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A NEW TRANSIENT SURFACE-CURRENT SENSOR AND RECORDER

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A NEW TRANSIENT SURFACE-CURRENT SENSOR AND RECORDER

ABSTRACT

We have demonstrated that a transient surface-current pulse can be sensed and recorded by a graded-Hc film, a magnetic film with the coercive force Hc varying along the length of the film. Information on the magnitude of the current can be obtained by comparing the domain-wall location with the distribution of Hc value along the film. The transient characteristic of the current pulse can be deduced from the V-shaped configuration of the domain wall.

INTRODUCTION

In a previous report[1] we described how a magnetic thin film could be used for the measurement of fast current pulses in a wire or cable. In that scheme the film could be used for indicating the peak current and the approximate pulse width only when the magnetic field associated with the current pulse varied with distance from the conductor. This limitation arises because the coercive force, Hc, was of constant value in the film used. We call this type of film a "constant-Hc film."

In a situation where the conductor is very wide compared to the film dimension, the spatial magnetic field associated with a current pulse has a small gradient near the conductor. A constant-Hc film only indicates whether or not the field has reached the Hc value. That is, either the entire film is switched or none is switched. The attempt to improve this measurement of uniform spatial fields led to our present work.

In this report we present a scheme for the measurement of transient surface current in a sheet conductor whose associated magnetic field is relatively uniform in space, at least within the dimensions of the magnetic thin film used for the measurement. The film used for sensing and recording the surface current is designed so that its coercive force Hc varies gradually along its length. We call this a "graded-Hc film." When this type of film is exposed to a spatially uniform magnetic field, only the portion of the film with an Hc value less than the applied field is switched. Thus, by knowing the distribution of Hc in the film one can relate the location of the domain wall to the intensity of the uniform spatial field and then in turn to the peak pulsed current.

EXPERIMENTAL DESIGN

We designed an experiment to demonstrate the feasibility of measuring transient surface current with the graded-Hc film. There was no question that the graded-Hc film, by the very nature of its gradually changing Hc value along the length of the film, could measure dc currents.[2] And we had shown previously that the V-shaped domain wall in a constant-Hc film is directly related to the transient nature of the current pulse.[1] We needed to investigate the relationship between the domain-wall configuration in the graded-Hc film and the transient nature of the surface current.

Film Preparation

The graded-Hc film used in this experiment required several manufacturing steps. An aluminum underlayer onto the glass substrate was required before the permalloy evaporation. The Hc/Hk ratio of the permalloy film is very sensitive to the surface structure of the substrate.[3] A granular surface tends to increase the Hc/Hk value of the permalloy film. Aluminum was chosen for the underlayer material because the granular structure of an aluminum film depends on its thickness. A tapered aluminum underlayer presents the gradually changing granular surface structure that is required for the graded-Hc film.[4]

The tapered aluminum film was produced by the scheme shown in Fig. 1. The shutter was moved slowly in the direction of the arrow, exposing first point (a) of the substrate to the source and later point (b). The thickness gradient of the tape of aluminum film depends on the rate of the shutter motion. In the present experiment the thickness gradient was not controlled from run to run owing to the limitations of the available vacuum system. The thicknesses at points (a) and (b) were estimated to be approximately 500 Å and 100 Å, respectively. The substrates were ordinary glass microscope slides and were heated to 125° C during deposition. This temperature is the optimum for depositing aluminum for the underlayer of permalloy.[4]

After the deposition of the aluminum underlayer, in a different vacuum system, a 500-Å permalloy film was deposited onto the heated substrate in a uniform magnetic field. The permalloy deposition was similar to that used for the constant-Hc films. The resulting graded-Hc film is shown in Fig. 2.

Experimental Setup

To make surface-current measurements, the film substrate (1 × 3 × 0.040 in.) was mounted on a copper strip (1 × 5 × 0.020 in.). The permalloy strip itself measures 0.2 in. × 3 in. × 500 Å. To the first estimation,[5] the magnetic field created by a current pulse in the copper strip is uniform across the entire permalloy film strip because of their relative dimensions. Figure 3 shows the experimental setup. The same film was used for all the runs in the experiment described below.

The magnetic film was initially magnetized to a single domain by an external field coil. When a surface current pulse of proper amplitude passed through the copper strip, the resulting field switched the lower-Hc region of the permalloy film to the opposite magnetization direction, thus creating a domain wall. The relative location of the domain wall yields information about the pulse current.

