OBSERVATION OF THE DOMAIN STRUCTURES IN SOFT MAGNETIC $(Fe_{97}Al_3)_{85}N_{15}/Al_2O_3$ MULTILAYERS

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1. Introduction

Iron nitride alloy films prepared in the form of laminated $(Fe_{97}Al_3)_{85}N_{15}/Al_2O_3$ multilayers (Ml's) due to excellent soft magnetic properties and high saturation magnetization [1,2] are very promising materials for poles and shields in ultra high density thin film heads. The present work concerns the ferromagnetic (FM) coupling effect as a function of the thickness of Al_2O_3 spacers by analysis of the magnetic domain structure.

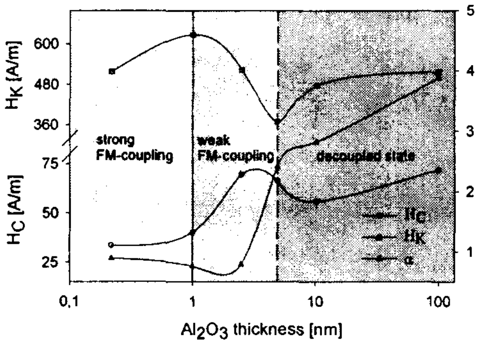

Fig.1 H_C, H_K and α vs. thickness of Al_2O_3 spacer.

2. Experiments

The RF sputtering technique and Si substrates buffered by 100 nm Al_2O_3 were used for deposition of $[(Fe_{97}Al_3)_{85}N_{15}/Al_2O_3]\times 16$ Ml's in Ar-N_2 gas mixture. The FM-sublayers $(Fe_{97}Al_3)_{85}N_{15}$ had a constant thickness of 26 nm and the thickness of the Al_2O_3 spacers was varied from 0.2 to 100 nm. A magnetic field (2 kA/m) was applied during deposition to induce uniaxial anisotropy. Recently published results of phase analysis show predominantly the α-Fe and the γ'-Fe_4N phase, regardless of Al_2O_3 thickness [2]. The coercivity (H_C) of Ml's is very small (40 A/m) and increases slightly with increasing thickness of Al_2O_3 (Fig.1). The uniaxial anisotropy field (H_k) increases from about H_k= 480 A/m at Al_2O_3 thickness of 0.22 nm to a maximum (H_k= 640 A/m) for 1 nm thick Al_2O_3. Above 10 nm thick Al_2O_3 the uniaxial anisotropy field is approximately constant ($H_k \approx$ 480 A/m) (Fig.1). The angular dispersion (α) of easy axis is small ($\alpha \approx 0.8^0$) in the range from 0.22 nm to 2 nm and then increases achieving $\alpha = 3.8^0$ for 100 nm (Fig.1). The saturation of magnetization is constant ($J_S \approx 1.6T$) and independent of thickness of Al_2O_3.The system for the observation of the magnetic domain structure, in the real time, using Kerr microscope was in [3] described in details.

3. Results and discussion

Depending on the thickness of Al_2O_3 different stages of FM-coupling were observed. For the thickness of 0.22 nm and 1 nm the strong FM-coupling was observed which led to: very soft magnetic samples, closed and linear hysteresis in the hard direction, very small dispersion of magnetization ($\alpha = 0.7^0$) and rectangular hysteresis loop in easy direction with $H_C \approx 40$ A/m. In consequence infinitely long domains develop, which coherently rotate (Fig.2) in external magnetic field ($H < 0.5H_K$). During magnetizing along the hard direction in the field $H > 0.5H_K$ parallel domain stripes and weak ripple structure from the top and bottom layer, respectively, are observed (Fig.3). Increase of the spacer thickness above 2.5 nm Al_2O_3 leads to weakening of the FM-coupling so that 360^0-walls are formed (Fig.4). The 360^0-wall may be generated if a 180^0-wall sweeps over pinhole, that is able to trap the Bloch line [4,5]. In a narrow angular range around the hard axis an irregular patch domain pattern develops (Fig.5a). This image can be explained qualitatively by reducing (in external field) the transversal component of magnetization as indicated in the sketch (Fig.5b) [6]. The transition from weak FM-

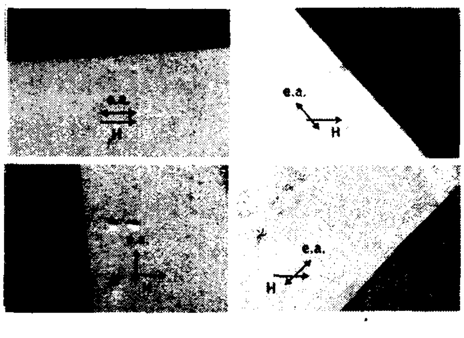

Fig.2 Infinitely long domains rotating in a field $H=0.13\ H_K$ for t = 0.22 nm of Al_2O_3. Size 275×179μm.

Fig.3 The ripple structure for t = 0.22 nm of Al_2O_3. Size 265×179 μm.

