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# CONTRIBUTION TO THE STUDY OF CREEP IN THIN PERMALLOY FILMS

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In the present paper we have experimentally studied the dependence of creep efficiency in Permalloy films of the composition 80 % Ni 20 % Fe in the thickness range of 1100–2300 Å on the thickness. A light increase of the creep efficiency with thickness was observed. An attempt to interpret the experimental results is made, using a suitable model.

## I. INTRODUCTION

The slow domain wall motion, the so-called creep, depends in Permalloy films on the wall structure. However, the wall structure depends on the film thickness and so the investigation of the thickness dependence of creep becomes important. Such dependences on thin Permalloy films were studied for example in [1–4]. Olson and Torok [1] investigated the creep threshold and found that for anisotropic films the normalized creep threshold with the increase in thickness (except in the range of 900–1500 Å). The creep threshold is defined as a point in field space at which the first non-reversible signal appears for at least one million transverse pulses in the presence of a dc longitudinal field. The sample was in a saturated state at the beginning of measurements. In [2] the so-called creep fraction was measured and it was found that in the thickness range of 600–2000 Å this quantity remained constant. The creep fraction is defined as a ratio of the transverse magnetic field required to reverse the magnetization of a given part of the sample with 15000 pulses to the transverse field required to reverse the magnetization of the same part with one pulse. Telesnin et al. [3] have taken as a measure of creep the magnitude of displacement of curves of equal velocities relative to the experimental curve of wall motion, normalized to the critical field of the wall start in the easy axis. The quantity, called creep efficiency, increases monotonically with the film thickness increasing over 1000 Å. The creep sensitivity is characterized in [4] by the maximal amplitude of the transverse pulse magnetic field $H_T$, normalized to the anisotropy field $H_K$ for a dc magnetic field equal to $H_C/2$, at which still no onset of creep is observed. For the film thickness $D \approx 400$ Å, the creep sensitivity reaches great values. This sensitivity exhibits its lowest values in the thickness range of about 600 Å and with a thickness increase over 1000 Å its comparatively low value decreases only slightly.

The object of this paper was to study how the creep efficiency depends on the thickness, or on the coercive force, respectively, of thin films of 80 % Ni 20 % Fe in the thickness range of 1100–2300 Å and to try to explain the results obtained, using a suitable model.

## II. EXPERIMENTAL PART

Measurements were made by the magnetooptic method, based on the Kerr magnetooptic longitudinal effect. The apparatus is described in more detail in [5]. In the hard axis of the sample the 50 Hz ac sinusoidal magnetic field was applied simultaneously with the dc magnetic field in the easy axis. Helmholtz coils were used both to apply the required magnetic fields and to compensate for the earth magnetic field influence. Samples of the composition of 80 % Ni 20 % Fe were prepared by vacuum evaporation at $10^{-5}$ torr onto a glass

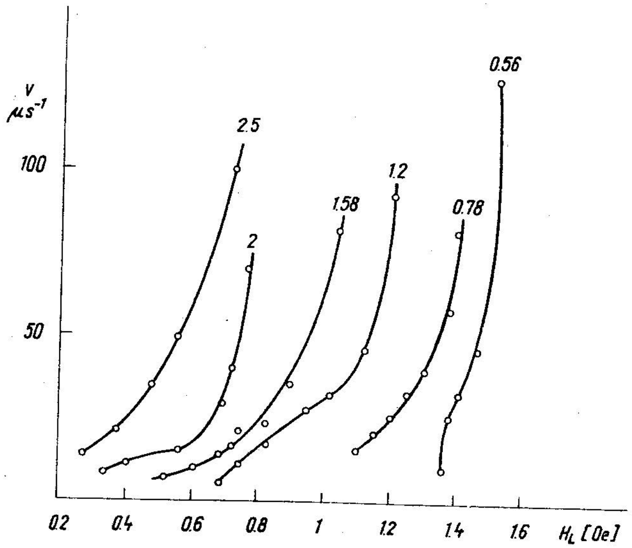

Fig. 1. Dependence of the wall velocity $V$ on the magnetic field in the sample easy axis $H_L$. Figures at each curve give the amplitude values of the magnetic field $H_T$ in Oe. ($D = 2300$ Å, $H_C = 1.9$ Oe, $H_K = 4$ Oe).

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substrate heated up to 200 °C in the presence of a 20 Oe magnetic field. Coercive forces of the samples varied between 1.4—4 Oe, anisotropy fields were in the range of 4—7.8 Oe.

