PROGRESS ON AN ELECTRON BEAM ADDRESSED MEMORY TUBE FOR HIGH-CAPACITY, FAST ACCESS, LOW COST MEMORY SYSTEMS

John Kelly

Stanford Research Institute
Menlo Park, California 94025

ABSTRACT

The development of an experimental Electron Beam Addressed Memory (EBAM) module is described. The module is limited to 65,536 address locations, but its development verifies that tubes of approximately 4×10^6 bits can now be made.

The key factors that lead to a practical, stable device are discussed. Emphasis is given to the development of the storage target and its mode of use. The paper shows how a simple refresh technique is used to retain information, provide a nondestructive readout capability, and achieve long-term address stability.

INTRODUCTION

Electron Beam Addressed Memories (EBAMs) promise to become a leading contender for low-cost, large-memory systems with fast random access times, high reliability, and high data rates. Considerable progress on the development of a practical electron-beam addressed system has been made during the last two years. Any EBAM system requires a finely focused and accurately positionable electron beam capable of making some physical change on a storage target. In addition, there must be some low-noise high-bandwidth system for obtaining readout. Two principal items are the key to making a practically successful device: the nature of the storage target and the means by which stored information can be repeatably located or addressed. It is these items, together with the inadequacy of supporting technologies, that prevented the Williams tube from being significantly more successful (1,2).

THE TARGET

Our approach uses the electrostatic storage target illustrated in Figure 1. The target is a metal-oxide-silicon construction with holes etched into the oxide. Two external connections are made: one to the metal gate and the other to the low-resistivity silicon base. A third electrode is deposited in the bottom of the dielectric holes, providing a microcapacitor or "mucap" electrode on which charge can be stored. A major advantage of this structure is that the primary beam approaching the target sees essentially only the potential of the metal gate, which is normally held at ground.

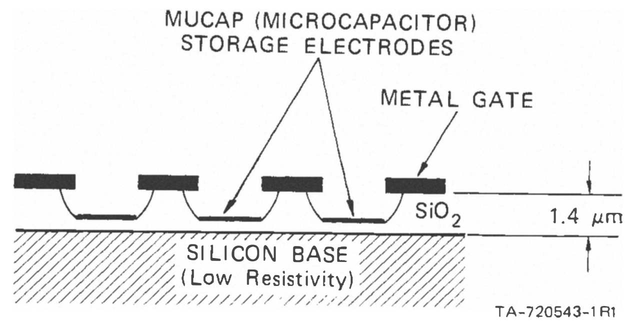

FIGURE 1 THE MUCAP (MICROCAPACITOR) STORAGE MEDIUM

Target Operation

All reading and writing effects are carried out by using secondary electron emission. To operate the target, a beam having a secondary electron emission ratio of greater than unity is required. Under these conditions, any mucap bombarded by the primary beam will tend toward +2 V with respect to the metal gate. This is the stable potential at which the effective secondary emission ratio of the mucaps will be reduced to unity, since the slower secondary electrons will be attracted back to the mucap at this potential. A binary ONE is represented by the storage of a -40 V charge on the mucaps, whereas a ZERO corresponds to the stable condition of the storage of +2 V, as illustrated on the left-hand side of Figure 2. It will be clear that reading a ONE for a sufficient time will generate a ZERO. Of course, in normal reading operations it is only necessary to sample the stored charge in such a manner that readout is only partially destructive. A write ONE operation is achieved by setting the bias voltage, which is normally set at -50 V for the reading and write ZERO operations, to 0 V, thereby forcing ZERO state mucaps to about +42 V. As mentioned above, bombardment with the electron beam will result in the

