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The Dispersion Locked Memory Mode for Magnetic Films

Abstract: In the usual thin film magnetic memory, that which utilizes the two stable easy direction magnetization states for storage, inverted films ($H_c > H_k$) are often used to reduce disturb sensitivity. In general, inverted films exhibit a high angular dispersion and an open hard direction hysteresis loop with considerable remanence. Middelhoek has attributed this high remanence to the large number of Néel walls formed after the application of a hard direction field exceeding the anisotropy field. The stable state resulting from this "dispersion locking" finds utility as a storage state and is the subject treated here. This paper describes an orthogonal storage mode which could form the basis for a word-organized high-speed memory using unipolar drivers. Test programs and the results obtained therefrom are illustrated to show the useful operating range in a typical film. The total absence of "creep" and the unipolar digit current input to the device are seen to be features of this dispersion locked mode.

Introduction

It is well known that irreversible processes can occur in the hard direction of Permalloy films. These processes result in a stable state in the hard direction which exhibits increasing stability with increasing angular dispersion. Middelhoek[1] attributes this locking to the stray fields resulting from the Néel walls formed after a hard-direction drive. His theoretical treatment of the ripple structure predicts quite well the observed hard direction stability. Other investigators have related ripple structures to grain size[2,3] and to local regions exhibiting a biaxial anisotropy.[4]

Observations of the hard direction hysteresis characteristics may be found in the literature[5–10] but little is said as to computer storage application. The use of hard direction stability as a storage state is of course evident. Billing[11] proposes the use of the two hard-directions for storage involving a rather complex write-in and read-out scheme. We propose here a simpler scheme using one easy direction and one hard direction for the binary storage. This storage mode (the dispersion locked, or "DL" mode) offers the advantage of unipolar drivers and avoids information loss by "creep".

The storage capability of the hard-direction is immediately seen in Fig. 1. The two hard-direction stable states are shown in trace (a) as the remanent points of the hard direction loop after a hard direction drive of magnitude exceeding the anisotropy field H_k. The closed hard direction loop may still be observed as in trace (b) by driving again into an easy direction and following with a hard direction drive sufficiently less than H_k. Trace (c) is obtained by field drives less than H_k after once exceeding H_k in the hard direction. The mechanism responsible for the hard direction locking is seen in the Bitter photomicrograph of Fig. 2. The wall structure is of the Néel type and is believed to be the mechanism responsible for the hard direction stability.

Dispersion locking characterization

Several 2″ × 2″, 81–19 NiFe films (with thicknesses of about 600Å) were selected for a study of the magnetic properties related to dispersion locking. The films selected have a distribution in angular dispersion of 1.5 to 30 degrees. Observations were made at the centers of the films with a laser light spot approximately 50 microns in diameter. All field plots are normalized against the anisotropy field, H_k.

A significant measurement in dispersion locking is the degree of locking, for it is here that stability is obtained. The degree of locking may be determined from the remanence of the hard-direction loop (Fig. 3). We see that the remanence increases rapidly with the angular dispersion to about 8°, where the film appears to be totally locked in the hard-direction. Bitter observations, through the

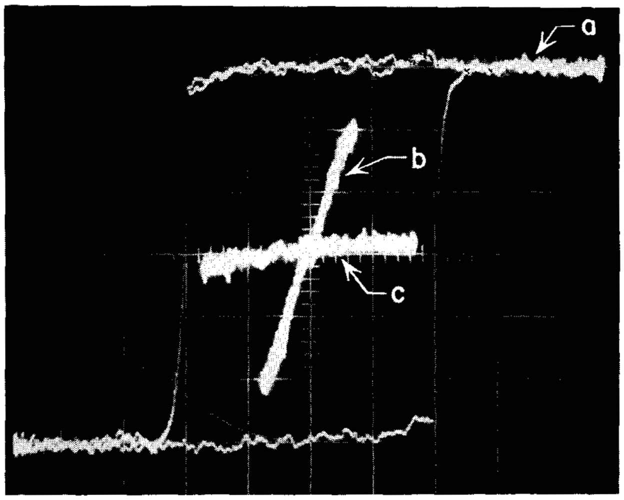
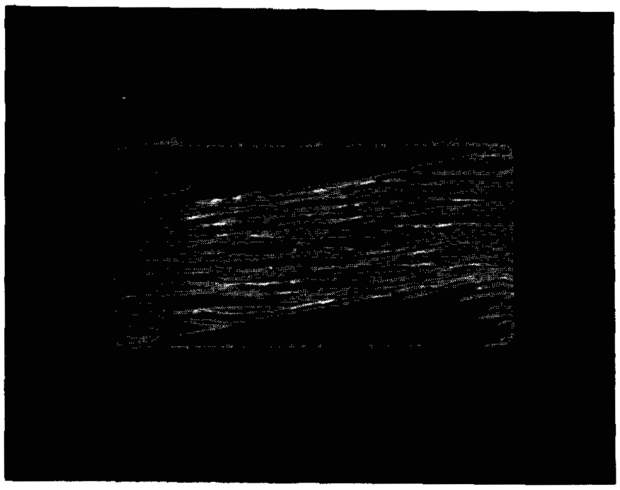


