

AN INVESTIGATION OF GIANT MAGNETORESISTANCE (GMR) SPIN-VALVE STRUCTURES USING X-RAY DIFFRACTION AND REFLECTIVITY

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ABSTRACT

A giant magnetoresistance (GMR) multilayer spin-valve stack was investigated utilizing X-ray diffraction (XRD), reflectivity (XRR) and cross-section transmission electron microscopy (XTEM). X-ray reflectivity analysis indicated that layer thickness and density values were within 10% percent of the nominal values with the exception of CoFe and Cu layers, both of which possessed lower than nominal thickness and density. Interface roughness/interdiffusion increased progressively from the substrate (2 Å) to the surface (20 Å) of the samples, especially with the addition of the antiferromagnetic NiMn layer. The top Ta layer possessed a thin (20 Å), low-density oxide and the buried Ta/NiFe interface was deemed to be associated with a thin (18 Å) low density Ta layer at the interface. X-ray diffraction analysis showed that the NiFe/CoFe/Cu/CoFe layers possess a single, sharp {111}fcc/(002)hcp fiber texture. A complex structural evolution was found to be associated with deposition of the NiMn layer. XTEM confirmed results of X-ray characterization.

INTRODUCTION

The need for high-density magnetic storage media for computers has led to the development of sensitive magnetic read head snsors based on the giant magnetoresistance (GMR) effect observed in some metallic-multilayer structures. One such multilayer structure is a spin valve stack, comprised of two ferromagnetic (F) layers separated by a non-magnetic layer. The spin vectors of one of the ferromagnetic layers (sensing layer) are allowed to freely orient themselves while the spin vectors of the other ferromagnetic layer (pinned layer) are pinned. Spin vectors of the pinned layer are pinned by an adjacent antiferromagnetic (AF) layer via exhange coupling biasing. Exchange coupling biasing stabilizes the sensor by reducing Barkhausen noise induced by domain motion. The AF layer is required to produce a low coercivity field, a high exchange field and be associated with high corrosion resistance.

The ferromagnetic layers are generally Permalloy (Ni-19 w/0 Fe) and/ or Co-alloy (e.g. Co-10w/0 Fe). The non-magnetic spacer layer is generally Cu. AF layers employed have been equiatomic FeMn and NiMn. A typical spin valve stack might be Ta /NiMn /CoFe /Cu /CoFe /NiFe /Ta.

GMR in spin valve structures is associated with spin dependent scattering at interfaces. Thus, interlayer interfacial roughness is deemed to be important with regard to spin valve functionality. Investigators of multilayer behavior have found GMR to increase with increasing interface roughness.

EXPERIMENTAL PROCEDURE

A spin-valve stack with the nominal structure Ta (100 Å)/50 a/0 Ni-50 a/0 Mn (230 Å)/Co-10 w/0 Fe (45 Å)/Cu (25 Å)/Co-10 w/0 Fe (20 Å)/Ni-19 w/0 Fe (50 Å)/Ta (100 Å) on a thermally oxidized Si substrate was investigated. To facilitate the X-ray investigation, a progressive series of specimens (i.e. Si, Si/SiO_2, Si/SiO_2/Ta, Si/SiO_2/Ta/NiFe, etc.) were produced by sputter deposition.

High angle XRD scans were acccomplished with a Rigaku DMAX diffractometer operated in coupled θ:2θ mode with Bragg-Brentano diffraction geometry, utilizing CuK_α radiation. Low angle, specular XRR was performed generally consistent with the theory and techniques developed by others(1-4) utilizing a Bede D1 diffractometer and CuKα radiation.

XRR data were quantitatively analyzed using the Bede REFS software. This is an autofitting software routine that employs the recursive theory proposed by Paratt to simulate the X-ray intensity reflected from a layered structure. Interface imperfections (specifically interdiffusion and roughness) are taken into account in accordance with the theory developed by Nevot and Croce. A novel genetic algorithm was used to fit the simulations to the experimental data. A least-absolute difference (LAD) cost function was used to objectively assess the quality of the fit. Values for the thickness, interface width and density of each layer within the structure were obtained by minimizing the cost function.

XTEM was performed on a stack with all layers except the top Ta layer.

RESULTS AND DISCUSSION

XRD indicated very fine grained, (002) crystallographically textured β-Ta layers. Peak breadth measurements indicate a diffracting domain size normal to the film plane of 60 to 80Å, generally consistent with the nominal Ta film thicknesses.