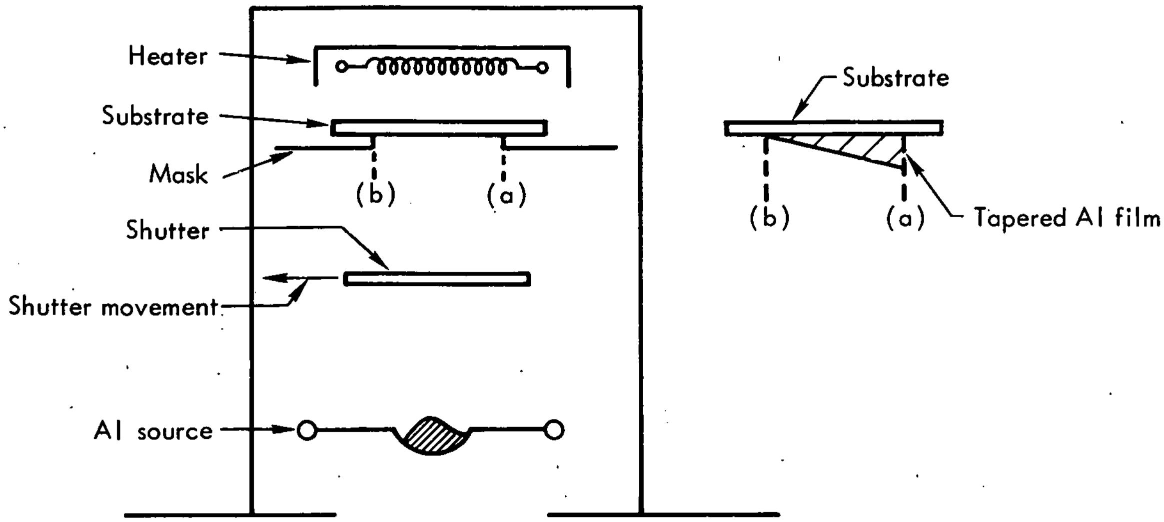


Fig. 1. Deposition of a tapered aluminum film. The aluminum is approximately 500 Å thick at point (a) and 100 Å thick at (b).

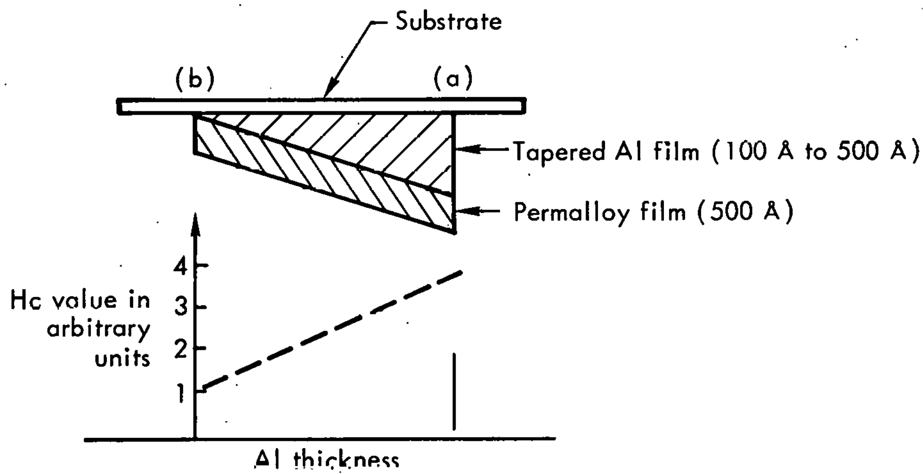


Fig. 2. Characteristics of a graded-Hc film. The Hc value is proportional to the thickness of the Al layer.

