Reprinted from:

JOURNAL OF APPLIED PHYSICS VOLUME 42, NUMBER 4 15 MARCH 1971

Magnetoresistive Detector for Bubble Domains

G. S. Almasi, G. E. Keefe, Y. S. Lin, and D. A. Thompson

IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598

This paper describes a simple Permalloy magnetoresistive readout transducer for detecting magnetic bubble domains. The advantages over inductive detection are a large increase in signal and an independence of bubble velocity. The advantages over Hall effect detection are simpler fabrication and higher efficiency. The detector is a strip of thin Permalloy film with two contacts, both of which can be deposited onto the same overlay used for bubble propagation. As an example, a 250 Å×38 μ× 138-μ device (52 Ω) was used with a measuring current of 7 mA to give a 2.3-mV signal when detecting 138-μ diameter bubbles in $TmFeO_3$. The response was constant up to the maximum data rate allowed by the bubble domain, in this case, 10^6 bits/sec in $DyFeO_3$. The detector itself can switch in less than 10^{-8} sec. It can be used when conducting strip lines are used for bubble propagation, and also when a rotating field and Permalloy overlay are used. Optimum device placement and shape, as well as ultimate limitations, are discussed in terms of the stray field contours of the bubbles.

Several methods of detecting bubble domains have been described.[1–3] Inductive detection[1] yields small signals because the flux available from a bubble is small. However, the bubble flux can be used to modulate power from an external source to yield larger signals. The Hall effect has been used to obtain a signal of 0.5 mV for a 10-mA input current in a 25-μ-diam integrated Si device.[2] Unfortunately, the carrier mobility of Si is relatively low, and the Hall effect in Si is an inefficient process for detecting the small flux densities associated with bubble domain materials; the ratio of output to input power is as low as 10^{-7} for orthoferrite and 10^{-6} for garnet.

A more efficient way to modulate an external power source is to use a magnetoresistive sensor made of the same Permalloy used to guide and propagate bubbles. The resistance of a polycrystalline Permalloy film changes by 1%–5% when its magnetization rotates by 90° from the direction of the measuring current.[4,5] This results in an output-to-input power ratio between 10^{-4} and 2.5×10^{-3}, and is the basis of the detection scheme depicted in Fig. 1. A spot of thin uniaxial Permalloy film is placed near the propagation path of the bubble domain. The geometry and material parameters of the permalloy spot are chosen in such a way that the permalloy magnetization rotates 90° from the easy axis to the hard axis when the bubble passes by. Two contacts allow measurement of the resistance of the Permalloy spot.

A variant of this device which has also been used to detect bubble domains is the Permalloy "pseudo-Hall" sensor.[3] Its efficiency should be the same as that of the magnetoresistive sensor, but because it is a four-terminal device, design flexibility is limited (the device must be basically square), and fabrication and placement are more difficult.

The design criteria for a two-terminal magnetoresistive detector are: (1) The sensor should be wide enough so that the sum of the anisotropy field and the demagnetizing field along the hard axis is less than the stray field from the bubble, i.e., the bubble must be able to drive the sensor. (2) The length of the sensor between the contacts should be such that the entire sensor switches. (3) The resistance and the sense signal should be a reasonable match to semiconductor sense amplifiers, say, 50 Ω and 1 mV; however, the Permalloy cannot be much thinner than 200 Å, otherwise the percentage resistance change $\Delta R/R$ decreases because of "size effects" in very thin conductors.[4] (4) The stray field from the Permalloy sensing element and from the measuring current within it should not influence the bubble. This implies thin Permalloy and small measuring currents. (5) The power dissipation must be acceptable.