Figure 1 Hard direction loop.

dispersion range, show an increasing density of Néel walls with increasing angular dispersion.

The remanence in the hard direction depends strongly upon the amount of skew, as shown in Fig. 4. Since the control of skew in Permalloy films is difficult to maintain over large areas, this factor is of particular significance. To assure a high degree of remanence, films with large angular dispersion must be selected. It must be remembered that we are studying large continuous films and the skew will be greater when the film is etched into small discrete bits. The discontinuity in the hard-direction loop has been described as a transition from the Néel wall structure to some other or to no wall structure. The field H_T at which this transition takes place is plotted as a function of angular dispersion in Fig. 3. It should be noted that the transition field increases with dispersion. Though not shown, the transition field may be negative for very low dispersions and the hard-direction loop exhibits little remanence.

Figure 2 Bitter pattern showing hard-direction locking.



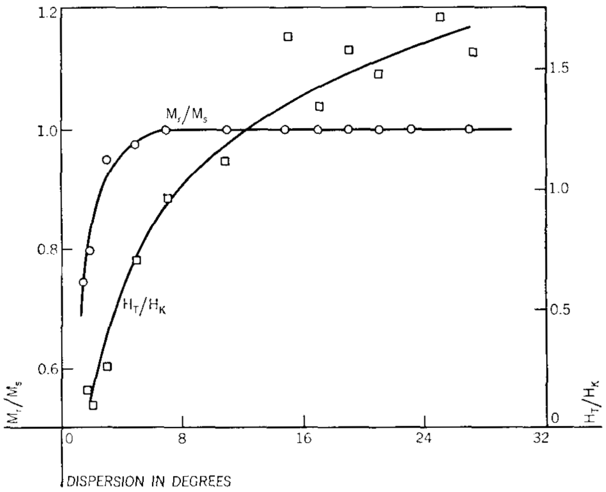
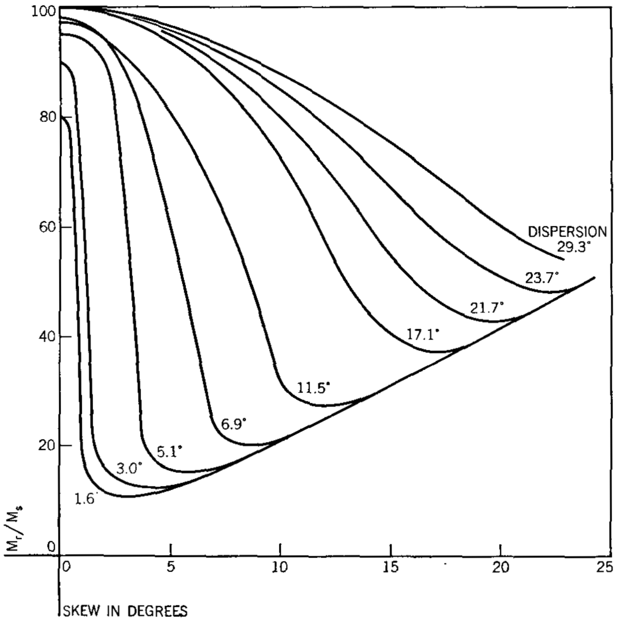


Figure 3 Remanence and hard-direction "unlocking."

The threshold H_T represents an "unlocking" threshold with the field applied in the opposite hard direction; however the film may be unlocked by fields applied in the easy direction as well. Such unlocking fields are shown in Fig. 5 as a function of dispersion. The field H_d is applied in the easy direction (without the application of a coincident hard-direction field) and will cause the film to be totally unlocked. The transition is so sharp that it is difficult to distinguish between the start and completion of unlocking. The unlocking field H_d, then, is a measure of the memory "bit disturb". H_d is seen to increase with dispersion to approximately 16 degrees where it attains relatively constant value.

