THE DEPENDENCE OF THE UNIAXIAL MAGNETIC
ANISOTROPY IN EVAPORATED FILMS ON THE ANGLE
OF INCIDENCE

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The method of local ferromagnetic resonance and direct torsional measurements were used to measure the dependence of the magnetic anisotropy in permalloy films on the angle of incidence in a broad range of such angles. It was found that this dependence is not monotonic and that at larger angles of incidence the easy axis of magnetization is rotated. An interpretation of this phenomenon is proposed.

ЗАВИСИМОСТЬ ОДНООСНОЙ МАГНИТНОЙ АНИЗОТРОПИИ ТОНКИХ СЛОЕВ
ОТ УГЛА НАПАРИВАНИЯ

Методом локального ферромагнитного резонанса и прямыми крутильными измерениями была измерена зависимость магнитной анизотропии тонких слоев пермаллоя от угла наращивания в широкой области этих углов. Было найдено, что эта зависимость немонотонна и что при больших углах наращивания происходит поворот оси легкого намагничивания. Предлагается интерпретация этого явления.

INTRODUCTION

In 1959 Smith [1] and Knorr and Hoffman [2] independently published measurements from which it follows that when films of ferromagnetic metals (permalloy [1], iron [2]) are deposited obliquely a strong uniaxial anisotropy is formed with the axis of easy magnetization normal to the direction of the metal vapour stream.

Several possible mechanisms of the origin of this anisotropy are discussed in both original papers. For iron films Knorr and Hoffman considered the combined influence of the fibre axis structure [111] and of the anisotropic stress. A fibre axis structure of this type and anisotropic stress with a larger value in the direction normal to the plane of incidence (which was experimentally observed [3, 4]) lead however to anisotropy with the easy direction in the plane of incidence in disagreement with experiment, as was shown in a detailed analysis by Pugh et al. [5]. Moreover, the absolute values of the anisotropy constants calculated in this way are too small [1, 5]. In the papers by Smith et al. [4] and Pugh et al. [5] another interpretation of the origin of anisotropy caused by oblique incidence was proposed — that it is due to the anisotropic distribution of inhomogeneities in the microscopic structure of the film. Smith's model of chain structure in the direction normal to the plane of incidence [4] explains the magnitude and sense of the observed anisotropy by the difference in demagnetizing energies in this and the normal direction and also the dependence on the composition in Fe–Ni alloys by taking into considera-
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The tension the tensile stress along the structure. He also explains the origin of this structure during oblique deposition and the growth of anisotropy with increasing angle of incidence by the self-shadowing model. The existence of such a structure is also confirmed by other experiments, reported on in [4] and [5].

Of the other influences discussed in the literature, one cannot eliminate the effect of the presence of oxygen during the formation and ageing of the film. However, very little is yet known about this influence and its mechanism.

All the experiments performed so far showed the growth of anisotropic properties with increasing angle of incidence. Also the models of the origin of anisotropy explain only such growth. In the present paper a report is given on the results of measuring the magnetic anisotropy in a broad range of angles of incidence. These measurements lead to new results which for angles of incidence greater than 45° are not in agreement with existing interpretations of the origin of anisotropy.

**PREPARATION OF FILMS AND METHODS OF MEASUREMENT**

Films of 78-permalloy (78% Ni in the melt) were prepared for studying uniaxial magnetic anisotropy caused by the oblique incidence of metal deposited on a slide. The source was a resistance heated tungsten wire, the slides were glass discs 15 mm in diameter, unheated. The series of films with differing angle of incidence were deposited all at once in two geometrical arrangements. In arrangement A (Fig. 1a) the slides lay immediately next to one another on a line. In order to balance the difference in thicknesses of the near and far films, the near ones were successively covered with a movable diaphragm during deposition. In arrangement B (Fig. 1b) the slides were placed around the source so that the mean thickness and mean amount of heat incident from the source were the same for all the films. (However, both quantities

**Fig. 1a.**

Fig. 1. Diagram of deposition geometry. S denotes source of evaporation, M movable diaphragm, 1 to 9 location of slides. The plane of incidence lies in the plane of drawing, the direction of the linear source is normal to it. The largest and smallest angles of incidence are dashed.