Resonance Widths in Polycrystalline Nickel-Cobalt Ferrites

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The width of the ferromagnetic resonance has been measured at 10 000 Mc/sec in polycrystalline mixed ferrites of the composition $Co_\alpha Ni_{1-\alpha}Fe_2O_4$, with α between 0 and 0.04. The minimum line width is found for $\alpha=0.025$ at 20°C. This, as well as the variation of line width with temperature, can be understood on the basis of known single crystal properties and the following assumptions: (a) line width is a linear function of $|K|$; (b) crystal anisotropy is an additive atomic property.

SEVERAL papers[1–3] have been published recently on the crystal anisotropy of cobalt ferrite and of mixed ferrites containing cobalt. The points of interest here are the following: (1) cobalt ferrite has an exceptionally large crystal anisotropy and, uniquely among known ferrites, a preference for magnetization along the [100] directions ($K_1>0$); (2) Co^{+2} ions tend to occupy octahedral sites as do Ni^{+2} ions; (3) for either nickel or cobalt ferrite the anisotropy above room temperature is quite well described by a K_1 term alone, the magnitude decreasing smoothly to zero at T_c; (4) the Curie temperatures of the two ferrites are nearly equal and high (about 600°C). Under these conditions, one expects that a ferrite of the type $Co_\alpha Ni_{1-\alpha}Fe_2O_4$ will have a crystal anisotropy constant K_1 equal to the weighted algebraic sum of the values of the individual ferrites. In particular, a composition can be picked with $K_1=0$ corresponding to a certain α_0. For $\alpha<\alpha_0$, $K_1<0$; for $\alpha>\alpha_0$, $K_1>0$. Moreover, since $|dK_1/K_1dT|$ is greater for cobalt ferrite than it is for nickel ferrite, one expects the following qualitative behavior of K_1 of the mixed ferrite as a function of temperature: (a) $\alpha\ll\alpha_0$: $|K_1|$ decreases for all temperatures above 20°C; (b) $\alpha\lesssim\alpha_0$: $|K_1|$ increases to a maximum, then decreases to zero; (c) $\alpha>\alpha_0$: $|K_1|$ decreases to zero, increases again to a maximum, and finally decreases to zero.

We have attempted to observe evidence of such behavior by measurement of ferromagnetic resonance line widths at 10 000 Mc/sec in polycrystalline materials. We assume that line width is a linear function of $|K_1|$. Though this evidence is clearly indirect and can under some circumstances be obscured by such influences as porosity of the ceramic (which produces a large broadening), it does offer the apparent advantage of allowing one to work with materials of prescribed composition.

The results of room temperature measurements on two sets of specimens are given in Fig. 1. While only fair reproducibility is obtained from set to set, it seems apparent that there is a minimum in the region of $\alpha=0.025$. Line widths in this region are usually below 200 oersteds and occasional widths have been as low as 150. When one considers that polycrystalline nickel ferrite is found to have a line width of about 400 oersteds and that single crystals have been reported to

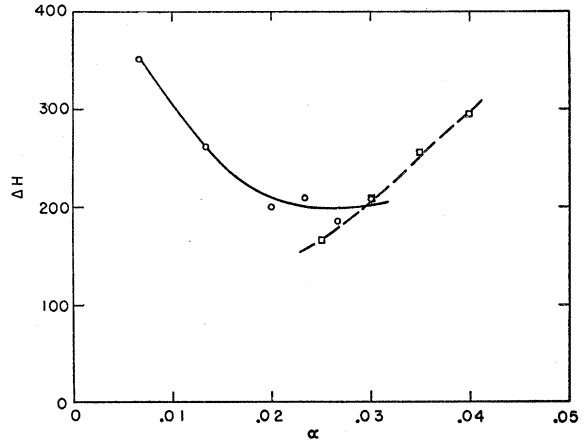

FIG. 1. Line width *versus* amount of cobalt substituted. The two sets of points correspond to specimens prepared under slightly different conditions.

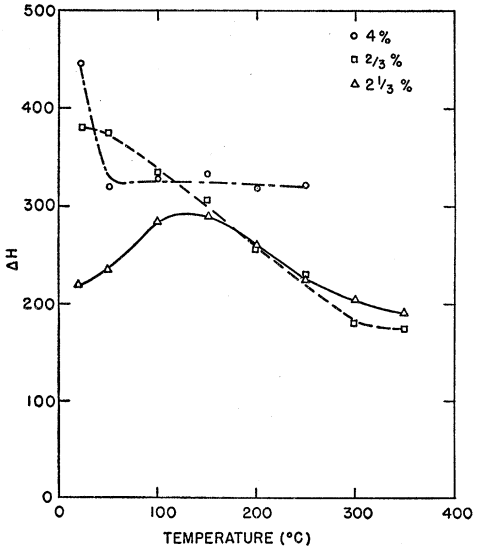

FIG. 2. Line width *versus* temperature for three different compositions.

