Impact of Large Scale Substrate Roughness on Giant Magnetoresistive Multilayers

WILLIAM & MARY

S. M. Watson[1], D. M. Vlassarev[1], B. C. Holloway[2], and A. C. Reilly[1]

1.Department of Physics, The College of William and Mary, Williamsburg, Virginia 23187
2. Department of Applied Science, The College of William and Mary, Williamsburg, Virginia 23187

Introduction

Roughness affects the electronic transport and magnetic properties of multilayer thin films. Increasing interfacial roughness can either lead to an increase in giant magnetoresistance (GMR) through enhanced interfacial and spin-dependent scattering, or to a decrease due to increased magnetic coupling[1,2]. Recent work has explored the effects of roughness on GMR and modeling has shown that such roughness may cause the GMR to increase or decrease depending on several parameters such as the roughness amplitude and period and the electron mean free path[3]. GMR values can be enhanced, to some limit, by manipulating interfacial roughness of individual layers[4]. An increase in GMR connected to increased scattering at the interfaces has been shown to be directly related to vertical and lateral roughness amplitude[5].

In previous studies, the roughness was varied through a change in sputtering parameters (e.g., sputtering gas pressure, sputtering power, or superlattice thickness) and produced lateral variations < 10 nm and rms roughness less than 5 nm.

We are exploring roughness on a much larger length scale (lateral period > 10 nm, rms amplitudes > 5 nm), introduced through the substrate. Does such large scale, conformal roughness have detrimental or positive effects on GMR? This question is important for applications in which GMR multilayers are deposited on non-standard substrates and buffer layers such as flexible media[6].

Our results on pseudo spin valves of Co/Cu/NiFe show that rather than having a detrimental effect, a small increase in magnetoresistance is found with increasing roughness.

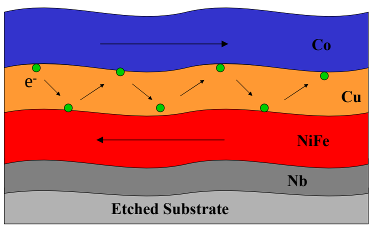


Figure 1. Interfacial roughness introduced through substrate roughness. Roughness can affect both electron scattering and magnetic layer (orange peel) coupling.

Magnetic Thin Film Preparation

- Substrates were amorphous boroaluminosilicate glass with a 1.1mm thickness
- Glass etched with a paste consisting of ammonium, sodium bifluoride, and <1% hydrofluoric acid
- Roughness determined by etch time
- Films grown with high vacuum dc Magnetron Sputtering
- Base pressure of 1 x 10^{-8} Torr
- Deposition rates were 1.0 Å/s in 2.8 mTorr of Ar
- Pseudo spin valve: 30Å Nb/ 50Å Cu/ 40Å $Ni_{81}Fe_{19}$/ 10Å Co/ 40Å Cu/ 40Å Co/ 20Å Cu/ 20Å Nb

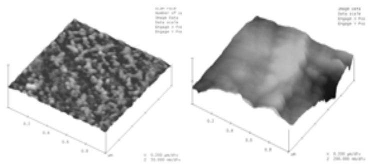
Sample Characterization

- Surface characteristics measured with Atomic Force Microscopy (Digital Instruments Nanoscope)
- Magnetization measured by Magnetooptical Kerr Effect (MOKE)
- Giant Magnetoresistance measured with the four-point probe method

Results and Discussion

AFM measurements show an increase in rms roughness of the films with increased etching time. Figure 2 shows AFM scans for two of the etched substrates. With increasing etch time, the substrates and films obtain larger peak roughness, larger rms roughness, and larger lateral dimensions for the roughness. Comparing all of the films, we observe a general increase in peak height with etch time (46.97, 28.8, 47.12, 96.78, 232.78 nm, respectively). The film deposited onto the substrate etched for 30s has lower roughness values due to an initial smoothing effect. ΔR/R is measured as R_{AP}-R_P/R_P, with current perpendicular to the applied field .

AFM Scans of Surface Roughness



- Figure 2. AFM scans showing film surface roughness. Left: 30s etch. Vertical scale is 50 nm. Right: 300s etch. Vertical scale is 200 nm. Lateral scale for both is 1 µm x 1 µm. AFM was in tapping mode.