Figure 4 Remanence vs skew.



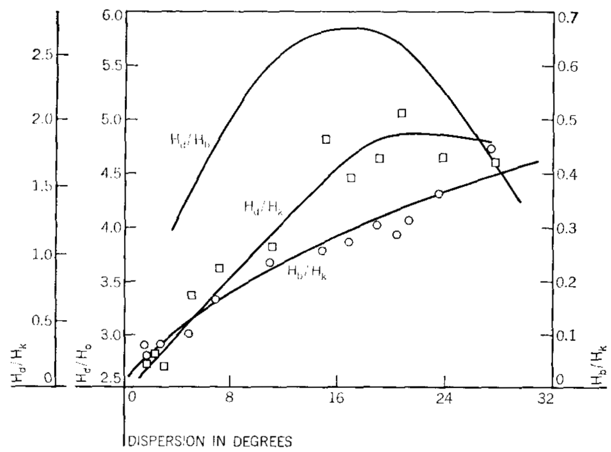


Figure 5 Easy-direction disturb.

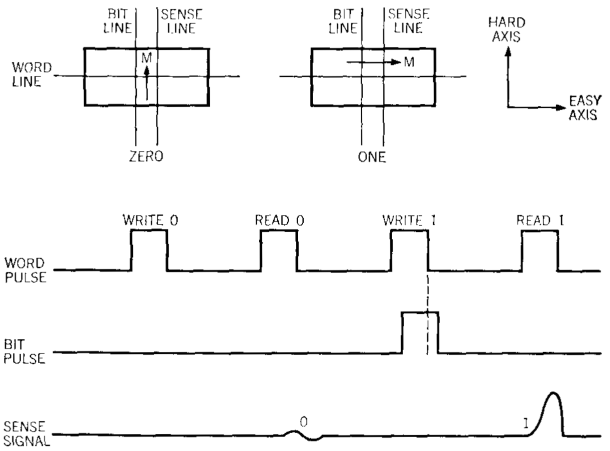


Figure 7 Bit wiring configuration and basic pulse pattern for DL mode.

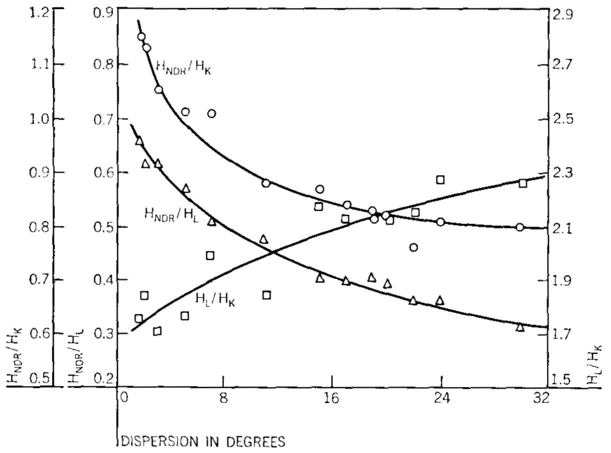
The field H_b, required to unlock the film with the coincident application of a hard-direction drive, is also the "bit" write field, i.e., the field required to write into the easy direction after having once read the stored information. H_b will of course increase with dispersion.

Plotting the easy-direction disturb ratio H_d/H_b (Fig. 5), we observe that the disturb ratio reaches a maximum at 16 degrees of angular dispersion. This should be the design point to achieve a hard-direction storage mode for films whose thicknesses are 600Å. The design point is expected to shift for different thicknesses and compositions.

This study is directed toward an orthogonal store of information, that is, storage in a hard and an easy-direction. Therefore the films were also studied as to the disturbance of easy-direction storage caused by hard-direction fields.

The hard-direction drive H_L, required to achieve full locking of the film into the hard-direction from an easy-direction, is shown as a function of dispersion in Fig. 6. H_L is seen to increase with dispersion. The onset of locking H_{ndr} is also shown, and represents the nondestructive read property. Observation using the Bitter technique has shown that the Néel walls which are always present during dispersion locking are not evident as the field in the hard-direction is increased. The walls appear only when the hard direction field is reduced, after exceeding the onset-of-locking field H_{ndr}. Also, Fig. 6 shows no optimum operating point for the locking fields.