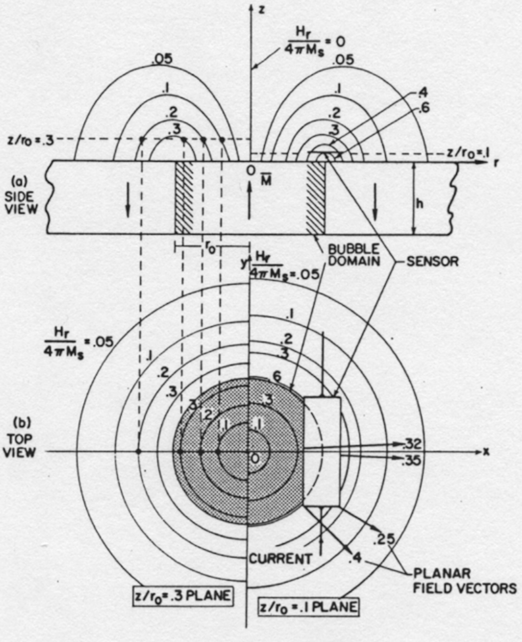
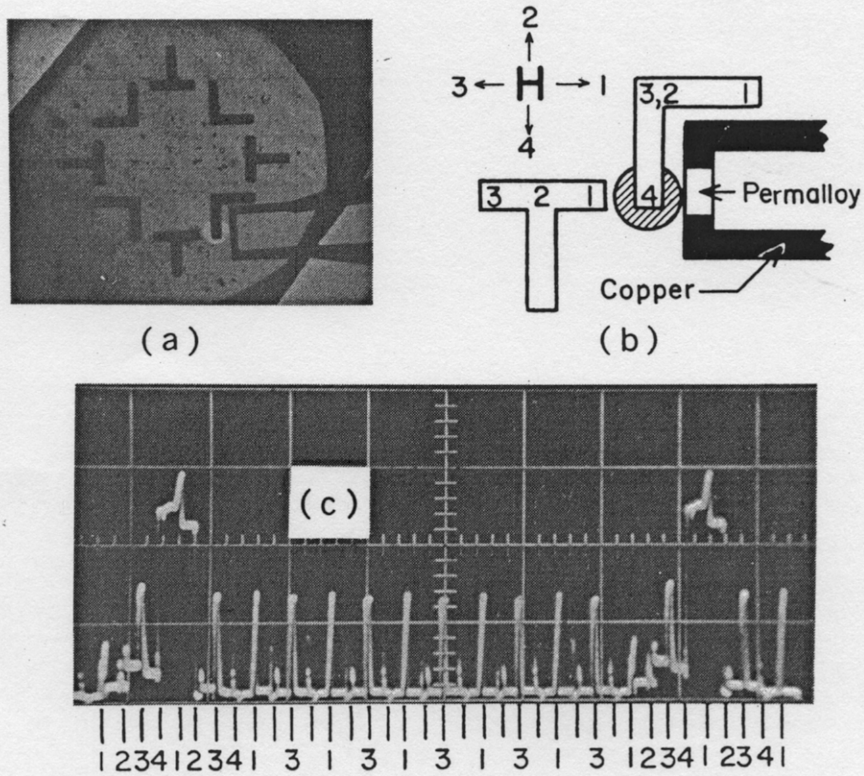


FIG. 1. Side and top views of contours of constant in-plane field from a typical bubble domain. The cylindrical-coordinate radial field H_r is shown normalized to $4\pi M_s$, the net magnetization of the bubble domain material; all dimensions are normalized to the bubble radius r_0. Placement of a magnetoresistive sensor and the field acting on it at several points are also shown.

The design of a sensor to satisfy these requirements is aided by a plot of the calculated stray fields from the bubble domain. The z component of the bubble field is not of interest because only sensors parallel to the surface of the bubble domain platelet are being considered. As can be seen from Fig. 1, the bubble field is strongly nonuniform over the area of all but the



(a) (b)

FIG. 2. Magnetoresistive sensing of bubble domains in a T-bar environment. (a) Propagation track and sensor placement. T bars are $50\times250\times1$-μ Permalloy, bubble diameter is 138 μ in $TmFeO_3$ (56-μ thick, $4\pi M_s=140$ G). (b) Field sequence, bubble progression, and sensor details. Active area of Permalloy sensor ($H_k=3.5$ Oe) is 38 $\mu\times138$ $\mu\times250$ Å. Easy axis along the long edge. (c) Signal for 7-mA input current. Vertical scale, 1 mV/major division; horizontal scale, 1 msec/major division. Field rotates counter clockwise at 1 kHz, bubble completes 125 clockwise circuits per sec. Drive field is a sequence of 5-Oe, 100-μsec pulses at 250-μsec intervals. These appear as 1.3-mV spikes in the sensor output whenever field is in direction 1 or 3. Bubble signal occurs every eight field cycles. Output rises to 2.3 mV when bubble arrives at position 4, drops slightly when it moves to 1, and returns to the base line when the bubble moves to position 2.

