ON THE THERMAL STABILITY OF THE DOMAIN STRUCTURE IN SILICON-IRON CRYSTALS

L. V. KIRENSKII and I. F. DEGTIAREV

Institute of Physics, Siberian Branch, Academy of Science, U.S.S.R.

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The longitudinal magneto-optical Kerr effect is applied to the examination of the domain structure of 3% silicon iron in the temperature range from 20° to 700°C. It is shown that the domain structure possesses high stability in this temperature range.

INTRODUCTION

A very great number of investigations, both theoretical and experimental, have been devoted to the study of the domain structure of ferromagnets. Such interest in their domain structure is fully justified insofar as the basic properties of ferromagnets in weak and intermediate fields are determined by the domain structure, and the magnetization process proceeds by way of the motion of domain boundaries.[1]

At the present time there are many methods for the study of domain structure. The principal, well-developed method is that of powder patterns.[2] The application of the powder-pattern method, however, is limited to relatively low temperatures. Besides, an examination of the dynamics of a domain structure by means of cinematography and powder patters is possible only for slowly varying fields or elastic stresses.[3]

Thus, attempts to find other methods of investigation of the domain structure of ferromagnets, free from the drawbacks indicated above, are quite natural. Among such methods, one must cite the electron-optical methods,[4] the permalloy-probe method,[5] and methods that utilize the magneto-optical Kerr effect.[6] As regards the last method, the polar Kerr effect has been successfully employed in the investigation of the domain structure of uniaxial crystals, in particular MnBi crystals. Application of this method is possible only in the presence of a magnetization component normal to the surface of the specimen.

There are comparatively few works employing the longitudinal Kerr effect with the magnetization vector in the plane of the surface of the specimen and in the plane of incidence of the light beam, and the investigation itself involves considerable technical difficulties. These difficulties are due to the fact that the angle of rotation of the plane of polarization upon reflection of light from a ferromagnetic mirror is small (maximum up to 5′) for the aforementioned Kerr effect. Besides, a major experimental difficulty lies in overcoming the effect of microrelief of the surface. Surface microrelief gives significantly more difference between intensities of beams reflected from different regions than between neighboring zones of spontaneous magnetization.

The small rotation of the plane of polarization in the longitudinal Kerr effect makes visual observation of the domain structure impossible on account of insufficient contrast. The authors of the works referred to above surmounted the effect of surface microrelief by applying a photographic method. The specimen under investigation was photographed in a state of magnetic saturation. The true surface microrelief was obtained in the negative obtained. From the negative, a transparent positive was prepared which was exactly superposed on the negatives taken with the specimen in the investigated state. This made it possible to disclose the domain structure.

The literature contains indications that the Kerr effect is reinforced by dielectric and semiconducting films.[7] This effect was utiized to develop a method for examining the domain structure. This method has no time delay and is applicable over a considerably broader temperature range.

EXPERIMENTAL PORTION

The basic idea of the experiment consists in employing the properties of the iron oxide film to increase the magnitude of Kerr effect observed, making possible visual observation of the domain structure along with still and motion picture recording.

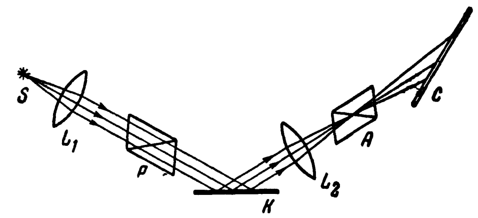

FIG. 1. Arrangement of apparatus for observation of a domain structure by means of the longitudinal Kerr effect.

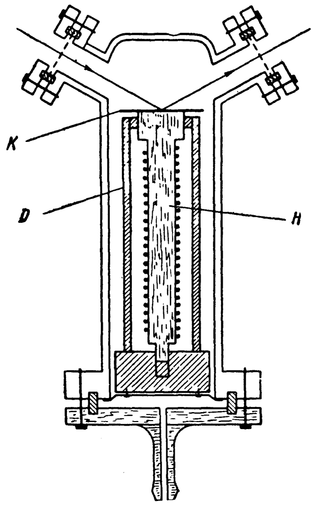

FIG. 2. Diagram of apparatus for the investigation of domain structure at various temperatures.

The diagram of the arrangement is shown in Fig. 1. Light from the source S (a prefocused incandescent lamp) is converted into a parallel beam by means of lens L_1. The polarizer P polarizes the light in a plane perpendicular to the plane of incidence. After reflection from the surface of the examined specimen K, the lens L_2 forms an image of the surface in the plane C, where the photographic plate is placed. The analyzer A is located at the point of maximum convergence of the reflected rays.

Before photographing, the polarizer and analyzer are adjusted for minimum light transmission. The analyzer is then turned through a small angle and, if visually observed through the ocular, the domains emerge clearly in the form of dark and bright bands. Since this method is instantaneous, the stroboscope effect can be used to observe the process of boundary displacement in applied fields of frequency 50 cps and higher.

It has been found possible also to study the domain structure over a very broad temperature range. For this, the specimen K was placed together with a heater H in a chamber which could be evacuated (Fig. 2). The chamber had two glass windows positioned normal to the incident and reflected beams. The heater was mounted in a porcelain tube D so that no shifting of the specimen occurred during a change in temperature. The temperature was measured by means of a nichrome-constantan thermocouple

At temperatures above 500°C the specimen began to glow, but for exposures up to ten seconds this natural radiation did not essentially affect the photographic film up to 700°C.