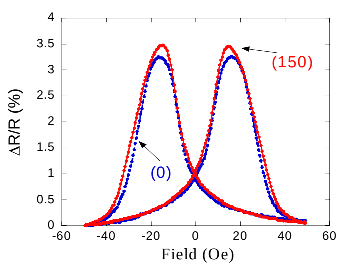
Roughness Effects on Properties

Etch Time (s)	RMS roughness (nm)	ΔR/R (%)	R (Ω)	Coercivity (Oe)
0	6.68	3.28	6.45	26.167
30	5.35	2.90	5.78	22.050
60	9.04	3.36	6.15	30.083
150	17.3	3.39	5.06	30.333
300	25.5	3.16	6.05	30.875

- Table 1. RMS roughness of films (measured by AFM), coercivity, and ΔR/R for substrates etched for different durations.

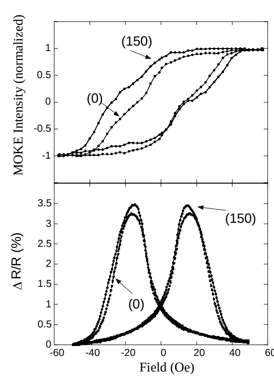
Figure 3 shows the GMR (ΔR/R) curves of two samples, one on unetched glass and the other on glass etched for 150s. The GMR is seen to slightly increase and the curve is seen to also slightly broaden. This broadening is also seen in the magnetization curves taken by MOKE (Figure 4). Figure 5 is a graph of ΔR/R and coercivity versus rms roughness. The coercivity is measured from the width of the MOKE curves and is taken as an indication of the Co layer coercivity. As the rms roughness increases, we observe an increase in GMR, which reaches a maximum value and then decreases. A similar trend in coercivity is also seen, although the coercivity levels off with higher roughness. This may indicate a relationship between increasing coercivity and GMR. This increase in coercivity could indicate a decreased coupling between the magnetic layers in the spin valve, leading to greater GMR, since the coupling of the layers hinders the achievement of the anti-parallel magnetic alignment.

Comparison of GMR curves for Etched and Unetched Films



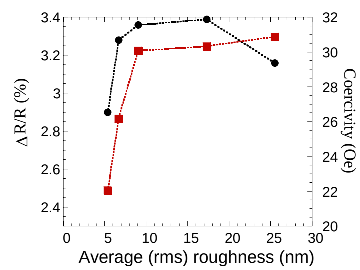
- Figure 3. GMR curves for pseudo spin valves on an unetched glass substrate (0, blue) and a substrate etched for 150 s (150, red).

Magnetization and GMR



- Figure 4. Comparison of magnetization (from MOKE) and GMR. Broadening is also seen in magnetization.

Relationship between roughness, GMR, and Coercivity



- Figure 5. GMR (ΔR/R, black circles) and coercivity (red squares) as a function of film rms roughness. Lines are a guide to the eye.

The effect of the substrate, and hence interfacial roughness, on the GMR of the spin valves can be due to several mechanisms. Past studies of fine-scale roughness (rms < 5 nm) have shown that increased interfacial roughness can increase GMR due to increased interface scattering (CIP) and increased spin-dependent scattering (CPP). The increase in coercivity may play a role. This could indicate a decrease in interlayer coupling. The roles of each of these mechanisms needs to be further explored.

Summary of Results

We have shown that introduction of large-scale roughness (up to lateral dimensions ~ 500 nm and rms roughness ~ 25 nm) does not have a detrimental effect on GMR. In fact, the GMR, initially, slightly increases with rms roughness.

Future Research

We are undertaking systematic studies of the effect of large-scale roughness, using substrates with randomly etched and also patterned roughness. We wish to know the length scale over which increased roughness can have a beneficial or null effect. The effect of large-scale substrate roughness on spin-dependent and interfacial scattering and magnetic coupling needs to be further explored.

References

1) M. C. Cyrille et al., Phys. Rev. B, 62, 3361 (2000), J. M. Colino et al., Phys. Rev. B, 54, 13030 (1996).
2) W. F. Egelhoff, Jr. et al., J. Appl. Phys., 82, 6142 (1997).
3) J. Alicea and S. Hershfield, J. Appl. Phys., 93, 7930 (2003)
4) E.E. Fullerton et al., Phys. Rev. Lett., 68, 859 (1992)
5) R. Schad et al., Euro. Lett., 44, 379 (1998)
6) S.S.P. Parkin, App. Phys. Lett., 69, 3092 (1996)

Deposition Chamber at W&M

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