Figure 6 Hard-direction disturb.



The DL mode

In the dispersion locked mode a ONE is stored in one of the easy directions while a ZERO is stored in a hard direction. Figure 7 shows the basic drive line configuration for a film bit, with arrows indicating the direction of magnetization in the ZERO and ONE states, and the basic pulse pattern for writing and reading ONE'S and ZERO'S. A ZERO is written by applying a word pulse of magnitude sufficient to lock the magnetization in the hard direction. The read pulse has the same characteristics as the write pulse and generally produces a small signal on the sense line. A ONE is written by applying a bit pulse in coincidence with a word pulse so that the magnetization will rotate toward the easy axis when the drive pulses are turned off. Upon application of a read pulse a large signal is induced in the sense line. The read-write "one" operation, therefore, is essentially the same as in the standard (180°) mode.

Experimental results

To verify the original assumptions regarding the dispersion locked mode and to determine the operating

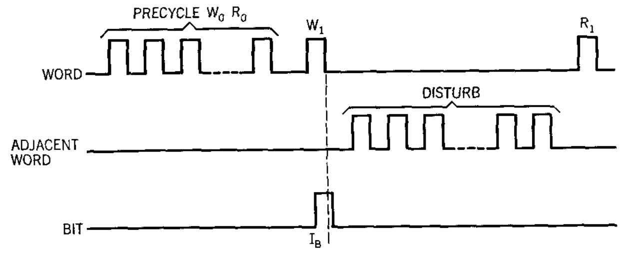


Figure 8 Test 1: Disturbed ONE vs I_B.

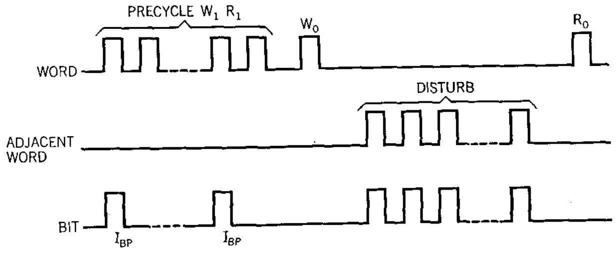


Figure 9 Test 3: Disturbed ZERO vs I_{BP}.

parameters, a series of pulse tests was carried out on etched bit planes. These are outlined below:

- *Test 1: Disturbed* ONE *vs* I_B *(Fig. 8)*

  In this test the bit is first conditioned by a sequence of W_0R_0 (write-ZERO, read-ZERO) cycles. A ONE is then written by the coincidence of a word pulse I_W and a bit pulse I_B. A burst of word-disturb pulses on an adjacent word line follows. Bit-disturb pulses (I_{BD}) are not used in the test because they are in the same direction as the write-one and would not give rise to any information loss. The signal is observed at R_1 time.

- *Test 2: Undisturbed* ONE *vs* I_B

  This program is the same as Test 1 except for the elimination of the disturb burst.

- *Test 3: Disturb* ZERO *vs* I_{BP} *(Fig. 9)*

  In this test, the bit is first conditioned by a sequence of W_1R_1 cycles. The DL ZERO is not directly a function of the bit drive in the same sense as the ONE, but it has been found that the ZERO signal depends on the ONE signal which may previously have been stored in the bit. For this reason, I_B at precycle time (I_{BP}) is used as the independent variable in this test. The ZERO is written by a word pulse alone and is followed by a burst of word and bit disturb pulses in coincidence. The output signal is observed at R_0 time.