Studies were carried out on single crystals of 3% silicon iron, cut in strips $25 \times 4 \times 0.3$ mm. in the (110) plane. The specimens, prepared in the same way as for observation of powder patterns, were annealed in vacuum on the order of 10^{-3} mm. Hg at a temperature near 1000°C for three hours. The annealing removed the mechanical strains and covered the surface of the specimen with a fine film of iron oxide. With an appropriate film thickness, the visual observation spoken of above was made possible.

The photographs of Fig. 3 illustrate the change in the domain structure during the application of an increasing magnetic field. The broadening of the domains most advantageously oriented with respect to the field at the expense of those less favorably oriented suggests that both the domain structure itself and its change with the field are recorded sufficiently reliably.

Photographs of the domain structure in the absence of a field at various temperatures from 20 to 700°C are presented in Fig. 4. It is seen that the domain structure of silicon iron is characterized by an unusually high thermal stability. In fact, the width of the domain strips is maintained strictly constant over the indicated temperature interval.

The domain structure shown can be called "normal." By "normal" domain structure in a given case we understand such a domain struc-

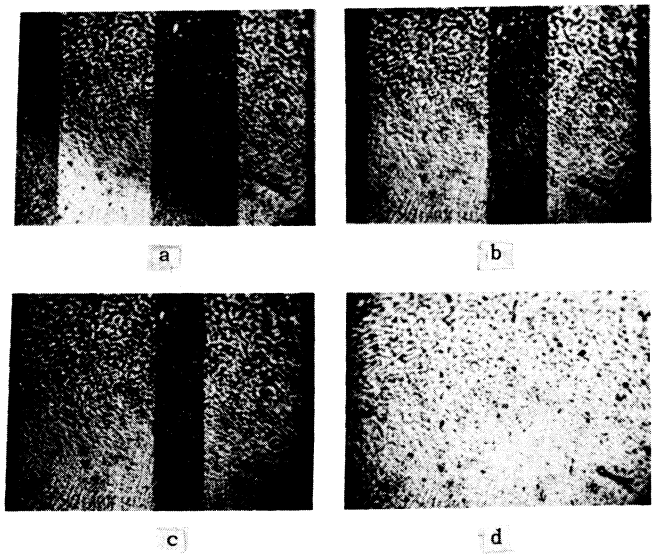

FIG. 3. Change of the domain structure during application of a field. a) H = 0, b) H = 15 Oe, c) H = 25 Oe, d) H = 60 Oe.

ture as is obtained by demagnetizing the specimen with an alternating field whose amplitude decreases to zero. In case of a specimen with some other prior magnetic history, the domain structure can be substantially different from normal. Visual observations made at temperatures from 20 to 500°C have shown that such an abnormal domain structure likewise remains unchanged with variation of temperature.

SUMMARY

1. Utilization of an iron-oxide film in the study of the domain structure of ferromagnets by means of the longitudinal Kerr effect allows visual observation of the domain structure and its still- and motion-picture photography.

2. Because of the absence of time delay, the magneto-optical Kerr effect method permits the conducting of examinations at substantial rates of change of the magnetic field and of the elastic stresses.

3. The magneto-optical Kerr effect allows investigations to be carried out over a broad range of temperatures.

4. The domain structure of silicon iron in the (110) plane is distinguished by high thermal stability.

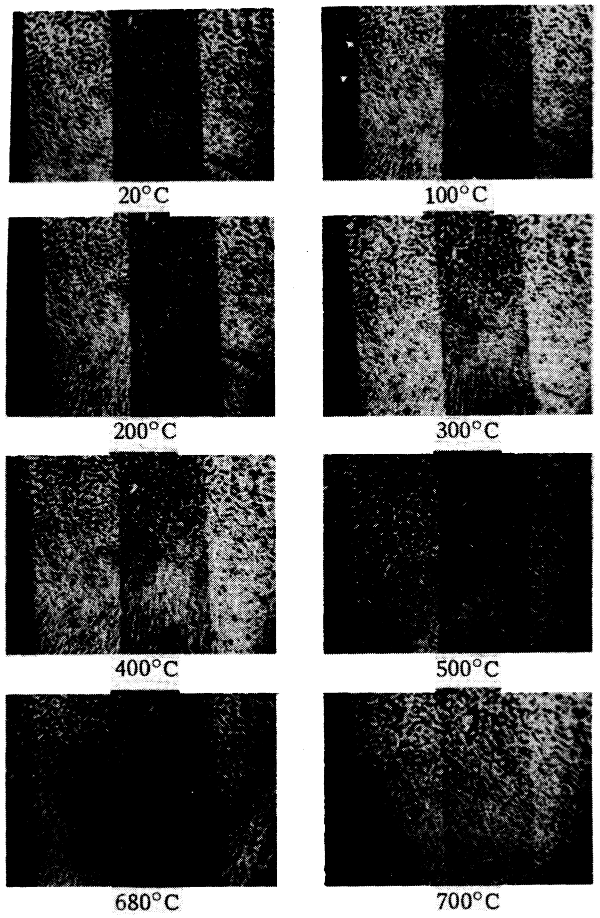

FIG. 4. Normal domain structure of silicon iron crystals in the absence of a magnetic field at various temperatures.

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