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A Magnetization and GMR Study on Multilayered Fe/Ag/Co Thin Film

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Abstract

Single layer Fe(20Å) and Co(20Å) and multilayered Ag(20Å)/[Fe(20Å)/Ag(40Å) /Co(20Å)/Ag (40Å)]x3 /Ag(20Å) films were prepared in UHV by magnetron sputtering technique onto the silicon substates. Films were determined to have polycrystalline nature through SEM examination. Magnetization measurements were made on single and multilayer films. Due to the polycrystalline structure of the films, rounded magnetization curves were obtained. The GMR effect showed a rounded behaviour which also is an indication of the polycrystallinity of the films. The GMR effect, measured in Fe/Ag/Co multilayer structure, was analyzed with the help of magnetization behaviour of the multilayer structure and magnetization behaviour of the single layer films Fe(20Å)and Co(20Å).

1. Introduction

Since the discovery of giant magnetoresistance (GMR) effect in magnetic multilayers, materials showing GMR have attracted interest due to their importance both for a fundamental understanding of the spin-dependent electron transport mechanism and for device applications. In recent years, multilayers composed of Fe, Ni ,Co and their alloys seperated with very thin buffer layers like Ag, Cu or Au become a major area of interest [1-8]. Magnetic layers interact antiferromagnetically and show significantly different magnetoresistance (MR) when small fields (typically 10-100 Gauss) are applied.

These structures yield promising sensors for magnetic read-write head applications as the effect manifests at small fields at room temperature. However if the spacer layer is made thick enough, multilayers don't interact ferromagnetically or anti-ferromagnetically. Such systems are called uncoupled systems yet still show GMR effect due to the coercive field differences of the layers. It is a well known phenomena, that the total hysteresis behaviour of a multilayer structure is, to a good extent, addition of the contributions from the layers that constitute the structure. The contributions from the layers can be used to calculate the GMR effect [5]. In this study, we report magnetization, and (MR) measurements of the polycrystalline [Fe(20Å)/Ag(40Å)/Co(20Å)]x3 multilayer film. In addition we calculated the GMR effect through hysteresis loops of the layers using single domain film and multidomain film approximations.

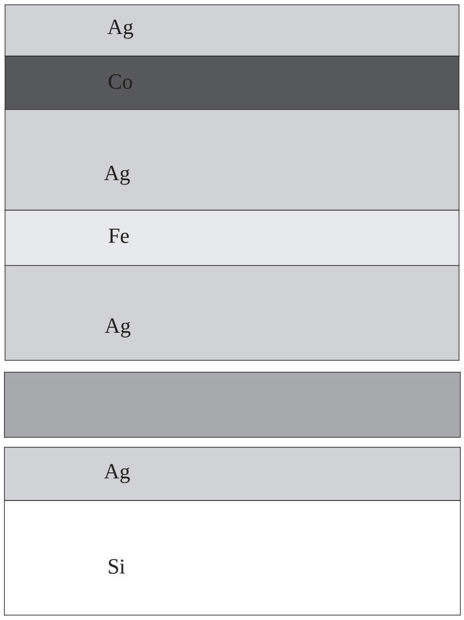

Figure 1. Cross section of the magnetic multilayer deposited on a silicon substrate.

2. Experimental Details

The films were grown on Si (100) substrates at room temperature, with a growth rate of 0.15 Å per second in UHV by DC magnetron sputtering. For the multilayer film Ag layers of 20Å thickness were used as buffer and top layers. The Ag spacer layer was 40Å thick to insure the absence of any magnetic interaction between layers (Fig. 1). The unit structure was repeated three times to obtain larger MR effect.Structural investigation was made by a SEM, which revealed the polycrystalline nature of the films. Grain structures of typical size 200-400Å were observed. Magnetization measurements were taken with a sensitive vibrating sample magnetometer [9] (Lake Shore 7300). During measurement, the magnetic field was parallel to the film surface. The rounded shape of the magnetization loops is interpreted to reflect the incomplete magnetic moment alignment of the polycrystalline film (Fig. 2). For the MR measurements, the stripe-shaped samples with dimensions of 100 $\mu m \times 3mm$ were prepared by lithography technique with current and potential leads attached to the springed contacts using silver-paint dots. The resistivity R(H) of the samples in the magnetic field was measured via standart in-plane geometry with current and magnetic field being parallel to each other in the film plane.

3. Calculation

Single Domain Film Approximation

This model assumes that layers of the film are single magnetic domains. According to this model, the moments point in any direction, but they stay in film plane because of the large shape anisotropy of the films. It is assumed that the magnetization at any magnetic field value is related with the saturation magnetization value of the single domain layers. It is found that this dependence can be explained as the rotation of total magnetic moment i.e. saturation magnetization vector. Magnetization measurement of a sample gives the total magnetization along the field direction. So the angle that the total magnetic moment makes with the magnetic field can be calculated from the magnetization measurements.

$M_{xy}(H) = M_{sat}\cos[\theta(H)]$.

