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To cite this version:
M. Luykx, C. Swuste, H. Draaisma, W. De Jonge. FERROMAGNETIC RESONANCE EXPERIMENTS ON Co/Pd, Co/Ni AND Fe/Pd MULTILAYERS. Journal de Physique Colloques, 1988, 49 (C8), pp.C8-1769-C8-1770. <10.1051/jphyscol:19888806>. <jpa-00229061>

HAL Id: jpa-00229061
https://hal.archives-ouvertes.fr/jpa-00229061
Submitted on 1 Jan 1988

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FERROMAGNETIC RESONANCE EXPERIMENTS ON Co/Pd, Co/Ni AND Fe/Pd MULTILAYERS


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Abstract. - Ferromagnetic resonance experiments are reported on Co/Pd, Co/Ni and Fe/Pd multilayers as function of layer thickness. It is found in all cases that the anisotropy is decreasing with decreasing Co or Fe layer thickness. A switching of the magnetic preferential direction occurs for the Co/Pd compounds when the layer thickness becomes smaller than 8 Å.

Introduction

Both from theoretical and technological point of view [1] the development of and research on magnetic multilayers is of considerable interest as these materials exhibit new interesting properties. For instance, in case of multilayered Co/Pd and Co/Ni films, magnetization measurements indicate a reorientation of the magnetization from in-plane to perpendicular to the plane for decreasing Co layer thickness [2].

In this paper we report on ferromagnetic resonance experiments which were performed to obtain an independent measure of the anisotropy. The samples were prepared at the Philips Research Laboratories by e-beam evaporation in UHV of the composing constituents at room temperature.

The FMR measurements were performed at room temperature in fields up to 1 T at frequencies of 9.5 and 20 GHz. Interpretation of the data was based on the conventional theory [3] which relates the following expressions to the resonance condition:

\[(\omega/\gamma)^2 = B^2 + 2BK/M_s (2\sin \varphi \sin \theta - \cos \varphi \cos \theta) + (2K/M_s \sin \theta)^2. \tag{1}\]

\[M_s \sin (\varphi - \theta) + K \sin (2\theta) = 0. \tag{2}\]

Here \(\varphi\) and \(\varphi\) is the angle between magnetization respectively external field \(B\) and film plane and \(M_s\) is the saturation magnetization. \(K\) contains all the contributions to the magnetic anisotropy i.e. shape dependent demagnetization anisotropy and intrinsic surface and volume anisotropy.

Results

Co/Pd multilayers and Pd/Co/Pd sandwiches. - Experiments were performed on multilayered films with Co layer thickness \(t_{Co} = 2, 4, 8, 10, 12\) and \(20\) Å and \(t_{Pd} = 27\) Å, \(36\) Å and \(45\) Å, and Pd/Co/Pd sandwiches with \(t_{Co} = 80, 40, 20\) and \(10\) Å and \(t_{Pd} = 200\) Å.

Figure 1 shows the anisotropy values for the multilayer systems for \(t_{Co} > 8\) Å fitting the data with equation (1). Although there is some scattering of the data, it appears that the overall agreement between FMR data and earlier reported magnetization data [4] is reasonable. However, the increasing linewidth of the observed uniform resonance mode indicates that there is an increasing magnetic disorder in the Co layers.

For multilayers with \(t_{Co} < 8\) Å only relatively narrow and strong signals were observed resembling the signals found in bulk Co films. The intensity of these signal was also strongly dependent on the "magnetic history" of the sample. These results can be explained by assuming that these multilayers consist of domains in which the magnetization is alternatingly normal to the film plane or in the plane.

In figure 2 the corresponding results for the Pd/Co/Pd sandwiches are shown. Using the phenomenological relation [5]:

\[t_{Co} K = t_{Co} K_v + 2 K_s \tag{3}\]

where \(K_v\) is the total volume anisotropy and \(K_s\) the surface anisotropy, we find \(K_s = 0.35 \times 10^{-3}\) Jm\(^{-2}\) and \(K_v = -1.08 \times 10^6\) Jm\(^{-3}\). These values for a Pd/Co/Pd sandwich are well within the range of anisotropy parameters which have been reported for multilayers prepared by sputtering or evaporation techniques [4].
Co/Ni multilayers. - Resonance experiments were performed on multilayers with $t_{Co} = 2, 4, 8, 12$, and 20 Å with $t_{Ni} = 12.2$ respectively 24 Å. In films with $t_{Co} > 4$ Å only one signal was found while in the other samples beside the main signal, satellites were observed. The intensity and linewidth of the main signal was considerably stronger, respectively smaller than in comparable Co/Pd films.

In figure 3 the results are shown for $t_{Ni} = 24.4$ Å. Assuming that the anisotropy can be written as:

$$DK = 2 K_s + t_{Co} K_{vCo} + t_{Ni} K_{vNi}$$  \hspace{1cm} (4)

where $D = t_{Co} + t_{Ni}$ and $K_{vNi}$ is the volume anisotropy of the Ni layers assuming that $K_{vNi}$ is only due to demagnetization ($K_{vNi} = -0.14 \times 10^6$ Jm$^{-3}$), this yields in case of $t_{Ni} = 12.2$ Å, $K_{vCo} = -1.00 \times 10^6$ Jm$^{-3}$ and $K_s = (1 \pm 1) \times 10^{-4}$ Jm$^{-2}$ and for $t_{Ni} = 24.4$ Å, $K_{vNi} = -0.83 \times 10^6$ Jm$^{-3}$ and $K_s = (1 \pm 1) \times 10^{-4}$ Jm$^{-2}$, respectively. From these values it is clear that in these compounds no switching of the magnetization can be expected.

For $t_{Co} < 4$ Å with the external field perpendicular to the film plane, extra signals were observed which probably arise from excited spinwaves. Applying the relation [6]

$$B_{res} = B_o - 2 A \mu_0 / M_s \cdot (n \pi / L)^2$$  \hspace{1cm} (5)

where $B_{res}$ is the observed resonance field, $B_o$ the resonance field of the uniform mode, $A$ an effective exchange constant, $n$ the modenumber of the excited spinwave and $L = t_{Co} + t_{Ni}$ we find for $A = 1.01 \times 10^{-11}$ Jm$^{-1}$. Given the values for the exchange constant in the bulk materials $A_{Co} = 1.30 \times 10^{-11}$ Jm$^{-1}$ and $A_{Ni} = 0.75 \times 10^{-11}$ Jm$^{-1}$ the description of the spinwave signals in terms of an effective, averaged exchange interaction seems appropriate.

Fe/Pd multilayers. - Resonance experiments were performed on multilayers with $t_{Fe} = 6, 4$ and 2 Å and $t_{Pd} = 18$ Å. The experimental results are given in figure 1. From figure 1 it is evident that the FMR data confirm the magnetization results also shown in this figure. Using equation (3) we find $K_v = -1.37 \times 10^6$ Jm$^{-3}$ and $K_s = 0.11 \times 10^6$ Jm$^{-2}$. Although $K_s$ in this case is also positive, a reorientation of the magnetization can not be expected for real layer thickness 2 Å.