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Microwave spectroscopic studies of obliquely deposited Co/Cr trilayers

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Abstract

Polycrystalline Co/Cr trilayers were grown by e-beam evaporation in ultra-high vacuum, with Co deposited at various oblique angles to the substrate. Microwave spectroscopic experiments were performed with the applied field in the in-plane and out-of-plane configurations to explore the resultant changes in anisotropy and interlayer coupling. The in-plane anisotropy, effective magnetisation and interlayer coupling strength are found to be greatly affected by the angle of Co deposition. In addition, it is found that samples deposited at intermediate angles exhibit absorption spectra which are more complicated than the two lines expected in a trilayer structure. This phenomenon is not fully understood at present, but may be due to the presence of Co atoms in the Cr interlayer. It can be concluded that the magnetic properties of these structures depend critically on the angle of deposition, and that the magnetic anisotropy and coupling can be modified by an appropriate choice of angle. © 1998 Elsevier Science B.V. All rights reserved.

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We report on microwave spectroscopic experiments undertaken on polycrystalline trilayer Co/Cr samples grown with Co deposited at various angles (φ) to the sample normal, in particular $\varphi = 0°$, $25°$ and $70°$. Samples were grown at room temperature by e-beam evaporation at a base pressure 5×10^{-10} Torr, with deposition pressures Co(5×10^{-8} Torr), Cr(2×10^{-8} Torr), on a substrate holder which can be tilted to the desired deposition angle. All samples are of the basic trilayer structure Si(111)/Co(200 Å)/Cr(15 Å)/Co(212 Å), with a correction being made to obtain the same thicknesses at each growth angle. The upper Co layer is 12 Å thicker than the lower as X-ray diffraction studies have shown that the top 12 Å layers are oxidised. A 15 Å interlayer was chosen as previous studies have shown that this thickness is conducive to antiferromagnetic coupling, and so should be more sensitive to any resulting changes. Microwave spectroscopy was performed at 16 GHz for in-plane experiments, and at 16.5 GHz for all other configurations. The magnetic field position of the resonance absorption line obtained from a thin single-film sample, at a given frequency (ω), depends upon the effective magnetisation (M_{eff}) of the sample. M_{eff} is the sum of the various anisotropy fields within the sample and the magnetisation of the material used. Vonsovskii [1] shows that the following equations can be derived for thin film samples with external field applied (1) in the sample plane and (2) perpendicular to the sample plane, where γ is the gyromagnetic factor, and H_{par} and H_{perp} are the positions of the resonance absorption line with the applied field in the parallel and perpendicular configurations, respectively:

$$(\omega/\gamma)^2 = H_{par}(H_{par} + 4\pi M_{eff}), \quad (1)$$

$$\omega/\gamma = H_{perp} - 4\pi N_{eff}. \quad (2)$$

Thus, any change in the effective magnetisation will alter the field position of the resonance line. The theory of Layadi and Artman [2] is used to measure the interlayer coupling between magnetic layers separated by a non-magnetic interlayer from the field separation and relative intensity of the two expected resonance absorption lines. Fig. 1 shows the variation of in-plane resonance field positions, for the three angles of deposition. It can be seen

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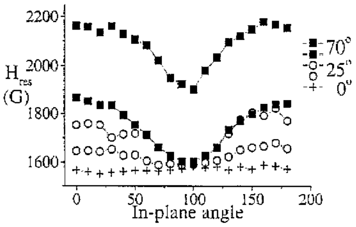

Fig. 1. Variation of in-plane resonance field position for the deposition angles indicated.

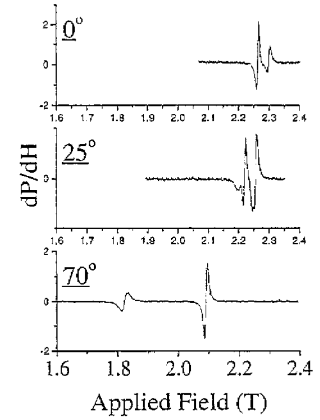

Fig. 2. First derivative of the perpendicular absorption spectra for the deposition angles indicated.

that the in-plane anisotropy is greatly enhanced by an increase in φ. In addition the two resonance lines move further apart due to the anisotropy contributions from the two layers diverging as φ increases. Fig. 2 shows the first derivative of the perpendicular absorption spectra obtained for the three angles of deposition. The appearance of the absorption spectra changes dramatically with φ. For deposition at normal incidence two absorption lines are obtained, as suggested by standard theory [2]. At $\varphi = 25^\circ$ the spectrum becomes complicated with at least four lines observable. This effect, though, has been observed before [3] and is attributed to Co atoms in the Cr interlayer. Only one resonance line is detected in our single-layer experiments, so we postulate further that the multipeak spectra must be related to the interlayer coupling, with the additional modes being due to either lateral variations in the interlayer thickness, or to a diffusion of Co into the Cr interlayer, which would effectively produce 'several' interfaces. At 70° the spectra reverts to the simple two line nature. The intensities of the two lines, obtained by integrating the differentials twice, are equal which suggests that the value of the interlayer coupling is zero. The different resonance fields can be ascribed to the two layers possessing different effective magnetisations. The lower line is the broader of the pair, corresponding

Table 1
Parameters obtained from microwave spectroscopic experiments

Deposition angle	In-plane anisotropy (± 5 G)	Effective magnetisation (± 20 G)	A_{12} (± 0.02 erg/cm^2)
0°	< 20	1320	− 0.08
25°	70	1350	0.17
70°	250	1052, 1198	0

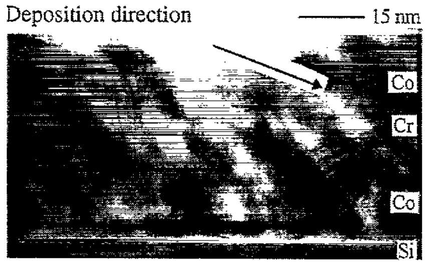

Fig. 3. Cross-section TEM micrograph of a trilayer deposited at 70°.

to the layer with the larger degree of inhomogeneity. Table 1 displays the magnetic parameters obtained from the microwave spectroscopic experiments. Fig. 3 shows a cross-sectional TEM (transmission electron microscopy) micrograph for a trilayer deposited at 70°. The picture is complicated, but the general canting of grains from top left to bottom right is clear. This effect provides a mechanism for the increased in-plane anisotropy due to the shape anisotropy of the grains. The variations in contrast shows that the grains are loosely packed, which explains the drop in effective magnetisation observed for this sample, while the lighter region running through the center of the picture is the Cr interlayer which is irregular and in some regions discontinuous. Thus, to conclude, increasing the angle of deposition of the Co causes a change in the microstructure of the magnetic layers, which in turn affects the interlayer coupling, effective magnetization and the in-plane anisotropy of the layers due to Co crystallites forming which are loosely packed and canted with respect to the sample normal. Further investigations are planned with a more complete series of samples, using TEM to map out the texture of the microstructure.

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