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A Coupling Phenomenon Between the Magnetization of Two Ferromagnetic Thin Films Separated by a Thin Metallic Film—Application to Magnetic Memories

J. C. BRUYÈRE, O. MASSENET, R. MONTMORY, AND L. NÉEL

Abstract—A new type of magnetic interaction between two ferromagnetic thin films separated by a nonmagnetic film less than 500-Å thick show different types of interactions. The simplest coupling that exists between ferromagnetic thin films is caused by the demagnetizing field which tends to align the magnetization of the ferromagnetic materials in an antiparallel orientation. Fuller and Sullivan [2] and Spain [3], [4] have shown evidence for an interaction between the elementary domain walls. It is also well known that the thin films show an “orange-peel” surface topography. Néel [1] anticipated the existence of magneto-static interactions when a correlation exists between the interfacial topographies with regard to the ferromagnetic media. The anticipated coupling energy is of the order of 0.01 erg/cm² for an intermediate layer 100-Å thick and for wavelength irregularities of 400-Å and 40-Å amplitude. Since these three types of interactions are independent of the nature of the intermediate layer, there is no reason why it may not be an insulator.

The new type of coupling described below is observed only if the intermediate material is conducting and if it is less than about 500-Å thick for the films that have been studied.

Experimental Conditions

The multiple thin films are prepared by vacuum evaporation. The first layer deposited is a Permalloy type alloy (81 per cent Ni, 19 per cent Fe), between 1000-Å and 2000-Å thick, with an uniaxial anisotropy. The top layer is a cobalt—nickel—iron alloy having zero magnetostrictive

Results

Experiments at Room Temperature

Figure 2 gives the results obtained for intermediate Palladium layers. For thicknesses greater than 300 Å, the coupling is no longer measurable. For thicknesses less than 50 Å, the value of the coupling field \( h \) is such that the
difference between $H_e$ and $H'_e$ is less than $h + h'$. In this case, the hysteresis loops for the two magnetic layers in the easy direction are the same. Two distinct loops appear in the hard direction, however, but it is not experimentally possible to obtain a value of the coupling field. Moreover, if the thickness is less than 50 Å, there is a possibility of the intermediate layer becoming porous and hence, of quite different phenomena appearing.

Let $J$ be the magnetization of the Ni-Fe layer layer ($J = 900$ emu), $e$ its thickness (1800 Å) for $h = 6$ Oe, and let the coupling energy $E_c$ be 0.1 erg/cm², i.e., ten times the maximum energy anticipated by L. Néel [1] for magneto-static coupling.

The results for intermediate layers of chromium, silver, and gold are summarized in Fig. 3. Several series of experiments have been carried out, especially one using an alloy composed of 45 per cent Ni, 45 per cent Co, 10 per cent Fe, and another using 52 per cent Ni, 35 per cent Co, 13 per cent Fe [6]. The bulk spontaneous magnetizations of the two alloys are almost the same ($\pm 10$ per cent). It is to be noted that for a chromium thickness of 75 Å, the coupling strength is three times as great when the composition of the Co - Ni - Fe layer goes from 35 per cent, 52 per cent, 13 per cent to 45 per cent, 45 per cent, 10 per cent. Using gold or silver and an alloy consisting of 35 per cent, 52 per cent, 13 per cent Co - Ni - Fe, the coupling fields are weak and hence the results are scattered; the use of an alloy of 45 per cent, 45 per cent, 10 per cent always increases the coupling strength, and the results are more accurate. A linear decrease of the coupling strength with intermediate metal thickness is observed for the following metals: Au, Pd, Cr, Ag, In.

**Experiments at Varying Temperatures**

The variation of the coupling energy with temperature for a specimen having an intermediate layer of Palladium
75-Å thick is shown in Fig. 4 with the temperature varying continuously from $-180°C$ to $300°C$. A significant decrease of coupling energy with rise in temperature is observed. Similar experiments carried out using samples with intermediate layers of Cr, Ag, Au show a much slower variation with temperature.

It has also been observed that, for a sample showing no coupling phenomena at room temperature (the Palladium layer was thick: $>300$ Å), an appreciable coupling field appeared on cooling. At $-180°$ the measured coupling field was 1 Oe. There is no thermal hysteresis.

The observation of the rapid variation of coupling energy with temperature for Pd suggests that this phenomenon cannot be of a magnetostatic origin. In fact if it had been, it could only be explained by a decrease of the spontaneous magnetization or by a reversible modification of the layer structure.

**APPLICATION TO MAGNETIC MEMORIES**

A memory element consisting of a “reading” layer with a weak anisotropy field separated from a “memory” layer with a higher anisotropy field by an appropriate metallic layer can be made. After recording the information, a magnetic field pulse applied in the hard direction turns the “reading” layer magnetization perpendicular to the easy direction, while the “memory” layer magnetization is turned through less than 90°. At the end of the pulse, the memory layer magnetization returns spontaneously to its original position, bringing with it the “reading” layer magnetization, because the two magnetizations are coupled.

The interest of this type of memory element lies in its novel construction and use. In fact, the coupling energy can easily be adjusted to the desired value by changing the nature and thickness of the intermediate layer material. Finally, the fact that there is a “positive” coupling (that is, one which tends to bring the magnetizations of the two films parallel) allows the strip lines to be placed outside the memory element.

**REFERENCES**