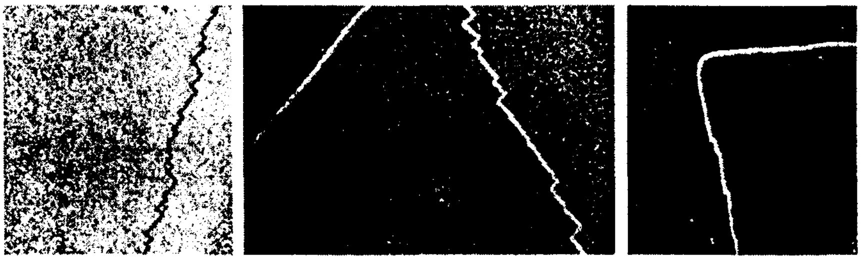

Fig.4 360^0–walls for t = 2.5 nm of Al_2O_3. The zig-zag is due to energy minimum. Middle picture size 265×179 μm, side pictures size 166×179 μm.

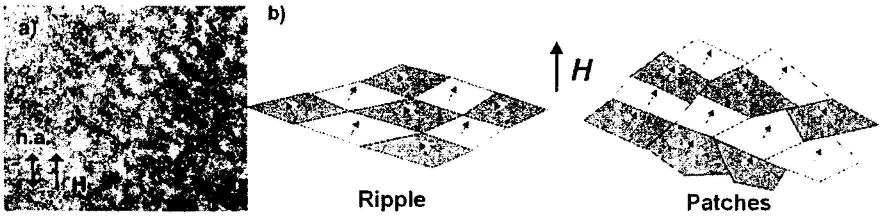

Fig. 5 a) Patch domain patterns for t = 2.5 nm of Al_2O_3, in field $H=0.91H_K$. Picture size 65×45 μm b) Ripple and patch images in MI's. Coupling by patches is weaker than by ripples because magnetic moments (indicated by white and black arrows, on the top and bottom layers, respectively) are not oriented in parallel.

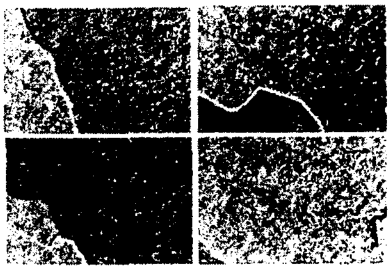

Fig.6 360^0- and 180^0–symmetric Nèel walls for t = 4.9nm of Al_2O_3. 360^0–wall separates equal contrast areas; a 180^0–symmetric Nèel wall is present when opposite contrast is seen. Size 265×179 μm.

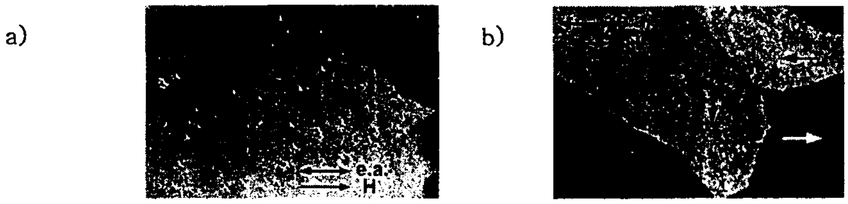

Fig.7 a) Irregular domain magnetized along the ea direction for t = 10 nm of Al_2O_3. Picture si 265×179μm. b) arrangement of 90^0–domains in t remanent state, for t = 4.9 nm Al_2O_3. Picture si 265×179μm.

coupling to decoupled state was investigated in 4.9 nm thick spacers of Al_2O_3. The patch domains effect in this case is very strong, therefore it is observed not only in the hard direction but also in between the hard and easy axis and additionally with 360^0–and 180^0–symmetric Nèel walls [6] (Fig.6). The strong influence of stray fields, in the case of very thick spacers (t = 10 nm), leads to irregular domains (Fig.7a) and arrangements of 90^0-domains when the sample is magnetized in easy direction (Fig.7b).

4. Conclusions

On the basis of magnetic domain analysis we conclude that strong FM-coupling, strong uniaxial anisotropy, very small dispersion of easy axis and coherent rotation of magnetization have been observed for the spacer thickness in the range of 0.22 nm $\leq t \leq 1$ nm. Weak FM-coupling, 360^0-walls and patch domain patterns (in hard direction) occur for spacer thickness of t=2.5 nm. The thickness of t=4.9 nm is characteristic for the transition from weak FM-coupling to the decoupled state where complex interlayer interactions and different domain walls (360^0– and 180^0–symmetric Nèel) have been observed. A totally decoupled state occurs for t>10 nm which leads to irregular domains in easy direction due to influence of the stray fields. Finally we conclude that multilayers of $(Fe_{97}Al_3)_{85}N_{15}$ (26 nm)/Al_2O_3(t) with $t \approx 1$ nm are very promising as novel material for high density thin films recording heads.

5. References

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