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DEPOSITION EXPERIMENTS OF THIN METALLIC MULTILAYERS WITH MAGNETORESISTIVE PROPERTIES

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The GMR properties are controlled by the materials composition, selected geometry, and the structure of interfaces of the films. A series of experiments involving RF diode sputtering deposition of GMR multilayers was presented. The process conditions used to deposit GMR multilayers have been systematically varied and the dependence of magnetotransport properties upon the process environment has been studied. Another systematic series of experiments has been conducted to evaluate the dependence of magnetotransport properties upon composition and morphology of a multilayer structure utilized for magnetic sensing.

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1. Introduction

The discovery in 1988 of the giant magnetoresistance (GMR) effect, or the spin valve effect has stimulated a large number of studies in the field of magnetic multilayers in which the effect was found for the first time. This effect, already applied in reading heads for hard disk drives, offers many advantageous properties for sensor applications. These properties are: a large output signal, miniaturization opportunities and the possibility to make a 3600 angle sensor that is independent of field strength over a broad field interval [1,2]. The applications of this type of structure include compasses, swipe-card readers, wheel rotation sensors in ABS brakes, and current sensors for use in safety power breakers and electricity meters [1].

2. Experimental procedures

Three-inch diameter p-type silicon wafers were used as substrates. A porous silicon film was grown on top of each wafer using an electrolytic method. The porous silicon film acted as an electrically insulating and diffusion-inhibiting layer between the silicon wafer and the subsequently deposited metal film. The PS layer is a buffer, to give a good surface to grow on. The whole sample is deposited on a Si wafer, which is in fact many thousands of times thicker than the whole multilayer structure. The GMR active region will be only about 100 Å thick, with the whole structure being about 300 Å, on top of a 0.5 mm thick Si wafer. For some device applications it is preferable to use a wafer that has been grown a porous silicon layer. These PS surfaces are considerably rougher than bare Si wafers. The working gas was 99.99% argon and the temperature was room temperature (300 K). The background pressure and input power were independently varied keeping the film thickness constant.

The emergence of GMR nano devices has created a need for improved methods to manipulate the atomic-scale structure of the surfaces and interfaces created during the sputtering deposition of GMR materials [3,4]. Pinholes were formed when pure Cu was used as a conducting layer in the GMR multilayer structure. The use of additional Ag and Au promotes smoother interfaces (Ag acts as a surface surfactant) and prevents formation of pinholes [5].

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3. Experimental results

Theoretically, any defect that can change the trajectory of electrons, such as grain boundaries and dislocations will have an effect on GMR properties. These defects perturb the periodicity of the crystal lattice and may disturb the switching character of GMR materials. The density and distribution of the defects did not change with external magnetic field, so the scattering caused by these defects can be considered noise. The details are not well understood.

Table 1 shows the experimental results of MIS test structure electrical measurements of the in the absence of the magnetic field.

Table 1. The results of electrical measurements.

Contact metal	Porosity (%)	I_o (A)	φ_B (eV)	n	Inflection point
Ni	70 50	1E^{-16} 5E^{-14}	1.43 1.27	0.6 0.74	0.1 V 0.45 V
Permalloy	70 50	1E^{-12} 1E^{-11}	1.19 1.2	1.5 1.2	0.25 V 0.2 V
Fe	70 50	1E^{-14} 1E^{-11}	1.31 1.1	0.9 1.6	0.35 V 0.45-0.5 V

Current density, J0, ideality factor, n, and the height of the potential barrier, Fb, are determined from the forward I – V characteristics of the metal / PS contact. The n values are connected to the to (V< 0.1V) existing in the SiO_2 layer to the PS surface. The low values of n low levels of injection are due to a low interface density of states and a good stability of the PS layer.

The values of the ideality factor, n, to high levels of injection are due to: contact resistance of the ferromagnetic metal on porous silicon and the tunnelling of the carrier to the FE/PS interface. In our experiment, all the structures using Fe as a ferromagnet show a great dispersion of I –V characteristics, while in the case of Ni or Permalloy the I–V characteristics are grouped.

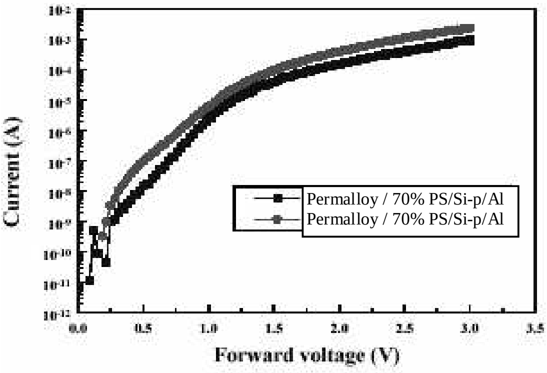

Fig. 1. The I–V forward characteristics of MIS structures with Permalloy on 70%PS.