Here M_{sat} denotes the magnitude of the saturation magnetization vector. As a first approximation, it can be assumed for a multilayered noninteracting structure that the magnetic moments of the layers behave in the same way as those of the separate films. Therefore, the magnetization curve of multilayer sample is simply the sum of the magnetizations of the separate Fe and Co films multiplied by an appropriate constant and the sum of the magnetization of the separate films can be fitted to the measured magnetization curve of the multilayer. Next, for the Fe(20Å) and Co(20Å) films, the angles between the magnetic moments and magnetic field can be obtained from these normalized magnetization curves . Finally, the MR of the film can be calculated by the following formula [7,8]:

$MR_{xy}(H) = G\sin^2\frac{\nabla\theta(H)}{2} = G\sin^2\left(\frac{\theta_1(H)-\theta_2(H)}{2}\right)$,

where G is the GMR coefficient which is a measure of the maximum achiaveble MR. Here, $\nabla\theta(H)$ is the angle between the magnetic moments of separate layers. So from measured magnetization curves of the layers, the MR curve of the sample can be calculated. Figure 3 shows the result of the MR measurement and the result of the above-mentioned calculation. All y coordinates are normalized values. Normalization is needed because the measured GMR effect is dependent many other parameters, one being the measurement geometry.

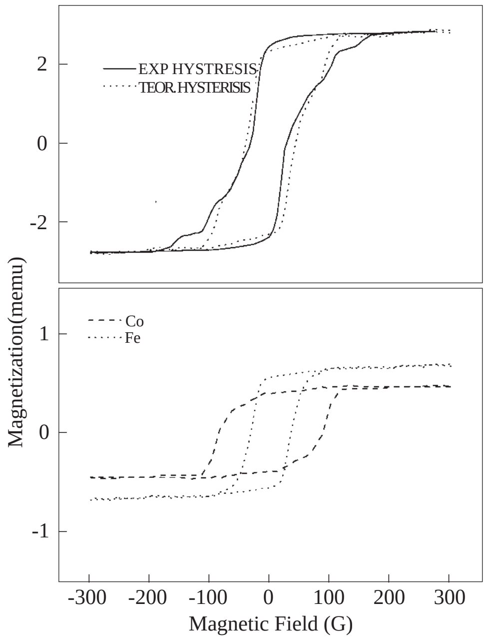

Figure 2. Room temperature magnetization measurements of Ag(20Å)/Fe(20Å)/Ag(20Å), Ag(20Å)/Co(20Å)/Ag(20Å) and multilayer films.

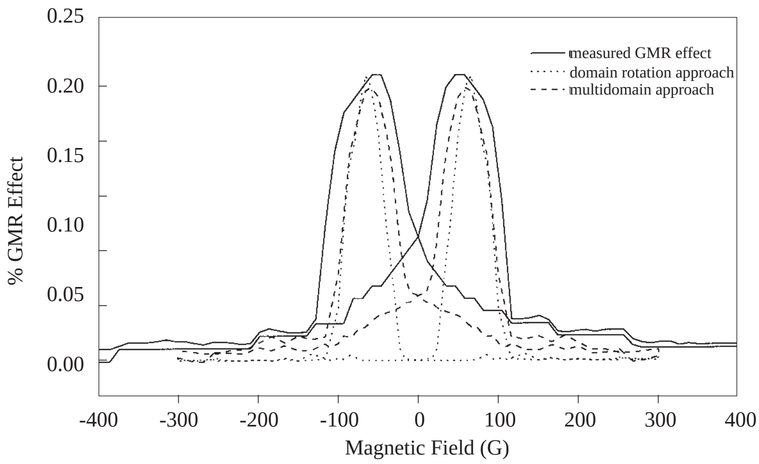

Figure 3. The result of the calculation using both both approaches. It can easily be seen that multidomain model better fits to the measured MR curve.

The Multidomain Film Approximation

According to this model each magnetic layer is composed of many, small magnetic domains. In the magnetic field each magnetic domain can only be parallel or antiparallel to the field. The magnetization measurements of a sample is only a measure of how many of the magnetic domains are parallel and how many of the magnetic domains are antiparallel to field. From the normalized magnetization curves of Fe and Co films the percent of aligned and antialigned domains can be calculated [5]: $M_{I\sin g}(H) = M_{sat}\left[f^{\uparrow}(H) - f^{\downarrow}(H)\right]$. It is shown that [7], if the GMR coefficient G is small, magnetoresistance calculation using the multidomain Ising model yields the following formula: $MR_{I\sin g}(H) \simeq G\left[f_1^{\uparrow}(H)f_2^{\downarrow}(H) + f_1^{\downarrow}(H)f_2^{\uparrow}(H)\right]$

Figure 3 shows the result of calculations using this approach. It can easily be seen that this model fits much better to the measured curve.

4. Results

We prepared the samples and measured the magnetization and MR of the films. The SEM of the films exhibited polycrystalline nature. Finally, the independent magnetization loop parameters of the layers were calculated using single domain and multidomain film approach. From those we calculated the MR behaviour. Calculated MR behaviour is in accordance with the literature [5] . In our case, films are polycrystalline and in each layer there are many grains, and in each grain there are magnetic domains minimizing the free energy of the layers. Calculations strongly supports these findings and assumptions.

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