

FABRICATION AND OPERATION OF A SELF-CONTAINED BUBBLE DOMAIN  
MEMORY CHIP\*

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ABSTRACT

This paper describes the fabrication and operation of a 52-bit bubble domain memory chip designed to test the concept of on-chip magnetic decoding. Access to one of the chip's four shift registers for the read, write, and clear functions is by means of bubble domain decoders utilizing the interaction between a conductor line and a bubble. All other functions are performed by a permalloy overlay driven by an external rotating field. The metallurgy consists of 200 Å evaporated permalloy for magnetoresistive sensors, 4000 Å electroplated permalloy for propagation etc., and 6000 Å electroplated copper for control lines.

INTRODUCTION

The concept of a self-contained magnetic bubble domain memory chip was set forth in a recent paper by Chang, et al.<sup>1</sup>. The chip contains a number of individual shift register, and is designed to be used in a memory which provides random access to blocks of information which are then read out serially. However, rather than using coincident block access<sup>2</sup> to select a chip and a common communication channel<sup>3</sup> to transfer information into and out of a chip, these functions are both performed using an on-chip magnetic decoder made up of logic gates utilizing the interaction between a bubble domain and a current-carrying conductor. The chief advantage of this approach is the simplicity of the resulting memory organization, as further discussed in a companion paper<sup>4</sup>. Here, we describe the design, fabrication, and operation of such a memory chip.

DESIGN

The design chosen to test this concept is shown in block-diagram form in Fig. 1. It consists of four shift registers and all the control functions necessary to write into, read out, and clear any one of the four shift registers. Each shift register has a built-in write decoder and read decoder section. Since the emphasis was on testing the control functions, the storage capacity of each register is small (only 13 bits). The same layout to be described here can provide access to four much longer shift registers, and in a full-scale chip, between 90% and 95% of the total area is available for storage.

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Methods for generation, propagation, and annihilation of bubbles with a permalloy overlay and a rotating in-plane field have already been described<sup>5,6</sup>. Magnetoresistive sensors for bubble domains have also been reported<sup>7,8</sup>. The write, clear, read decoder, and write decoder functions make use of a current-controlled switch which is shown in Fig. 2. This switch allows a small control current to select one of two alternate paths in the permalloy overlay for the bubble domain. A bubble B entering the switch from the right will emerge from the upper port if the current I is positive, and from the lower port if I is negative. The complete chip layout is shown in Fig. 3.

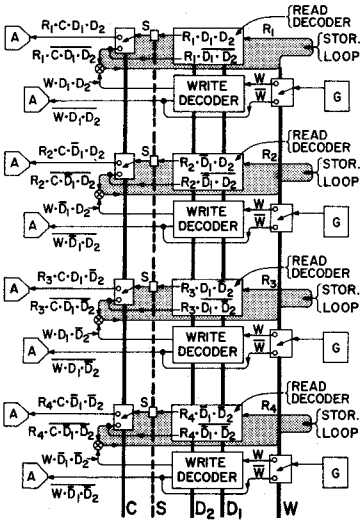


Fig. 1. Block diagram of the memory chip's operation. (G--generator, A--annihilator, S--sensor, W--write control line,  $D_1$ ,  $D_2$ --decode control lines, C--clear control line,  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ --information stored in register 1, 2, 3, or 4)

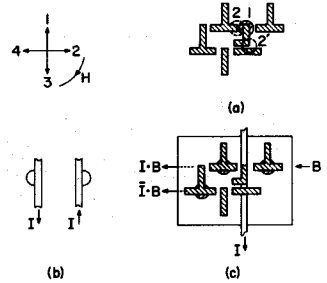


Fig. 2. The basic switch.

- a.) In the absence of control current, it is uncertain whether the bubble will move from position 1 to 2 or 2'.
- b.) Effect on bubble position of current in a stripline.
- c.) Combining the permalloy and conductor patterns as shown results in the "single-pole, double throw" switch whose Boolean representation is shown here. (The current is on between field positions 1 and 2.)