smallest sensors. Fields become larger as the platelet surface is approached, but sensor placement and geometry become more critical. Figure 1 may be used in cut-and-try design and in the interpretation of experimental results.

A sensor which gives satisfactory results for orthoferrite bubbles is shown operating in a T-bar[1] environment in Fig. 2. The T bars and the sensor are on opposite sides of a $TmFeO_3$ platelet (56-μ thick). The sensor resistance is 52 Ω, the input current is 7 mA, and the signal is 2.3 mV. This is the maximum signal, obtained when the center of the sensor is over the edge of the bubble domain and the sensor is as close to the orthoferrite surface as possible. This is predicted by Fig. 1.

Figure 2 shows operation at a data rate of 10^3 bits/sec. When strip lines rather than T bars were used to propagate a 100-μ-diam bubble in $DyFeO_3$, the magnetoresistive sense signal was constant up to the maximum data rate of 10^6 bits/sec. Since rotational switching in Permalloy films occurs in less than 10 nsec,[6] the sensor should have a flat frequency response up to at least 30 MHz.

The 2.3-mV signal of the 138-μ-long sensor corresponds to an effective $\Delta R/R$ of 0.63%. Saturating this sensor with a uniform external 30-Oe transverse field yields 3.5 mV and a $\Delta R/R$ of 0.97%. A sensor of the same width but a length of only 25 μ between contacts yields a $\Delta R/R$ of 0.97% for both the 30-Oe external field and the bubble (138-μ diameter). Thus the bubble saturates the center of the longer sensor, but not its ends.

How well does the sensor of Fig. 2 satisfy the design criteria? (1) The width is satisfactory, since at least the center of the sensor is being saturated. As found also by Hunt,[7] demagnetizing field is larger than calculated for ellipsoidal cross sections, due to curling,[8] i.e., inhomogeneous demagnetizing effects associated with a rectangular cross section. (2) The sensor is somewhat too long with respect to the bubble diameter, since the magnetization at its ends is switched by less than 90°. This seems consistent with Fig. 1. (3) The conditions are satisfied. (4) Neither the magnetoresistive strip nor the measuring current influence the bubble's propagation. (5) Power dissipation = 2.55 mW, local density = 48 W/cm², compared to 100 mW and 25 000 W/cm² for the Si Hall sensor.[2] This reflects the greater efficiency of the magnetoresistive device.

In conclusion, Permalloy magnetoresistance can be used to make fast, simple, and efficient sensors for bubble domains.

The authors gratefully acknowledge the encouragement of Dr. Hsu Chang and the fabricational skills of E. Castellani and A. Pfeiffer.

---

[1] A. H. Bobeck, R. F. Fischer, A. J. Perneski, J. P. Remeika, and L. G. Van Uitert, IEEE Trans. Magnetics **5**, 544 (1969).

[2] W. Strauss and G. E. Smith, J. Appl. Phys. **41**, 1169 (1970).

[3] W. Strauss, Proc. IEEE **58**, 1386 (1970).

[4] E. N. Mitchell, H. B. Haukaas, H. D. Bale, and J. B. Streeper, J. Appl. Phys. **35**, 2604 (1964).

[5] P. Huijer, *Proc. Int. Solid State Circuits Conf.*, 5th, Philadelphia, 1962 (Lewis Winner, New York, 1962), p. 36.

[6] D. O. Smith, J. Appl. Phys. **29**, 264 (1958).

[7] R. P. Hunt, IEEE Trans. Magnetics **6**, 602 (1970).

[8] R. M. Hornreich, J. Appl. Phys. **34**, 1071 (1963).