Measurements consisted of observing the mean velocity of the whole domain wall. They were realized on the suitable selected part of the sample with one domain wall to eliminate the influence of sample non-homogeneities. The initial state was the state after sample demagnetization with a small number of 180° domain walls. Demagnetization was accomplished by an ac magnetic field successively decreasing to zero. At suitably set amplitudes of both the dc magnetic field in the easy axis and the ac magnetic field in the hard axis the domain wall parallel to the easy axis moved in the direction of the hard axis. Reversing the direction of a dc field leads to the wall motion in the opposite direction. Velocities of the wall motion in both directions were measured, and their average value was taken as the true one.

The dependence of the domain wall velocity on the field in the easy direction $H_L$ for one sample 2300 Å thick is shown in Fig. 1. The parameter is the field amplitude in the hard axis $H_T$. The curves show an exponential behaviour in most cases. Deviations from this behaviour were found to occur at lower wall velocities. From the dependences of velocity $V$ on the field $H_L$ the curves of the constant velocity were constructed, which were plotted together with the measured critical curve for wall motion in $h_L$, $h_T$ plane (Fig. 2), where $h_L = H_L/H_W$ and $h_T = H_T/H_K$. $H_W$ is the field of the wall start in the easy direction, $H_K$ is the anisotropy field. The critical curve for the wall motion was measured under the influence of a dc transverse magnetic field in the presence of a dc or ac magnetic field in easy axis. As a measure of creep efficiency the quantity $\Delta H_L/H_W$ (Fig. 2) was taken, in accordance with [3]. Values of $\Delta H_L/H_W$ were plotted against the film thickness for velocity $V = 20$ µm/s $h_T = 0.1$, for $V = 10$ µm/s, $h_T = 0.1$ and for $V = 20$ µm/s $h_T = 0.2$ in Fig. 3, and from samples prepared were chosen those following the Nèel relation $H_C \approx D^{-4/3}$, expressing relatively well the coercive force dependence on film thickness above 1000 Å. Measurements have shown that the ratio $\Delta H_L/H_K$ increases only very slightly in comparison with the results of [3], where for example for $h_T = 0.2$ the value of the measured efficiency increases from 0.35 to 0.5 for films of 79 NMA in the thickness range of 1200 to 2000 Å. In addition, measurements on the number of samples with an equal thickness but with various coercive forces have shown that the value of $\Delta H_L/H_W$ was greater for samples with relatively lower coercive forces compared with the samples from the first series and vice versa.

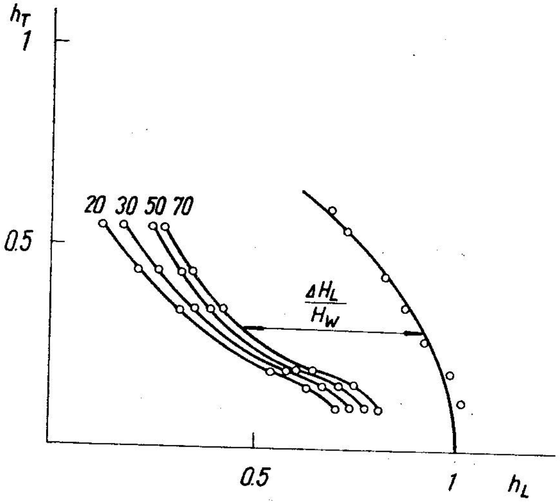

Fig. 2. Curves of equal velocities with the measured critical curve for wall motion plotted in the plane $h_L$, $h_T$, where $h_L = H_L/H_W$, $h_T = H_T/H_K$. At each curve the value of the wall velocity in µm/s is indicated. ($D = 1800$ Å, $H_C = 2.2$ Oe, $H_K = 4.8$ Oe).

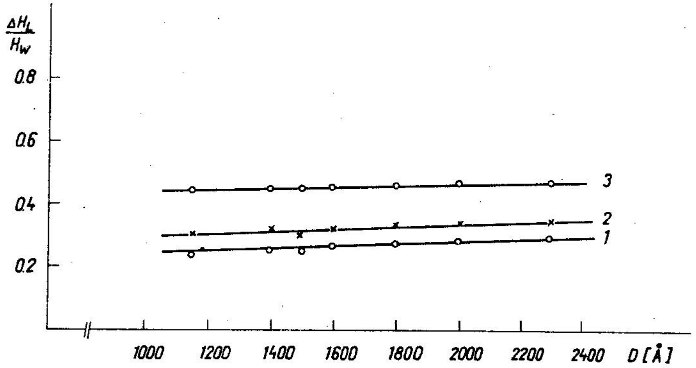

Fig. 3. Dependence of the creep efficiency on the film thickness for: 1. $h_T = 0.1$, $V = 20$ µm/s; 2. $h_T = 0.1$, $V = 10$ µm/s; 3. $h_T = 0.2$, $V = 20$ µm/s.