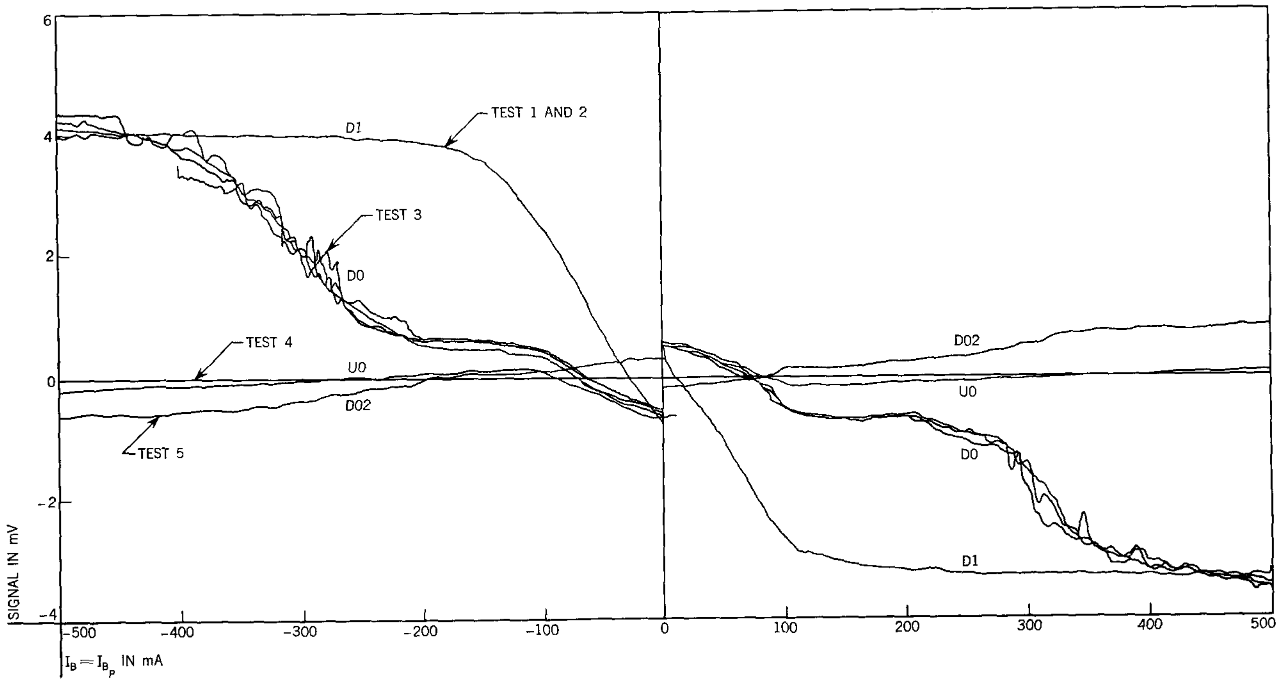
- *Test 4: Undisturbed* ZERO *vs* I_{BP}

  This pulse program is the same as Test 3 except for the elimination of the disturb burst.

- *Test 5: Trailing edge* ZERO *vs* I_{BP}

  The program is the same as Test 3 except that the signal of interest is that occurring at the trailing edge of the read pulse instead of that at the leading edge.

Figure 10 Plot of signal vs I_B from Tests 1–5.