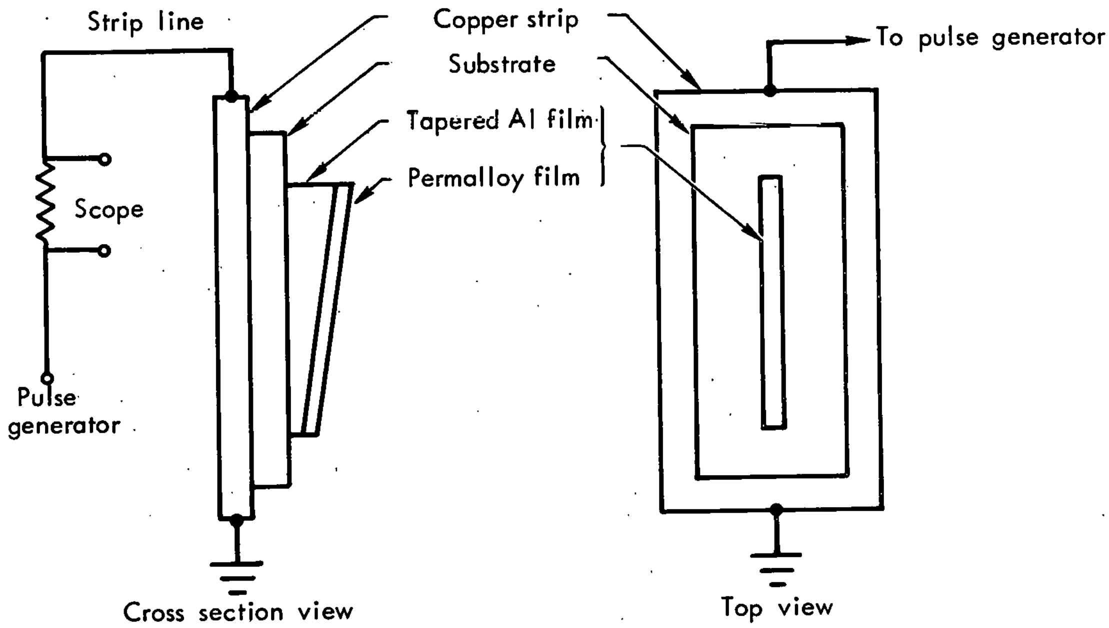


Fig. 3. The experimental setup.

Kerr magneto-optic technique was used to make the domain observations.[6] A closed-circuit TV system provided visual display of the domain walls. Permanent records were then obtained by photographing the TV monitor. The complete observation station is illustrated in Fig. 4.

Experimental Procedures

We employed three excitation conditions in our investigation. First, repeated small-amplitude current pulses were used. The magnitude was sufficiently small that no portion of the magnetic film was switched by a single pulse. However, the current was large enough to cause the growth of edge domains. Repeated current pulses of equal amplitude were applied and domain-wall growth was studied. In effect, we were studying the wall formation in slow motion.

In the second set of experiments larger current pulses were used. The current magnitude was large enough to switch a portion of the magnetic film by a single pulse.

Results from these two sets of experiments can be compared to yield information on the effect of current magnitude on the graded-Hc film.

The last set of experiments involved single current pulses of large amplitude. This excitation condition most nearly simulates the applications in which we expect to use the new sensor/recorder. After each pulse, the film was reset to a single domain so that the same initial conditions existed for the next pulse.

RESULTS

In the present experiment the goal was to demonstrate the feasibility of transient surface-current measurements by graded-Hc films. No attempts were made to shape the current pulses or to calibrate the current magnitudes accurately. These and other associated problems will be tackled in later experiments. For instance, when we can acquire a proper current-viewing resistor then we will be able to measure accurately the current magnitude.

Repeated Current Pulses at Small Amplitude

The small-amplitude current pulses were used to cause the edge domain to grow slowly. The current pulse is shown in Fig. 5(a). Figures 5(b) to 5(e) show the initial formation of a V-shaped domain wall at the end of 10 pulses and its movement to the higher-Hc region after 14, 18, and 21 pulses. Notice that the vertex of the V-shaped wall is located at the lower-Hc portion of the film. Under a uniform spatial field the edge domains moved faster in the lower-Hc region. This is to be expected because the speed of domain-tip movement is a function of the ratio of applied magnetic field to Hc.[7]

