JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962
PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRAPHY, 1961, VOL. I

Magnetostriction Constants of $Mn_xFe_{3-x}O_4$ Ferrites

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Magnetostriction constants, λ_{100} and λ_{111}, of $Mn_xFe_{3-x}O_4$, where $x=0.1, 0.4, 0.6, 0.75, 0.85, 0.95$ and 1.05, were measured in the temperature between room temperature and about $-100°C$ by the strain gauge technique. λ_{100} is negative and λ_{111} is positive for all specimens. λ_{111} increases with decreasing temperature, except in the case of $x=0.1$ in which it decreases, like magnetite, at the temperature below $-50°C$. $|\lambda_{100}|$ *vs.* composition curve shows a minimum at about $x=0.6$ but λ_{111} increases monotonously with decreasing x except the case of $x=0.1$ at low temperature.

It was reported previously by authors[1] and others[2] that the ferromagnetic crystalline anisotropy of $Mn_xFe_{3-x}O_4$ shows the characteristic dependence on composition, x. Here, the magnetostriction constants, λ_{100} and λ_{111}, of the same ferrite system in the temperature range between about $-100°C$ and $+20°C$ are presented.

The crystal, grown by the Bridgman method, is cut as a disk parallel to a (100) or (110) plane. Strain gauges (Kyowamusen Kenkyujo Co., K-19-1, non-magnetoresistance type) are cemented to the surface to measure strains in [001] and [011] directions in (100) plane, and [001] and [1$\bar{1}$0] or [001] and [1$\bar{1}$1] directions in (110) plane. Usually, the magnetostriction at saturation of the single crystal of cubic ferromagnetic materials, such as ferrite, is described by a 2-constant expression,

$$\lambda=\tfrac{3}{2}\lambda_{100}(\alpha_1^2\beta_1^2+\alpha_2^2\beta_2^2+\alpha_3^2\beta_3^2-\tfrac{1}{3})$$
$$+3\lambda_{111}(\alpha_1\alpha_2\beta_1\beta_2+\alpha_2\alpha_3\beta_2\beta_3+\alpha_3\alpha_1\beta_3\beta_1).$$

Here, λ is the fractional change in length measured in the crystallographic direction having the direction cosine $(\beta_1, \beta_2, \beta_3)$ with respect to the crystal axes, when the crystal is magnetically saturated in the direction $(\alpha_1, \alpha_2, \alpha_2)$. In our case this equation is simplified as follows:

$$
\begin{aligned}
&(100)\ [001]: && \lambda=\text{const}+\tfrac{3}{4}\lambda_{100}\cos 2\theta \\
&\quad {''}\quad [011]: && \lambda=\quad{''}\quad +\tfrac{3}{4}\lambda_{111}\sin 2\theta \\
&(110)\ [001]: && \lambda=\quad{''}\quad +\tfrac{3}{4}\lambda_{100}\cos 2\theta \qquad (1) \\
&\quad {''}\quad [1\bar{1}0]: && \lambda=\quad{''}\quad -\tfrac{3}{8}(\lambda_{100}+\lambda_{111})\cos 2\theta \\
&\quad {''}\quad [1\bar{1}1]: && \lambda=\quad{''}\quad +\tfrac{1}{4}\lambda_{111}(2\sqrt{2}\sin 2\theta-\cos 2\theta),
\end{aligned}
$$

where θ is the angle between the direction of the applied field lying in the plane of the disk and the [001] direction. λ_{100} and λ_{111} are determined from the measurement of λ as a function of θ.

The size of the specimen is about 10mm in diameter and 1~2mm in thickness. The concentration of Co-impurity is less than 0.01%. An applied static magnetic field is about 6000 Oe and is sufficient to achieve technical saturation. The change of the electric resistance of a strain gauge is measured

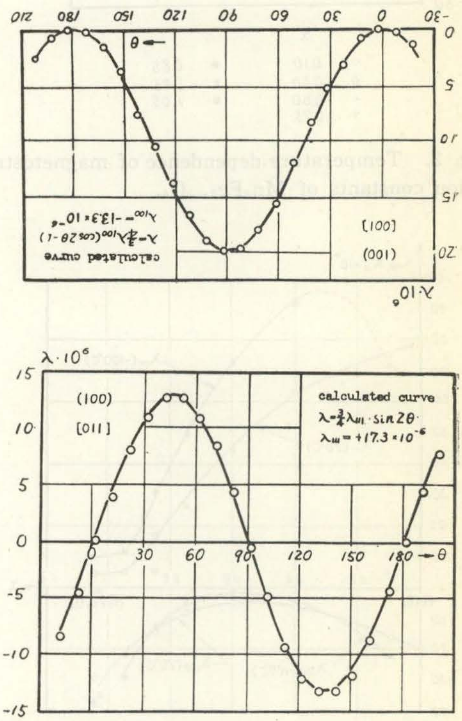

Fig. 1. An example of the magnetostriction measurement ($Mn_{0.85}Fe_{2.15}O_4$ at 25°C).
∘ : observed value,
Solid curve: calculated from Eq. (1) with suitable magnetostriction constant.

by the ordinary Wheatstone bridge. The gauge factor of the strain gauge at room temperature can be used at a lower temperature (down to about $-100°C$) within the error of 5%. One of the results of magnetostriction measurements is shown in Fig. 1. Observed values are expressed very well by the calculated solid curve with a suitable magnetostriction constant.

