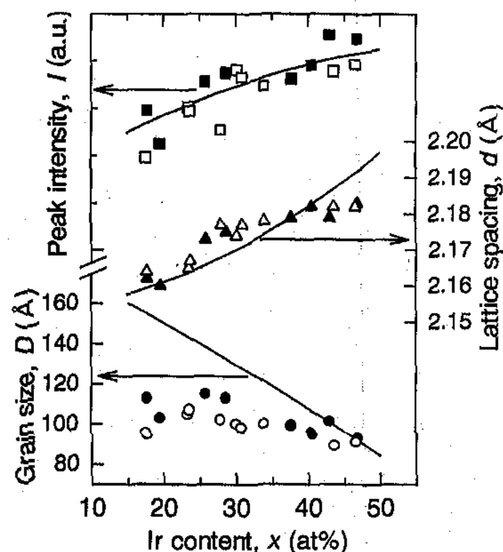

Fig. 5 Changes of diffracted intensity, I, lattice spacing, d, and grain size, D determined from Mn-Ir (111) peaks, as a function of Ir content, x. Filled symbols correspond to the films deposited under the higher rate (≥ 0.4 Å/s) of Mn-Ir film; open symbols represent the lower one (< 0.4 Å/s). Solid lines correspond to the calculated profiles.

difference between the values of the specimens having small J_K (filled symbols) and larger one (open symbols). Filled symbols correspond to the films deposited under the higher rate (≥ 0.4 Å/s) of Mn-Ir film; open symbols represent the lower one (< 0.4 Å/s). Here 0.4 Å/s is the middle value of all the deposition rates of Mn-Ir films in logarithmic scale in the present study. Both marks show similar tendencies in Ir content dependence of all three characteristics. This result means that there are little microstructural changes in Mn-Ir films depending on deposition rate within the accuracy of XRD. However, in order to explain the change of J_K at constant Ir content, some changes of magnetic properties are indispensable. Thus we have to say at present that quite slight changes in microstructure of Mn-Ir films, undetectable with XRD, induced changes of some magnetic properties of Mn-Ir, such as magnetic anisotropy energy.

IV. Conclusion

We investigated the power and gas pressure dependence of exchange anisotropy induced in Ni-Fe/Mn-Ir layers fabricated under the extremely clean sputtering process. We found that the Ir content and the deposition rate of Mn-Ir films, which varied with sputtering conditions, strongly influenced the exchange anisotropy, and that the unidirectonal anisotropy constant J_K monotonously increased with increasing the Ir content and decreasing the deposition rate of Mn-Ir films in as-deposited films. The change of J_K against the deposition rate of Mn-Ir films is possibly caused by quite slight changes of the microstructure of Mn-Ir films, which were undetectable with XRD.

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