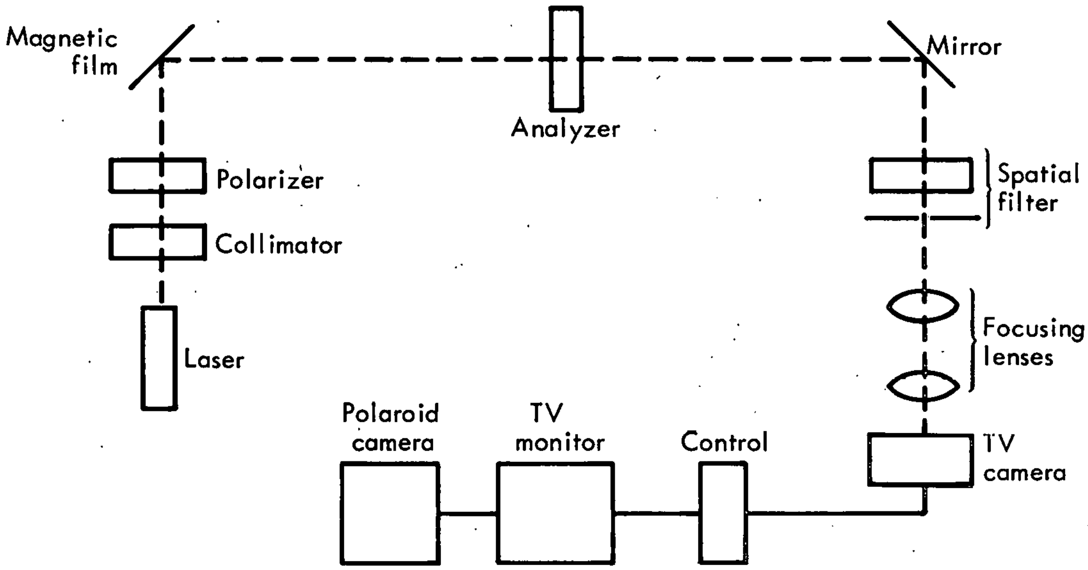


Fig. 4. Closed-circuit TV station for magneto-optic observation.