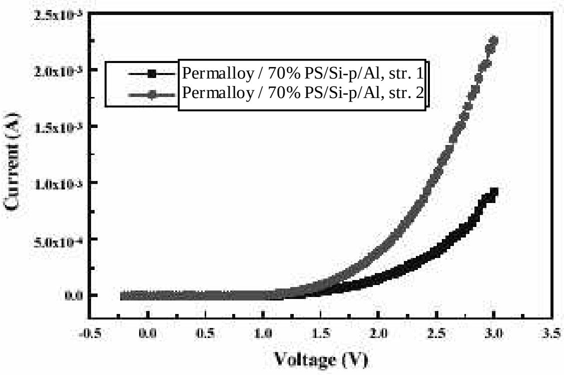

Fig. 2. The I–V characteristics of MIS structures with Permalloy on 70%PS.

The electrical measurements bring in front a high contact resistance because the FM/PS interface is a crowd of contact dots that lead to local injections of carriers and to the focus of the electric field. Among the ferromagnetic metals and alloys, Co gives the largest magnetoresistance, followed by NiFe, Fe and Ni. In our experiment, all the structures using, Fe as a ferromagnetic layer shows a great dispersion of I –V characteristics, while in the case of Ni or Permalloy the I–V characteristics are grouped (Fig. 1, 2). The type of the deposition process used and the architecture of the multilayer selected control the GMR properties in the first time [5]. As efforts to implement applications of grows, a methodology to link the controllable parameters of a deposition process and layer composition to film microstructures and properties is urgently needed. Since the sputtering process is used for the majority of devices, an understanding of the relationship between variables of the sputtering process and the structure and properties of resulting films is needed. Background pressure is one of the most important parameters to establish in a sputtering system. In a series of experiments, the input power was held constant at 200 W and the background pressure was varied from 10 mTorr (1.33 Pa) (the lowest achievable one without losing the discharge) to 50 mTorr (6.65 Pa). The deposition rate and composition for each target under the different background pressure had been previously measured and are shown in Fig. 3. Over most of the pressure range studied, the deposition rate decreased with background pressure. However, at very low pressure, the Ar+ ion population needed for sputtering drops (eventually to zero) and the deposition rate must in the low-pressure limit eventually drop to zero. The substrate was then moved under each target to deposit a multilayer structure. For a second series of experiments, the background pressure was held constant at 20 mTorr and the input power was varied from 50 to 350 W. The deposition rate increased with power. Fig. 4 shows that the variation was almost linear.

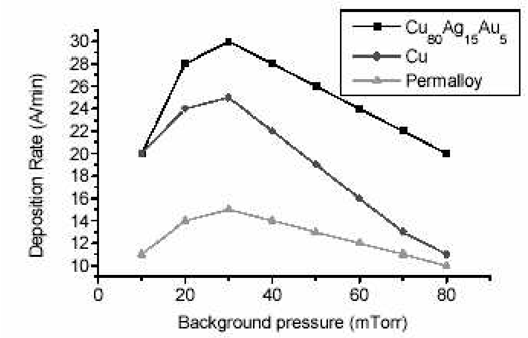

Fig. 3. The dependence of the deposition rate upon the background pressure for different metallic layers.

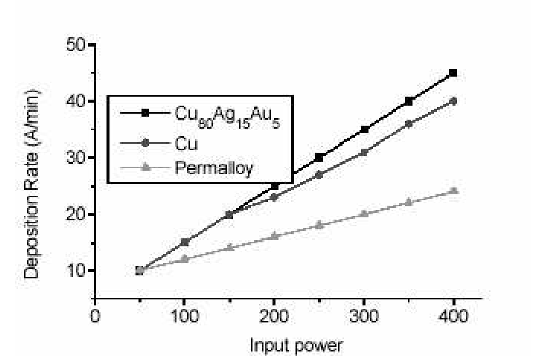

Fig. 4. The dependence of the deposition rate upon the input power for different metallic layers.

Fig. 5 shows the dependence of the measured GMR ratio upon the background pressure. The maximum GMR ratio was achieved at an intermediate background pressure (20mTorr). Fig. 6 shows the dependence of the measured upon the input power. The maximum GMR ratio was achieved at an intermediate input power (200W).