Since logic as well as storage are being accomplished on the chip, it is useful to represent the switch in Boolean algebra. The switch may be viewed as a two-output logic element operating on the two binary inputs B and I. B will be considered 1 when a bubble is present and 0 when a bubble is absent; I will be considered 1 for positive current and 0 for negative current. Then the output at the upper port is the Boolean "And" function ( $B \cdot I$ ), whereas the other

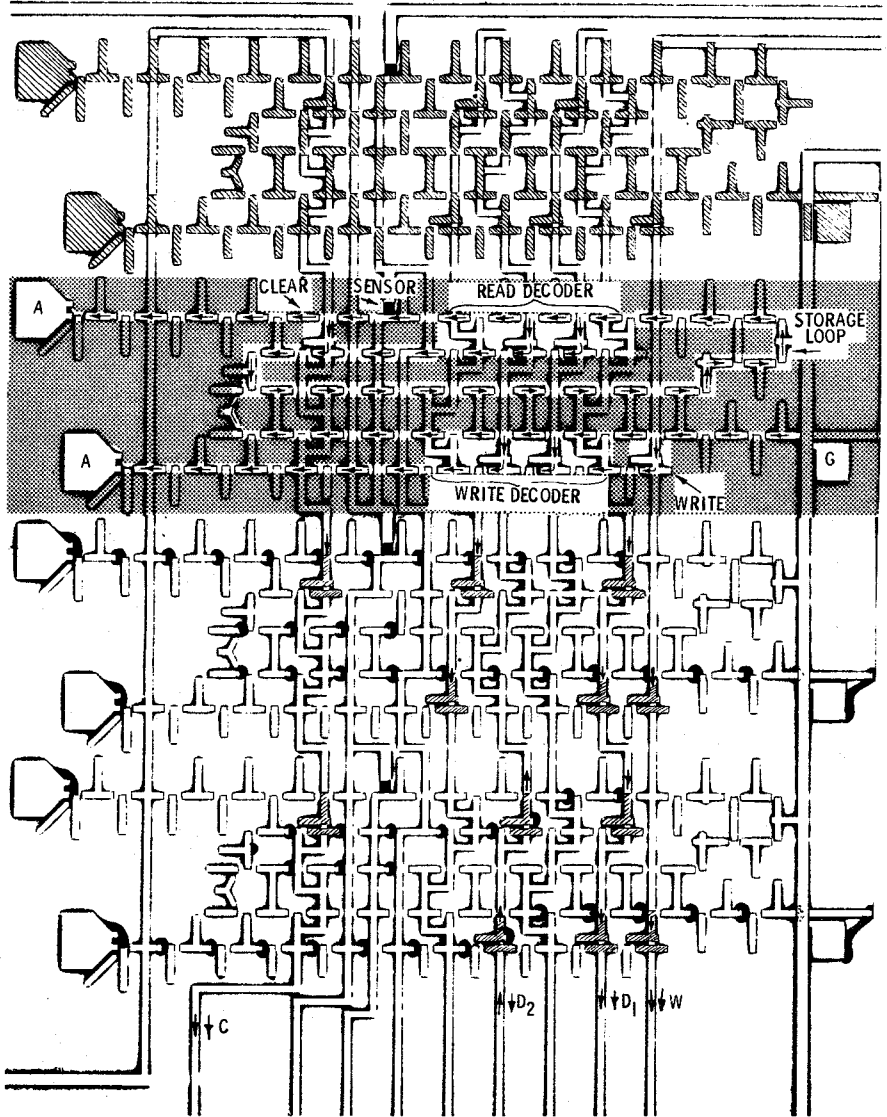


Fig. 3: Layout of the chip. In the top register, the permalloy pattern is cross-hatched, the overlapping conductor is clear. In the next shift register down, the essential functions of Fig. 1 have been highlighted. The actual control currents are shown as arrows on top of the control lines.

output is  $(B \cdot \bar{I})$ , where  $\bar{I}$  is the binary inverse of I.