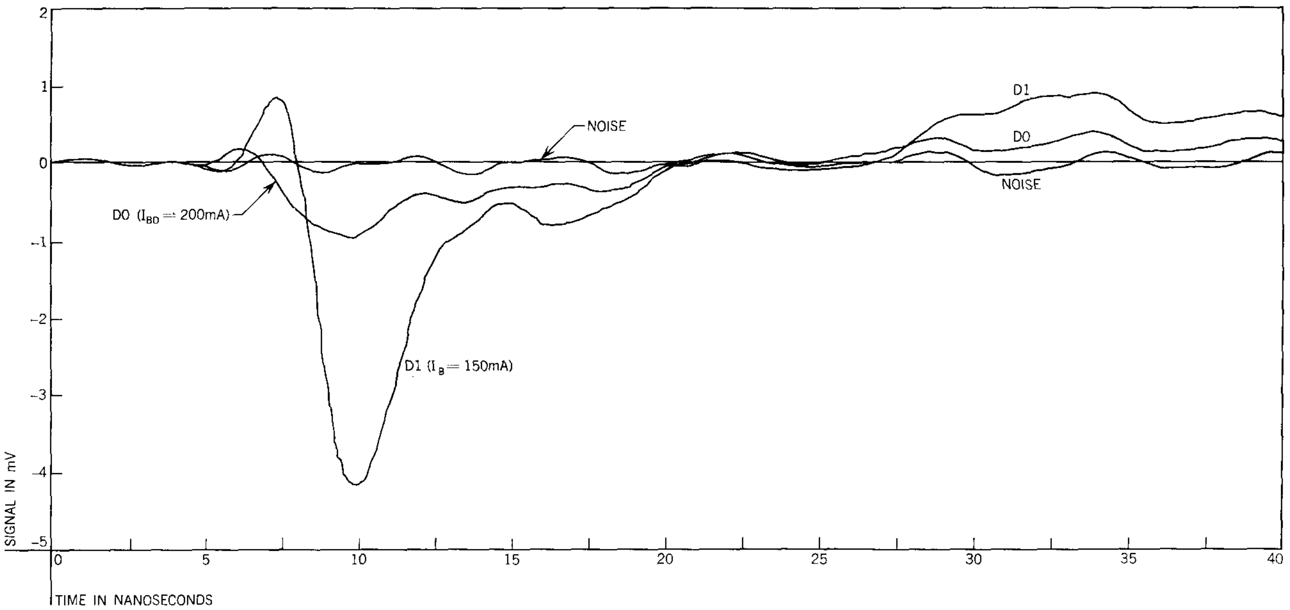


Figure 11 ONE and ZERO signals; noise pattern (vs time).

Figure 10 shows a typical plot obtained from the test, with positive values of I_B and I_{BP} plotted to the right and negative values to the left. The data were taken on a bit having the dimensions 24 mils × 40 mils. A slotted word line 15 mils wide and a slotted bit line 42 mils wide were used. The sense line was a strip in the center of the bit lines. Figure 11 is a plot of the ONE and ZERO signals and the read noise for $I_B = 150$ mA and $I_{BD} = 200$ mA as chosen from the curves of Fig. 10.

The plot of the disturbed ONE signal (Test 1) is labeled D1 on the graph. The undisturbed ONE (U1) shows no deviation from the D1 curve. The disturbed ZERO curves (Test 3) are marked D0 and were taken at 10^3, 10^4, and 10^5 disturb pulses. These curves show that a bit operated in the DL mode is virtually insensitive to varying numbers of disturb pulses. The ZERO signal will eventually increase if the bit disturb amplitude becomes too high, but the data indicate that this occurs with relatively few disturb pulses. Therefore, if a proper operating point is selected, no further allowances for ZERO signal increase due to disturb effects are necessary. The initial, rising part of the D0 and U0 (Test 3) curves is due to the action of the increasing bit pulse amplitude during the pre-cycle part of the program which, for these curves, is plotted on the horizontal axis. If a fixed bit-precycle amplitude were selected and I_{BD} chosen as the independent variable, this part would disappear. The droop in the U0 curve can be shown to be caused by ground plane current effects and varies with the duty cycle of the bit pulses. The trailing edge ZERO signal (Test 4) is marked D02 and is of opposite polarity to the leading edge signal. It is of interest because of the potential discrimination problem in the sense amplifier.

From Fig. 2, the edges of the bit are seen to have a lower density of locking walls than the center after the application of a hard-direction drive pulse in the word line. For low-dispersion films the locking walls may be absent altogether at the edges. This arises from the lower hard-direction field due to demagnetization and non-uniformity of field under a drive line. The lower wall density results in a low effective locking field and the film may be driven into an easy state with relatively low easy direction fields, e.g. a bit disturb pulse. It follows then that after the application of a read pulse these edge regions will result in a small signal on the sense line which is generally in the same direction as the ONE signal.

A method has been developed[12] to ensure that any zero signal will be of opposite polarity to the one signal and thus eliminate the possible discrimination problem. The bit drive pulse is shaped to have a relatively short-duration, opposite-polarity excursion on the leading portion. This resets any "loosely" held, hard-direction locked region in the element to an easy direction opposite to the ONE storage direction. It will be noted that this type of bipolar bit drive does not cost an extra bit driver, does not introduce a "creep" loss mechanism (since a bipolar pulse occurs with every bit disturb pulse) and probably does not cost memory cycle time since write noise decays more rapidly with the bipolar bit pulse. This technique results in an undisturbed ZERO of zero amplitude and a disturbed ZERO of opposite polarity to the ONE signal (although of lower amplitude).

Conclusions

This paper has described a new thin film storage technique which utilizes the stable hard-direction remanence found in high-dispersion films. Disturb sensitivity is extremely low and, because of the absence of creep, unipolar operation is practical. While the unipolar output presents a discrimination problem to the sense amplifier-detector, a memory scheme exhibiting significant cost and performance advantages is forseeable. Testing techniques have been developed and results presented which indicate that parameters of interest can be optimized in the vacuum deposition process.

Acknowledgments

The authors wish to express their appreciation to Mr. G. Taylor for pulse measurements, Mr. E. Wallace and Mr. A. Reimer for film plane preparation, and to Dr. E. W. Pugh, who reviewed the paper.

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Received May 19, 1965.