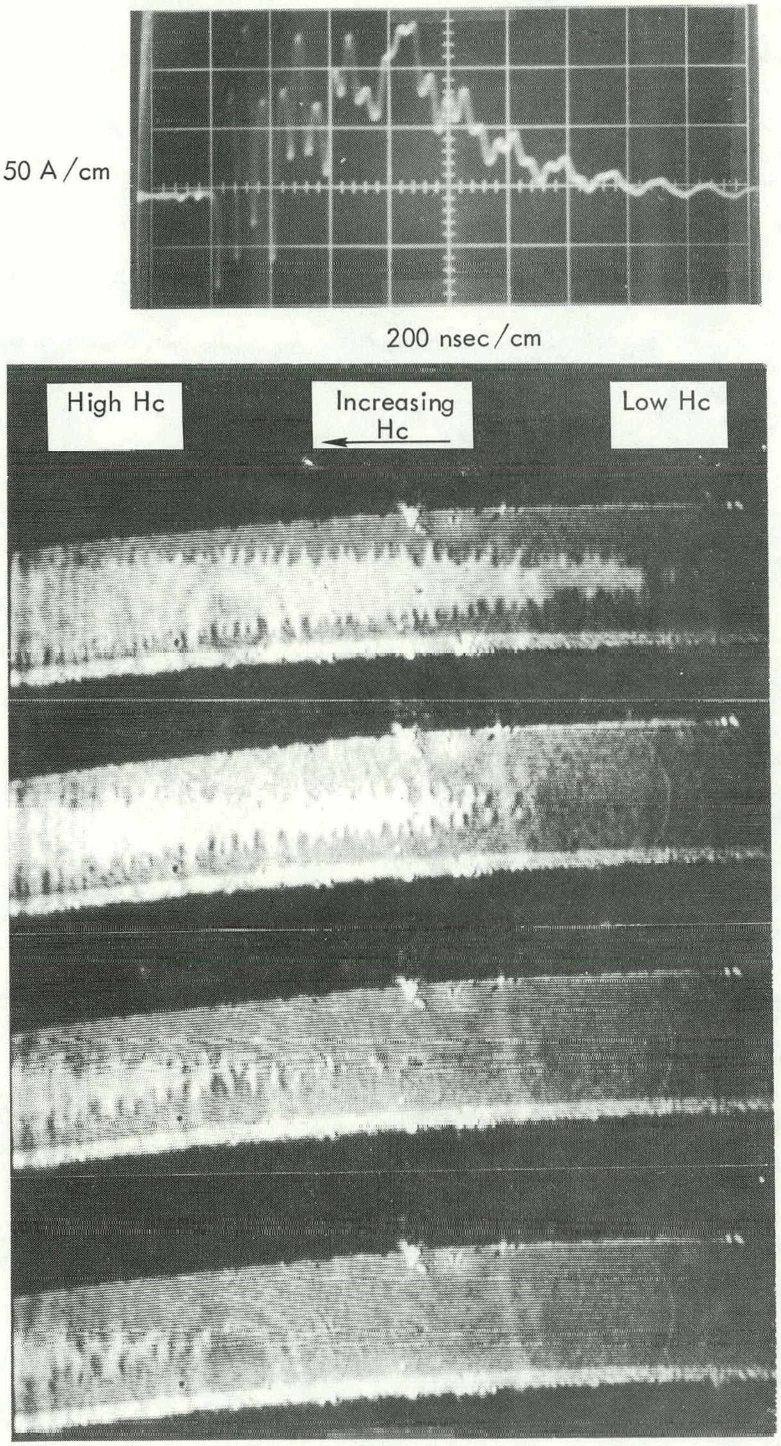


Fig. 5. Formation of a V-shaped domain wall in graded-Hc film with repeated small pulses of current. A representative pulse is shown in (a).

Figure 6 gives a theoretical model for the formation of a V-shaped wall in a graded-Hc film. The film is arbitrarily divided into numbered sections. The domain-tip velocity for the lower-Hc sections is always higher than that in higher-Hc sections. Based on this model the vertex of the V-shaped wall should be located at the lower-Hc portion of the film and should move toward the higher-Hc region as more pulses are applied.

Repeated Current Pulses at Large Amplitude

The current amplitude in this set of experiments was large enough to cause the formation of a V-shaped wall with a single pulse. When the same pulse was repeated without resetting the film to a single domain configuration, the vertex of the domain wall moved toward the higher-Hc portion of the film. The current pulse is shown in Fig. 7(a) and the movements of the vertex are shown in Figs. 7(b) to 7(e). Eventually a saturation point should be reached when the domain wall would move no further, signifying that the Hc value at that location had reached the value of the applied field.

One significant difference could be observed in the transition regions of the domain walls between the small- and large-current excitations. In the small-current situation the transition region was well defined. The large-current excitation, however, caused a filamentary type of growth in the reversed domain and resulted in a diffused transition region. Similar results were reported by other experimenters.[7] At this point, it is not clear whether we can take advantage of this difference in the transition region to help in interpreting test results.

Single Pulse

In this set of experiments the magnetic film was reset to a single domain (the initial condition) after each pulse so that the effect of different current pulses could be investigated. Figures 8(a) to 8(e) show the diffused domain walls when current pulses of increasing amplitudes were applied. The figures clearly show that the vertex moved toward the higher-Hc portion of the film as current amplitude increased. The relative current amplitudes were gauged by the dial positions of the pulse generator.

CONCLUSION

We have shown in the present experiment that a graded-Hc film can be used to sense and record a transient surface-current pulse. A plausible explanation is given for the V-shaped domain wall observed in the graded-Hc film. The relationship between the domain-wall configuration and the transient property of the surface-current pulse should be similar to that established for the constant-Hc film. Calibration of the graded-Hc film sensor/recorder will be possible when a more accurate current-measuring scheme can be established in our laboratory.

