Magnetic Properties of Uniaxial Synthetic Antiferromagnetic (USA) Films

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THE UNIVERSITY OF ALABAMA
Antiferromagnetic Coupled (AFC) Media

Advantages:

- Reduce effective Media’s Areal Moment Density (Mrt)
  \[ M_{rt\text{eff}} = M_{rt\text{top}} - M_{rt\text{bottom}} \]

- Decrease media thermal instabilities caused by superparamagnetic effect.

Anisotropy in AFC Sensor Applications

An in-plane anisotropy is preferred for sensor application, i.e. spin valve devices, in which the magnetization switching occurs by coherent rotation.

An obliquely sputtered Ta under layer can generated strong anisotropy in sequentially sputtered magnetic layers.

Structural Origin of Uniaxial Anisotropy

- AFM image of the as-deposited obliquely sputtered Ta underlayer which reveals the structural origin of the anisotropy.
- H.A is inside the Ta incidence plane.
- E.A is perpendicular to the Ta incidence plane.
Optimization of AFC Spacer Layer Thickness

- Ir and Ru were selected as spacer materials since Ru and Ir have the strongest antiferromagnetic coupling force.
- Our experimental results showed that Ru has a stronger coupling force through a broader thickness range than Ir. This agrees with the results reported by Parkin*.
Co/Ru/Co USA Films

Brillouin Light Scattering and GMR experiments have been measured by G. Gubbiotti, INFM, c/o Dipartimento di Fisica, Piazza dell’Università, Italy.

FMR measurement has been performed by Chengtao Yu, Miami University, Ohio.

Hk = 2K/Ms = ~ 1500 Oe

- Strong antiferromagnetic exchange coupling was observed in USA structures.
- Distinguishable Easy and Hard axis loops were also observed.

Ta(50Å)/Co(44Å)/Ru(6Å)/Co(44Å)/Ta(100Å)  Ta(50Å)/Co(44Å)/Ru(6Å)/Co(130Å)/Ta(100Å)
Polarized Neutron Reflectivity (PNR) Measurement of USA Structures

- PNR measurements confirm that when the sample magnetization changes from saturation to the antiferromagnetic state with reducing applied field, the moments in the thinner Co layer rotate to the opposite direction.

- PNR also confirmed the switching of the moments in both Co layers during magnetization reversal.
Coupling Behavior & Magnetron Gun Configuration

- Symmetric magnetron gun configuration produced zero field at sample position.
- We intended to add one more magnetron gun to make spin valves. The field at the sample position became nonzero.
- Nonzero Mr appeared due to the extra gun!
If we put in biquadratic coupling force with an external field, can we control it?
Perpendicular Field Effect

Experimental results

- Hard axis loops show Mr/Ms increases with an increasing perpendicular field.
- Energy minimization model confirms that the increase of J2 is the origin of the observed trends.
- It shows the magnitude of biquadratic coupling can be controlled with external field applied during deposition.
Perpendicular Anisotropy

- Brillouin light scattering experiment confirms perpendicular anisotropy in the bottom Co layer covered by 0.6 nm Ru and 10 nm Ta capping layer.

- Uniaxial in-plane anisotropy: \( K_u = (0.76 \pm 0.04) \times 10^6 \text{ erg/cm}^3 \)

- Out-of-plane anisotropy: \( K_s = (2.60 \pm 0.06) \times 10^6 \text{ erg/cm}^3 \)

Ref: G. Gubbiotti, et al. to be published.
Effect of Top Co Layer Thickness

Dependence of easy axis critical fields\( H_{c1} \) and \( H_{c2} \) on top layer Co thickness. The dotted line is a fit to an energy minimization model.

\[
H_{c1} = \frac{1}{2M_s} \left( \frac{1}{a} - \frac{1}{c} \right) (J_1 + J_2) + \frac{1}{M_s} \sqrt{\left[ \frac{1}{2} \left( \frac{1}{a} - \frac{1}{c} \right) (J_1 + J_2) + 2K_u \right]^2 + \frac{4K_u J_1 J_2}{c}}
\]


The data further confirms that the external field caused biquadratic coupling.
Conclusions

✓ USA films have been successfully made by oblique sputtering methods. The wavy structure of Ta underlayer shows the origin of the uniaxial anisotropy.

✓ Polarized Neutron Reflectivity confirms that the thin layer switches first during the reversal process.

✓ Biquadratic coupling can be controlled by applying a perpendicular field during the deposition process.

✓ Brillouin light scattering confirms that perpendicular anisotropy is caused by the applied perpendicular field.