Coupling phenomena observed in multilayer films composed of two ferromagnetic layers separated by a non-magnetic intermediate layer

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Summary of paper presented at the Conference

In order to re-examine the results of Maurain's experiments at the beginning of this century (Maurain 1902 a, b) we have prepared by vacuum evaporation a series of multilayer thin films. These consist of two ferromagnetic layers separated by a non-magnetic metal. If the intermediate layer has an appropriate thickness, between 50 Å and a few hundred ångströms, it is observed that there is an interaction between the magnetizations of the ferromagnetic layers, which we call positive, in the sense that it tends to align two magnetizations parallel (Bruyère et al. 1964 a,b, c). Two measurement techniques have been employed to measure this interaction: a measurement of hysteresis loop displacement, by Kerr effect (Bruyère et al. 1964 a, c) and a pulse technique (Bruyère et al. 1964 d).

We have observed two sorts of variation of coupling energy with thickness of the intermediate layer. The first is observed with films of NiFe-metal-NiFeCo. The coupling field appears to decrease linearly with increasing thickness of the intermediate layer for Au, Cr and Ag. This sort of behaviour is also observed with Pd (Bruyère et al. 1964 c). When the structure is NiFe-metal-Co the decrease is no longer linear but is rapid at first, and then becomes slower.

The variation of coupling has been studied in the temperature range −180° to 300°C. For Cr the coupling decreases slightly over the temperature range for all thicknesses of the Cr layer. This behaviour has been observed for different compositions of the high H_c film, in particular, two compositions of NiFeCo and pure Co. This behaviour is also characteristic of intermediate films of Au and of Ag, independent of the magnetic film composition.

When Pd is used as the intermediate film, the behaviour is strikingly different. The variation with temperature is much more rapid and the coupling disappears at a temperature which depends upon the thickness of the Pd film. The behaviour is the same if the hard film consists of Co, NiFeCo, Fe, or of several compositions of FeCo. Thus, the behaviour as a function of temperature appears to depend uniquely upon the nature of the intermediate layer. The unique temperature behaviour of the films with Pd, plus the fact that dilute alloys of ferromagnetic metals in Pd are ferromagnetic, suggests the production of such alloys by diffusion in this case. Experiments to verify this possibility are in progress.

For films with intermediate Cr, Au or Ag layers there are three possible explanations for the observed coupling behaviour. First, it is known that the surface topography of thin evaporated films is highly irregular. If there is a correlation between the topographies of the two magnetic films, there may exist a magnetostatic coupling tending to align the magnetizations parallel. However, the strength predicted by Néel (1962) for this sort of coupling is an order of magnitude lower than that experimentally observed. Another possibility is the existence of physical connections between the two magnetic layers produced by the passage of magnetic material either through holes or by grain boundary diffusion through the intermediate layer. Finally, there may exist a long range interaction between the magnetic films due to the polarization of conduction electrons in the intermediate film. Such a possibility has recently been considered theoretically (Dreyfus et al. 1964). In this connection, one might observe that the coupling phenomenon discussed here has never been observed for insulating intermediate films of more than 60 Å thickness.

In order to attempt to distinguish between the last two possibilities, some experiments have been undertaken with intermediate Au layers. Films with the structure NiFe-Au-NiFeCo have been evaporated and the coupling measured. The NiFe and NiFeCo have then been dissolved away with nitric acid, and the remaining Au film has been floated on to an electron microscope grid and examined by transmission electron microscopy and diffraction. For the thickest Au films for which coupling is observed there is no possibility of any holes larger than 15 Å. Diffraction indicates that all of the ferromagnetic constituents have been removed. Thus, if we wish to consider a physical connection it must be one produced by diffusion in openings of 15 Å or less in diameter, or along grain boundaries. Within these limitations, however, we are still unable at present to distinguish between the two possibilities.

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Discussion

W. D. Doyle (Univac)

Is the case of two films with no insulating intermediate layer well understood?

R. Montmory

When two films, for example NiFe and NiFeCo, are evaporated, one expects a coupling due to the direct exchange. The two films exhibit the same hysteresis loop, corresponding to the situation when the coupling fields are very strong. The perpendicular susceptibilities are somewhat different, and the values found are in reasonable agreement with values calculated using the exchange constant for Permalloy.

F. G. West (Texas Instruments)

Is it necessary to make the layered structure by multiple evaporation without exposure to atmosphere in order to observe the coupling?

R. Montmory

For films with the structure NiFe-Au-NiFeCo or NiFe-Ag-NiFeCo, if the film is exposed to air after the evaporation of the first NiFe layer, no coupling is observed. However, for films with the structure NiFe-Cr-NiFeCo or NiFe-Pd-NiFeCo exposure to air after the evaporation of the Cr or Pd film does not disturb the coupling. We have not yet made a systematic study of this effect.