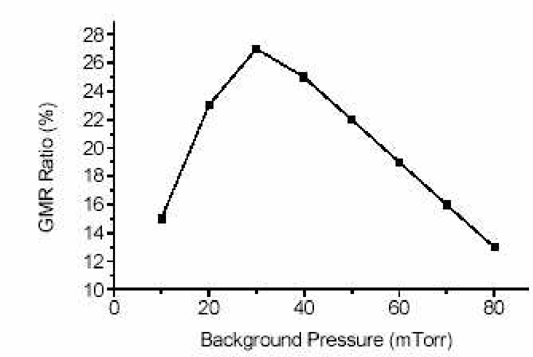

Fig. 5. The dependence of magnetoresistance ratio upon the background pressure for multilayers with a fixed CuAgAu layer thickness of 20 Å.

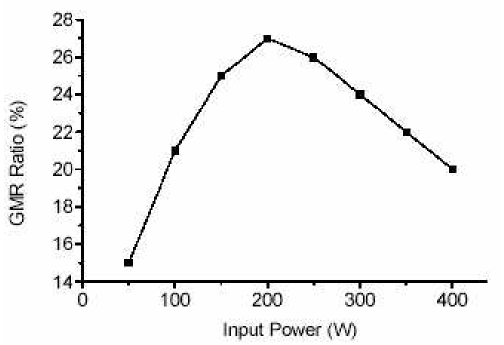

Fig. 6. The dependence of magnetoresistance ratio upon the input power for multilayers with a fixed CuAgAu layer thickness of 20 Å.

The background pressure and input power were independently varied keeping the film thickness constant. In a series of experiments, the input power was held constant at 200 W and the background pressure was varied from 10 mTorr (1.33 Pa) (the lowest achievable without losing the discharge) to 50 mTorr (6.65 Pa). For a second series of experiments, the background pressure was held constant at 20 mTorr and the input power was varied from 50 to 350 W.

4. Discussion

The films deposited at low pressure and high power were relatively smooth whereas hose deposited at high pressure and low power were very rough. The deposition rate was found to increase with the increasing power. The differences in morphology of the thin films deposited under different pressure and RF power are a result of variations in the metal impact energy. The initial rise in GMR ratio with power is in part a result of the surface smoothing associated with more energetic metal atom impacts. The drop in GMR as the pressure is increased beyond 20 mTorr also is linked to a reduction in surface mobility as metal atom energy decreases. Energetic Ar+ ions transfer their kinetic energy to the metal atoms and induce local heating. Increasing the Ar+ ions energy will reduce the surface roughness and increase the adatom mobility promoting larger column widths and smooth surfaces, but high energy Ar+ ions bombardment may also cause interfacial intermixing of the magnetic and nonmagnetic atoms. Both silver and gold have significantly higher mobility than copper atoms. Gold is incorporated in the lattice whereas silver tends to segregate (and concentrate) upon the free surface, enhancing its potency as a surfactant. Silver reduces the Ehrlich-Schwoebel barrier for copper promoting a step flow growth mode. Gold reduces also the Ehrlich-Schwoebel barrier, but its potency is less than that of silver due to its lower surface concentration [6].

These observations suggest that small alloy additions can be used to manipulate the energy barriers that fundamentally control atomic assembly during sputtering deposition, and provide a potentially powerful means of controlling the structure of thin films.

In view of the above observations, we undertook experimental studies on the effect of the deposition process by vacuum cathode pulverization on the multilayers with giant magnetoresistance. In particular, the study is focused on two key parameters of the deposition process: the RF input power and the gas pressure in the reactor chamber.

5. Conclusions

We studied the magnetotransport properties of a NiFe/Co/Cu80Ag15Au5/NiFe multilayer, made up of 12 thin magnetic and non-magnetic layers, deposited on silicon wafers, on the surface of which porous silicon of various densities has been grown. In the first set of experiments, the RF input power has been kept constant at 250W and the pressure in the reactor chamber has been varied from 10 to 50 mTorr. Under 30 mTorr, the domain of relatively low pressures, the deposition rate increases with increasing pressure, while above 30 mTorr pressure, the deposition rate decreases with increasing pressure. The highest magnetoresistive ratio has been observed at 30 mTorr pressures; the roughness of the copper surface is better if the deposition is performed even at a higher pressure. For the second set of experiments, the pressure in the reactor chamber has been kept at 30 mTorr, while the RF power has been varied from 50 W to 350 W. The deposition rate linearly increases with the RF power. The highest magnetoresistive ratio has been observed for a RF power of 250 W for the deposition of the intermediate non-magnetic layer; the roughness of the copper surface improves, if the deposition is performed at a lower RF power. Relatively smooth surfaces have been observed for layers deposited at low pressure and high power, while not so smooth layers have been observed for deposition conditions requiring high pressure and low power.

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