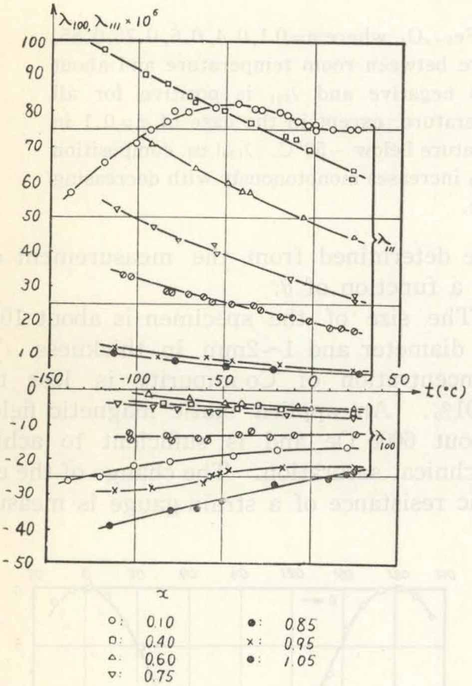

Fig. 2. Temperature dependence of magnetostriction constants of $Mn_xFe_{3-x}O_4$.

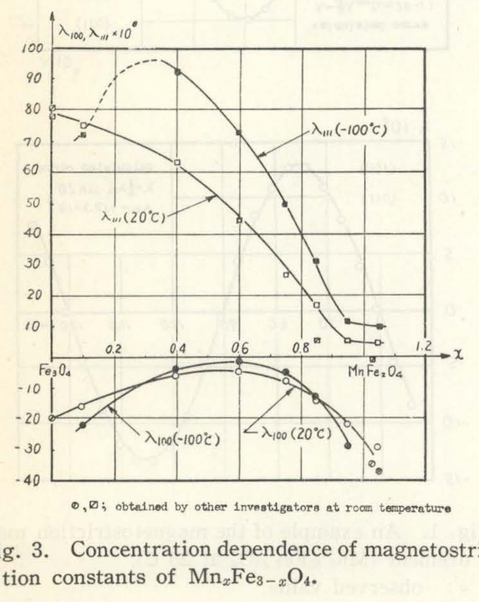

Fig. 3. Concentration dependence of magnetostriction constants of $Mn_xFe_{3-x}O_4$.

The temperature dependence of magnetostriction constants for each specimen in the temperature region between room temperature and about $-100°C$ is shown in Fig. 2. λ_{100} is negative and λ_{111} is positive. With decreasing temperature λ_{111} increases except the case of $x=0.1$. Bickford and others[3)] reported an abnormal character on λ_{111} for magnetite which is similar to our case of $x=0.1$.

The concentration dependence is shown in Fig. 3 with the results obtained previously by other investigators at room temperature[3),4)]. λ_{100} has a maximum, that is, a minimum for the absolute value, at about $x=0.6$. λ_{111} increases with decreasing x, except the case of $x=0.1$ at low temperature. There are some disagreements between the results obtained by other investigators and ours. One of the origin of the disagreement may be attributable to the difference of specimens, that is, the difference of ferrous-ion concentration owing to the different method of crystal growth.

It has been known that magnetite has inverse spinel structure and manganese ferrite is nearly normal type. The concentration dependence of ionic distribution and ionic valency of ferrite solid solution mentioned here is not clear enough, so that no further theoretical consideration is attempted here. Accumulation of experimental data is hoped. Research work on other ferrite solid solution is now in progress in our laboratory.

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DISCUSSION

G. W. RATHENAU: Can you explain the abnormal behaviour of the magnetostriction for $x=0.1$?

N. MIYATA: No, we can not clearly explain the characteristic temperature dependence of λ_{111} for $x=0.1$. But, it may correspond to the abnormal dependence of K_1, the anisotropy constant, on temperature for the same composition. Both of them are thought to have the same origin as the abnormal behavior of magnetite just above the transition temperature, which may be attributable to the short range order of Fe^{2+} and Fe^{3+} on the B- site of the spinel lattice.

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Theoretical and Experimental Study of the Induced Anisotropy in Iron-Cobalt Ferrites and Disaccommodation Phenomena in Ferrites

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The mechanism of the relaxation of induced anisotropy in iron-cobalt ferrites has been studied theoretically and experimentally. It has been made clear that the relaxation time in an isothermal annealing is inversely proportional to the density of cation vacancies in a certain range of the density. The relaxation time in general has a distribution in a wide range, but it becomes single when cobalt content is very small. Quantitative expressions have been given to this relaxation time from both theory and experiment and a reasonable agreement has been obtained between the two. It is concluded that, in general, ferrites have an uniaxial anisotropy due to the presence of oriented arrangement of various cations on their regular sites, and the relaxation time of the reorientation should be also inversely proportional to the density of cation vacancies. On the basis of this conclusion, our technique of controlling cation vacancies has been applied to Mn-Zn ferrites, having shown a realization of good control of the disaccommodation phenomena.

1. Introduction

There has been a considerable progress in the last few years in the study of the induced anisotropy of iron-cobalt ferrites[1)-6)]. Here we shall report a summary of our recent study of the relaxation of the induced anisotropy of this material. As a result of this study we believe now that the induced anisotropy in ferrites in general originates primarily in the oriented configuration of cation arrangements in the spinel matrix, and so far as the density of cation vacancies is over a certain lower bound, say 10^{-8} or 10^{-9} for iron-cobalt ferrites, the process of reorientation takes place mainly through vacancy migration mechanism.

2. Theoretical Considerations

The rearrangement process of cations may be described mathematically in terms of time-dependent populations (or the probabilities) of various configurations of certain cat-