The operation of the chip can now be explained in terms of Figs. 1, 2, and 3. The generators G are all designed to emit a steady stream of bubbles. To write a 1 into one of the  $2^n$  registers, the write control current W is made positive. This allows a bubble to enter each of the  $2^n$  write decoders. In one of these write decoders, the n decode currents will have the right combination to allow the bubble to propagate out the upper port and into the storage loop. In all the other  $2^n - 1$  write decoders, the bubble will exit from the lower port and into an annihilator. In Fig. 3, the third register from the top,  $(D_1 \cdot \bar{D}_2)$ , is being written into. The simultaneous proceeding in an unselected register are shown in the bottom register  $(\bar{D}_1 \cdot \bar{D}_2)$ .

When writing is finished, the write switch is turned off (W becomes negative), and as long as the clear control current C is negative, the information will circulate in the storage loop. Each storage loop contains a read decoder section whose layout is identical to that register's write decoder section. Therefore, the same combination of decode currents which selected a register for write-in also selects it for read-out. In the selected register, the bubble exits at the top port of the read decoder and goes by a magnetoresistive sensor. In all the other registers, the bubble exits at the bottom port and bypasses the sensor.

After passing the sensor, the bubble in the selected shift register enters the clear control switch. For negative clear control current  $\bar{C}$ , the bubble is returned to the storage loop. However, if new information is to be entered into the register, the clear current is made positive, and the bubbles go to an annihilator. This is shown happening in register  $D_1 \cdot \bar{D}_2$ , Fig. 3. Thus, information may be written into, read out of, and cleared out of any one of the  $2^n$  registers by activating n decode lines.

#### OVERLAY FABRICATION

The design was tested using separate overlays formed on a glass substrate. A 200 Å film of permalloy (81% Ni, 19% Fe) was evaporated onto the glass substrate at a substrate temperature of 330°C; this 200 Å permalloy film serves as a base for subsequent electroplating and is also used to form the sensor element. The 7.5µm-linewidth copper conductor metallurgy was formed by electroplating to a thickness of 6000 Å using a mixed copper sulfate/nitrate plating bath. The 7.5µm-linewidth T-bar metallurgy was formed by electroplating permalloy to a thickness of 4000 Å using a modified Wolf's plating bath. Finally, the magnetoresistive sensor elements were defined by etching of the 200 Å permalloy.

#### OPERATION

The overlay designs were tested with  $\text{Sm}_{0.1}\text{Gd}_{2.24}\text{Tb}_{0.66}\text{Fe}_5\text{O}_{12}$

bulk garnet platelets and  $\text{Eu}_{0.7}\text{Y}_{2.3}\text{Fe}_{3.8}\text{Ga}_{1.2}\text{O}_{12}$  epitaxial garnet films grown by the LPE technique. The bulk garnet platelets were polished down to a thickness of about  $30\ \mu\text{m}$ . Nominal epitaxial film characteristics were a thickness of  $15\ \mu\text{m}$ , a bubble diameter of  $12\ \mu\text{m}$ , and a  $4\text{mM}$  of 125 gauss.

The main problem encountered with the bulk platelets was a rather strong sensitivity to temperature and in-plane field. All of the device functions shown in Fig. 3 were operational; however, the annihilators required greater than 40 Oe drive field at quasi-static frequencies. Spacing between the overlay and the platelet was found to be very critical. A spacing of less than  $5,000\ \text{\AA}$  caused domain nucleation, and a spacing greater than  $10,000\ \text{\AA}$  resulted in poor device operation. The sensitivity of the bubble diameter to the in-plane field was quite serious for fields greater than 30 Oe. This in-plane field response was probably due to the fact that the easy-axis was not exactly normal to the platelet. There were also problems associated with stray bubbles in the regions surrounding the active device; these stray bubbles tended to enter the active device and cause errors.

In general the device operation was better for the LPE films than the bulk platelets; however, the larger bubble diameter to height ratios obtained with films required design changes in some of the device functions which were satisfactory for platelets. The corner design was found to be more critical for films than platelets. The current-controlled switches also required modification. Typical in-plane drive field requirements at quasi-static frequencies were as follows: straight line propagation - 10 Oe, corners and junction - 13 Oe, generators - 20 Oe, and annihilators - 25 Oe. The switches required a control current of 25 mA with an in-plane drive field of 30 Oe. The magnetoresistive sensor signal was  $200\ \mu\text{V}$  for a sensor current of 2 mA.

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