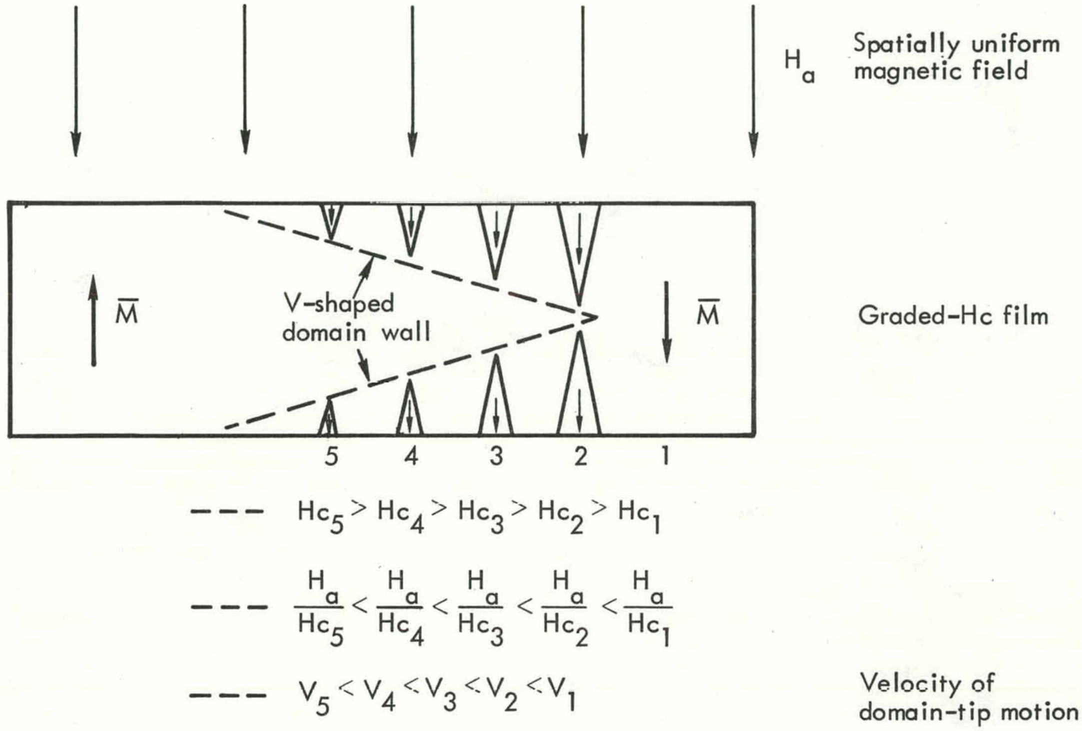


Fig. 6. A theoretical model for the formation of a V-shaped domain wall.