## III. DISCUSSION

The creep phenomenon in thin Permalloy films has been very intensively studied in recent years and a number of authors hawe suggested models for its explanation [1, 3, 4, 6—13]. However, not one of them can explain all the effects connected with this type of magnetization reversal in thin films and thus the validity of each model is much or less limited. All the models can be divided into two groups: the first group includes models based on the particular structure of the domain wall, whereas to the second group all models independent from the wall type can be counted. The first category includes the model of the structural change of the Nèel wall [8], the model of the stray fields connected with the motion of the 90° and Bloch lines and models connected with the transition of the Bloch walls into the Nèel walls [9. 10]. To the second category the Olson-Torok lever model [1] and the model of the varying wall curvature [3] are included. More recently some authors supposed local non-homogeneities of the critical field for the wall motion have their direct role in creep [6, 11, 12]. According to them the field in the easy direction causes the wall to bulge in points where $H_L > H^*$. The symbol $H^*$ designates the local value of the critical field for the wall motion. Each of the several possible mechanisms can then cause the spreading of such bulges.

Models based on the creation of the magnetic charge on the wall give an appreciable rising dependence of the creep efficiency on the thickness [3], or in other words, the appreciable decrease of the threshold with the thickness increase [1]. Our experimental results show only a slight increase in the creep efficiency in the thickness range of 1100—2300 Å on Permalloy films, whose coercive force fulfills the $H_c \approx D^{-4/3}$ dependence. It follows further from measurements on samples with equal thicknesses but different coercive forces that creep efficiency decreases with the increase in the coercive force. These results indicate that in the thickness range considered the creep efficiency depends rather on the coercive force whose magnitude may be affected — in addition to the thickness — by other factors, too. In [6], where the creep threshold in films with a thickness of over 3000 Å was investigated, this quantity is also put into connection with the coercive force.

When trying to explain the measured dependences we shall expect first that the creep threshold depends on the distribution of the local threshold fields for the wall motion. Considering the existence of Bloch-Nèel walls in Permalloy films with a thickness of over 1000 Å, that is walls with regularly changing Bloch and Nèel segments, and also the existence of Bloch walls [14] (Fig. 4), we can use the model proposed by Doyle et al. [6].

First we consider the influence of the field $H_L$. This field, smaller than the sample coercive force, will cause the domain wall to bend at places where the local threshold field for the wall motion is expected. The bulges originate on the wall with the simultaneous increase in the volume of the preferably magnetized domain. A low frequency sinusoidal field $H_T$ causes a stray field parallel to the wall, which superposes over the longitudinal field and causes an expansion of the bulges along the wall leading to their consecutive levelling, followed by the motion of the whole wall. The best conditions for the creation of the stray field are on the edges of bulges. It is clear from this model that better conditions for a lower creep threshold and a higher creep efficiency exist on samples with such domain walls on which a greater number of bulges at a given $H_L$ are originated.

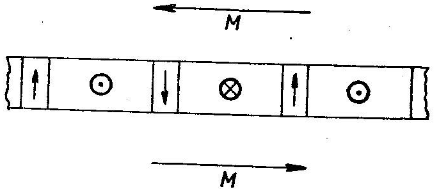

Fig. 4. The Bloch wall model according to [14]. Bloch segments with an opposite polarity are separated by Nèel lines. (View from the top).

We consider now the distribution curve of local threshold fields. (The distribution curve of local threshold fields represents the dependence of $\mathrm{d}N/\mathrm{d}H^*$ on $H^*$, where $H^*$ is the local threshold field and $\mathrm{d}N$ is the number of places with the value of the local field lying between $H^*$ and $H^* + \mathrm{d}H^*$). Supposing the same form of this curve for all samples with a different coercive force, the number of exceeded local threshold fields for the given $H_L$ (for example $H_L = H_C/2$) increases with the decrease in the coercive force. It would mean that with the decreasing coercive force also the field $H_T$ required for bulges expansion should decrease, leading to the threshold lowering and to the increase in creep efficiency. However, it is hardly to be expected that the form of the distribution curve remains constant for various coercive forces. It is more real to suppose that this form will vary from sample to sample, usually in such a manner that samples with a greater coercive force will show a relatively greater dispersion of critical fields and so the number of exceeded local fields will increase with the decreasing coercive force only slightly. This assumption was confirmed also by our first experiments, in which the distribution of critical fields in the samples considered was investigated, using the method of Barkhausen jumps. The results of the paper will be published later.

The decrease in the number of 90° lines per wall length unity in the thickness range considered can also contribute to the slow-down of the creep efficiency increase. Within the thickness range investigated of Nèel segments occurs with the increase in thickness. This worsens the conditions for the creation of the stray field and results in a slow-down in the threshold decrease and thus in a slow-down in the creep efficiency increase with the increase in the sample thickness.

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