[1] Bickford, Pappis, and Stull, Phys. Rev. **99**, 1210 (1955).
[2] Bozorth, Tilden, and Williams, Phys. Rev. **99**, 1788 (1955).
[3] H. Shenker, Ph.D. thesis, University of Maryland, 1955 (unpublished).

have lines about 75 oersteds wide,[4] it is apparent that a sizable decrease in K_1 has been obtained. An estimate of K_1 seems impossible because of our inability to take into account the effect of ceramic imperfections (pores, etc.) and of deviations from uniform distribution of cobalt in the specimen. From the papers of Bozorth[2] and Healy[4] we may take $+2\times10^6$ and -5×10^4, respectively, as the anisotropy constants of cobalt and nickel ferrites. These values, obtained for the most nearly stoichiometric crystals, do, of course, lead to a prediction of zero anisotropy for $\alpha=0.025$ if K_1 is considered a purely additive atomic property.

In Fig. 2, we show some typical results of measurements of line width as a function of temperature in the region 20°C to 350°C. The curves with $\alpha\ll\alpha_0$ and $\alpha\lesssim\alpha_0$ quite obviously behave as expected. The latter case is particularly gratifying in that it is in general very difficult to conclude that line width changes in polycrystalline materials are not due simply to such causes as changes in grain size. Since such contributions to line width will always decrease with M_s, an increase in width with temperature seems very strong proof that we are dealing with a case in which anisotropy is largely determining the width. The curves corresponding to $\alpha>\alpha_0$ show the initial precipitous decrease predicted but do not go to very low values. This may be due to nonuniform cobalt distribution. If this is the case, other ceramic procedures may help, and the narrowness of the line at this first minimum for $\alpha>\alpha_0$ can be used as a "quality control" of the process. This work is in progress.

We want to express our appreciation to Dr. S. L. Blum and Mr. J. Zneimer who supervised the preparation of the specimens discussed in this paper.

[4] D. W. Healy, Jr., Phys. Rev. **86**, 1009 (1952).

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Work Function of Lead*

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The work functions of twelve lead surfaces have been determined by measurement of their contact differences of potential with respect to barium reference surfaces of known work function. The lead surfaces were prepared by subjecting Hilger's spectroscopic lead to intensive outgassing followed by fractional distillation, redistillation, and deposition on glass targets. The barium surfaces were prepared by a similar standardized technique which yields surfaces constant and reproducible to 0.01 ev. Measurement was by the electron beam method, and the time lapse between deposition and measurement of a fresh surface was five seconds.

The contact difference of potential for Ba−Pb is found to be 1.48±0.01 v. The work function of lead, referred to a Ba work function of 2.52 ev, is then 4.00±0.02 ev. No drift of work function exceeding 0.01 ev was found on aging. Since the minimal time required for deposition of a monolayer of gas is large with respect to the metal deposition-measurement interval, it is concluded (1) that the film of gaseous contaminants adsorbed by a lead surface during equilibration is insufficiently dense to affect the work function, and (2) that the observed work function is probably characteristic of clean lead.

WE report here further results from a program of work function studies in which the contact difference of potential between the "unknown" metal and a reference metal of known function, barium, is measured in a barium gettered vacuum. Lead was selected for study because existing data for this metal were obtained under experimental conditions which are no longer regarded as adequate. The present measurements furnish evidence, not available heretofore, for the conclusion that lead surfaces which are initially clean undergo no detectable change of work function on prolonged exposure to the residual gas present in a sealed-off, barium-gettered tube.

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TUBE DESIGN. OUTGASSING PROCEDURES

The tubes, in which all the steps involved in the preparation and measurement of the lead and barium films were carried out, were similar to those employed for copper[1] except for the design of the lead vaporizers. Since molten lead alloys with metals of the tungsten group on prolonged contact, the first lead vaporizers (Fig. 1) were 45–60° silica cones set in close fitting conical heaters of 25-mil tungsten wire. The use of twin cones provides insurance against the loss of a tube from failure of a single heating element and increases the total lead charge to 4–5 grams. The lead was Hilger's spectroscopic standard material containing 0.0001% bismuth as the only impurity which can be estimated.

[1] P. A. Anderson, Phys. Rev. **76**, 388 (1949).