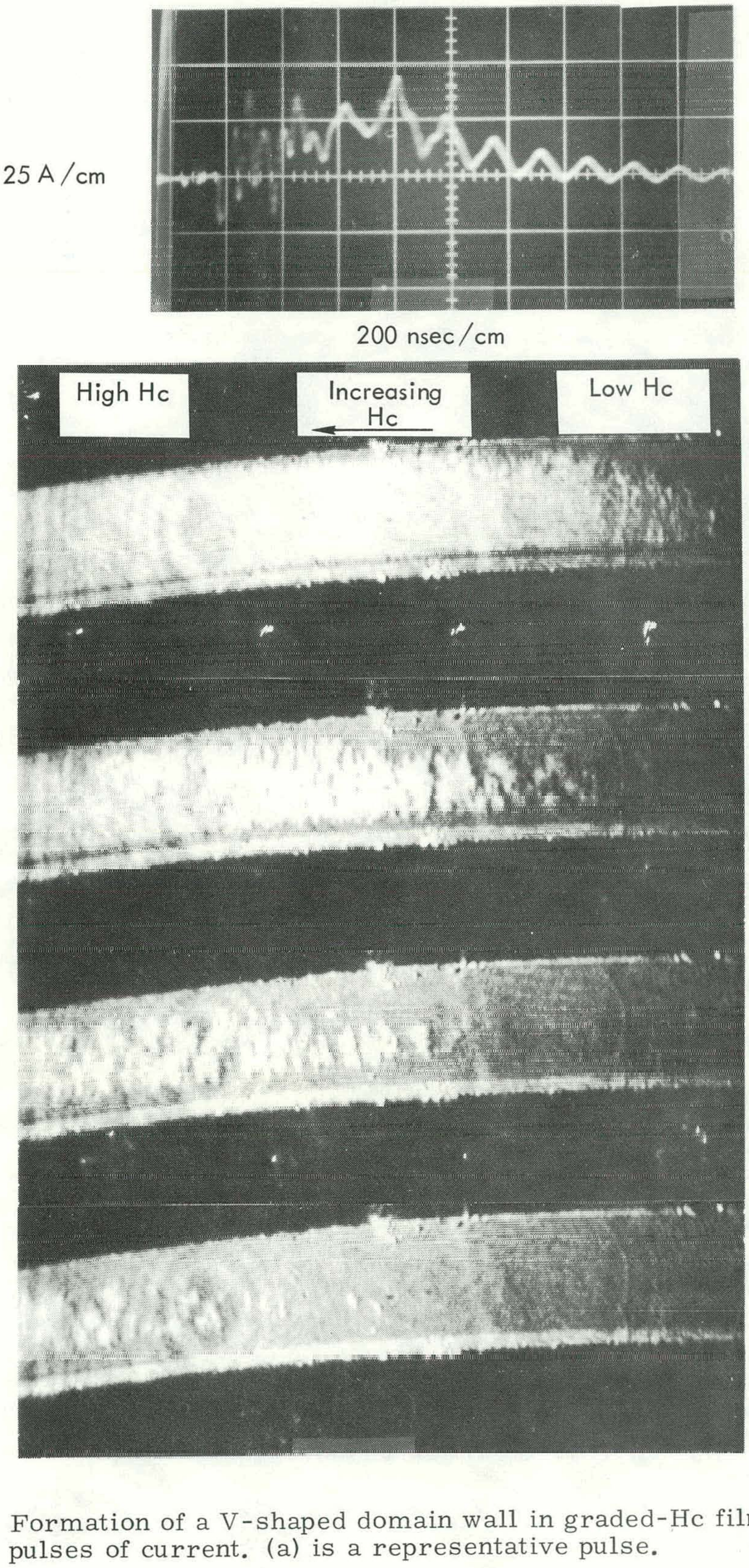
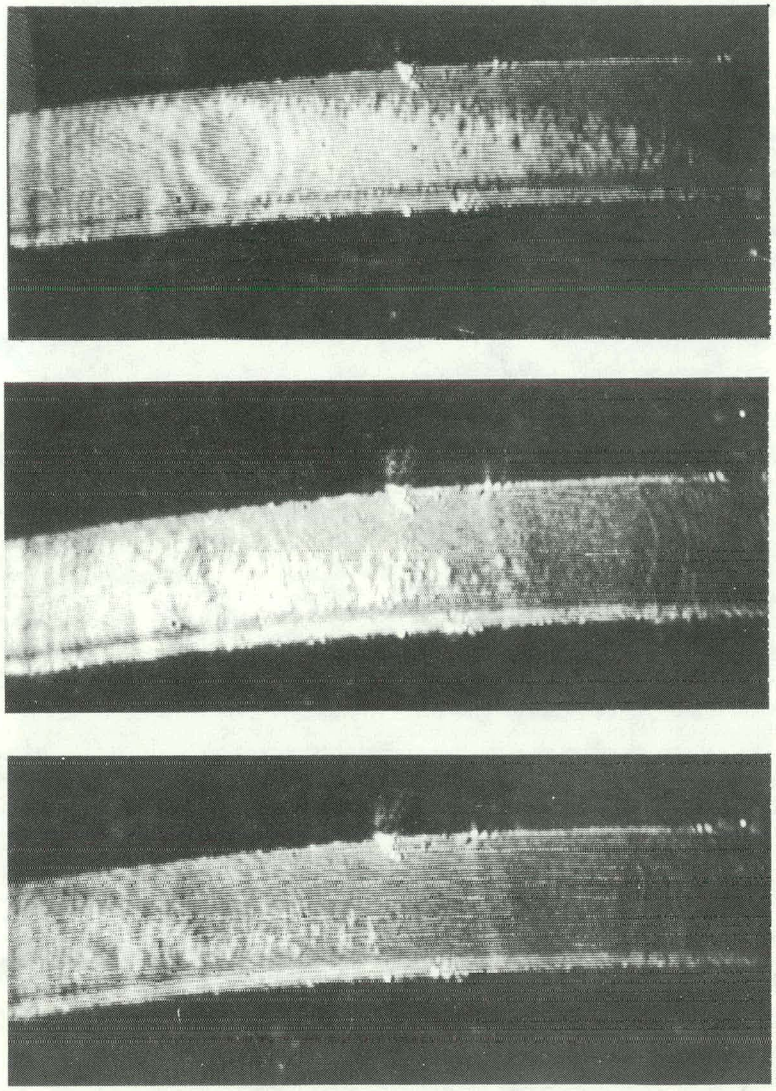


Fig. 7. Formation of a V-shaped domain wall in graded-Hc film with repeated large pulses of current. (a) is a representative pulse.



(a) Current pulse I_a

(b) Current pulse $I_b > I_a$

(c) Current pulse $I_c > I_b$

Fig. 8. Formation of a V-shaped domain wall with large-amplitude single pulses.

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