As the NiFe, CoFe, Cu and second CoFe layers are successively added to the stack only a single major diffraction peak is apparent, Figure 1. This single diffraction peak is consistent with a strong {111}NiFe/(002)hcpCoFe/{111}Cu fiber texture and granular epitaxiality for this sequence of layers. All of the single major peak diffraction patterns are characterized by Laue satellite peaks on the low 2θ flank of the major peak. The d-spacing of the fiber texture peak decreases to a minimum with deposition of the

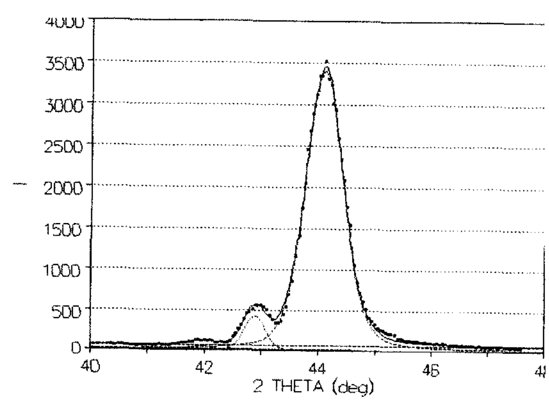

Figure 1

Cu film and then increases again with addition of the second CoFe film. A likely source of the variation in d-spacing is the state of in-plane film strain and stress. A decrease in d-spacing normal to the film plane could imply an increase in spacing in the film plane; i.e. an increase in the tensile character of the in-plane film stress. Thus, the observed variation in d-spacing would be associated with a decrease in compressive nature of the film stress to the minimum and an increase in compressive nature of the stress after the minimum.

When the NiMn AF layer is deposited two major diffraction peaks are added to the spectrum. A high intensity peak with d=2.093Å to 2.098Å can be associated with either the {111}disordered, fcc NiMn or {111}θ-NiMn plane, Figures 2. The second additional major peak, with d=2.062Å to 2.069Å, is intermediate to and convoluted with the NiMn peak and the major peak from the underlying layers that is described in the previous section. This intermediate peak cannot presently be rationalized except as a significant layer produced by interdiffusion of the NiMn AF layer and the underlying stack. Evidence for this conclusion is that the d-spacing associated with the fiber texture peak of the underlying layers remains essentially unchanged when the NiMn layer is deposited but the intensity of that peak decreases. In addition, the sum of the integrated intensities for the intermediate peak and the fiber texture peak approximately equal that of the integrated intensity for the underlying layers, suggesting that the phase associated with the intermediate diffraction peak grew at the expense of material from the underlying layers. Data derived from XRR are summarized in Figure 3. In general, as film layers are added to the stack details of the low angle regime of XRR spectra change most drastically.

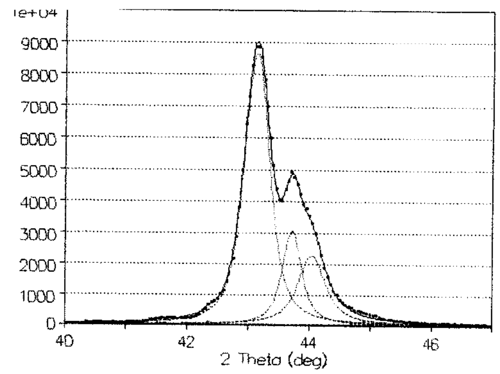

Figure 2

The assumption of a simple Ta/NiFe buried interface would not produce adequately good fits of experimental data. Introduction of a low density Ta layer between the bottom Ta layer and the NiFe layer was required to produce high quality fits of experimental data. Thus, in specimens with a buried bottom Ta layer that layer is approximately 85Å in thickness and of nearly theoretical density. A lower than theoretical density Ta layer beneath the NiFe layer is approximately 18Å in thickness. However, the total thickness of the buried Ta layer is close to nominal. The top or capping Ta layer is adequately modeled with a thin outer oxide layer (35.20Å). This indicates significant interdiffusion between the Ta and NiFe layers. The measured

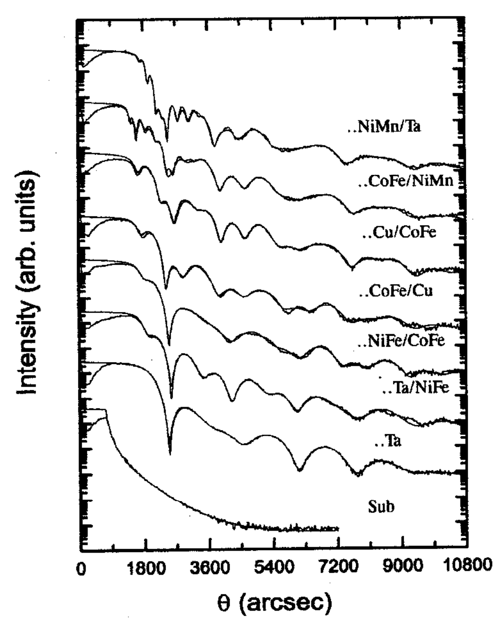

Figure 3

thickness of the NiFe layer (53.22Å) is quite comparable to the nominal. In addition, the NiFe layer was modeled at very close to theoretical density. Both CoFe layers possessed measured thicknesses (12.11 and 25.72Å) and modeled theoretical densities less than nominal, perhaps indicating incomplete film coverage. The measured thickness of the Cu layer (16.36Å) is significantly less than nominal but it may be adequately modeled at near theoretical density. The mean thickness of the NiMn AF layer (222.94Å) is very close to the nominal and the layer is modeled adequately at very close to theoretical density. The thinnest layers in the spin valve stack would seem to suffer from a lack of density and/or incomplete coverage.

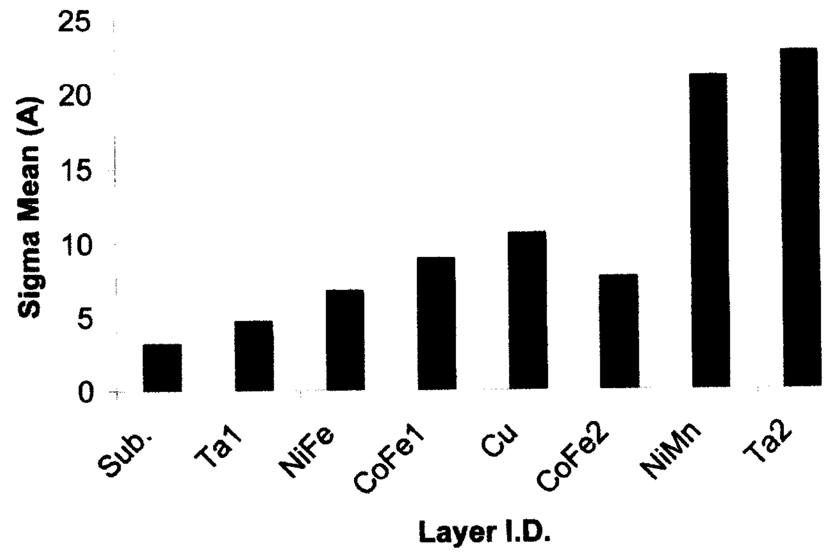

Figure 4

Figure 5

The mean interface roughness or width cumulatively increases with progressive deposition of layers, Figure 4. The interface roughness is especially large after deposition of the NiMn layer. Thus, roughness of the substrate is not merely mapped into the stack.

XTEM observations generally confirm those of XRR, Figure 5. A lower density Ta layer is evident at the buried Ta/NiFe nominal interface. Progressive increase in interfacial roughness is confirmed by comparing roughness at the substrate/Ta and Ta/NiFe interfaces with that of the top surface. Faulting parallel to the film plane is also noted. These faults were identified as twins via electron diffraction.

XRD and XRR would seem to be complementary analytical techniques for study of the evolution of spin valve film structures. XRD provides information on crystal structure, state of stress, crystallinity, grain size and preferred orientation. XRR provides information with regard to film thickness, film density and interface and surface roughness/ width, without regard to crystallinity of a film layer. The investigation showed that the deposition processes were well controlled with low specimen-to-specimen variability.

CONCLUSIONS

(1) Deposition processes were well controlled with low specimen-to-specimen variability.

(2) Layer thickness and density values were within 10% percent of the nominal values with the exception of the CoFe and Cu layers (thinnest layers), which both possessed lower than nominal thickness and density.

(3) Interface roughness/interdiffusion increased progressively from the substrate to the surface of the samples, especially with the addition of the NiMn layer. The top Ta layer possessed a thin, low-density oxide and the buried Ta/NiFe interface was deemed to be associated with a thin low density Ta layer at the interface.

(4) Fine grained (002) textured β-Ta layers were formed.

(5) The NiFe/CoFe/Cu/CoFe layers possess a single {111}fcc/(002)hcp fiber texture.

(6) A complex structural evolution was found to be associated with deposition of the NiMn layer.

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