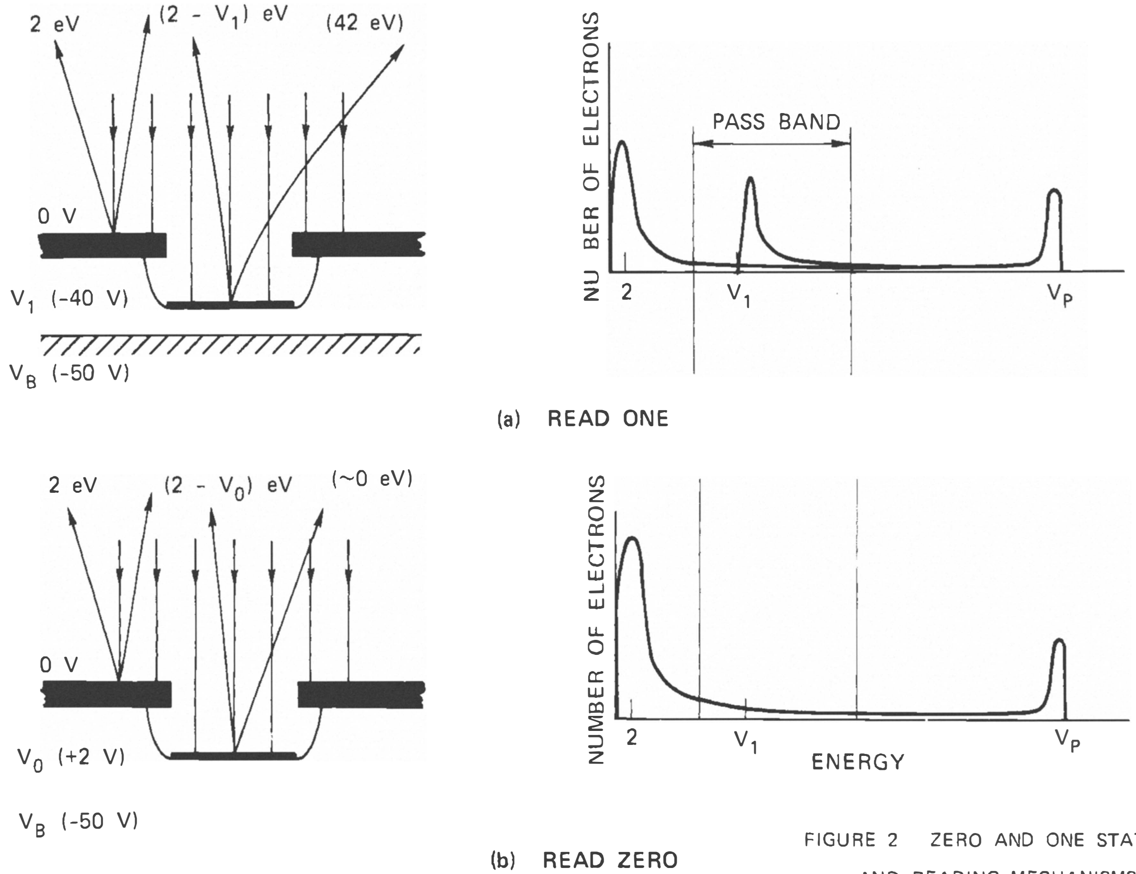

FIGURE 2 ZERO AND ONE STATES AND READING MECHANISMS

mucap being stabilized at +2 V. Return of the base to -50 V sets the ONE condition for reading.

Readout Signals

On the right-hand side of Figure 2 are shown the secondary electron spectra for the ONE and ZERO states. Secondary electrons from ONE-state mucaps are accelerated through a 40-V drop and therefore enter the field-free region with an energy of approximately 42 eV. The two other peaks on the figure correspond to the elastically scattered electrons and to slow secondaries emitted from the gate electrode. In the case of a ZERO, there is no corresponding accelerating field and also relatively few 42-eV electrons. Readout is therefore a simple matter of incorporating a suitable pass band into the device, that will accept only the ONE-state electrons.

The existing readout analyzer is illustrated in Figure 3. This system uses two energy barriers. An -80 V barrier at the left-hand end mirrors all the slower secondary electrons. A -20 V equipotential arranged in front of the continuous-dynode electron multiplier and predynode prevents slow secondaries from gaining access to the multiplier. The majority of slow secondaries are collected on the ZERO collector, which is held a few volts positive with respect to the target. The performance of this readout system is illustrated by Figure 4, which shows a set of curves corresponding to different barrier electrode potentials, V_B. Below the threshold voltage extremely few electrons

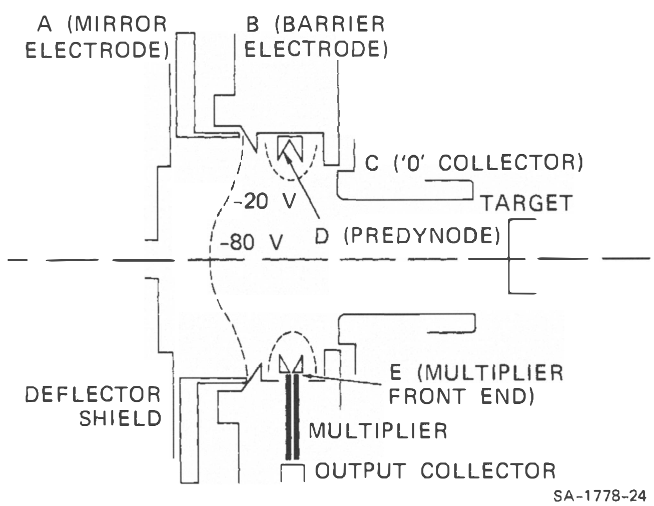

FIGURE 3 SCHEMATIC REPRESENTATION OF THE READOUT SYSTEM

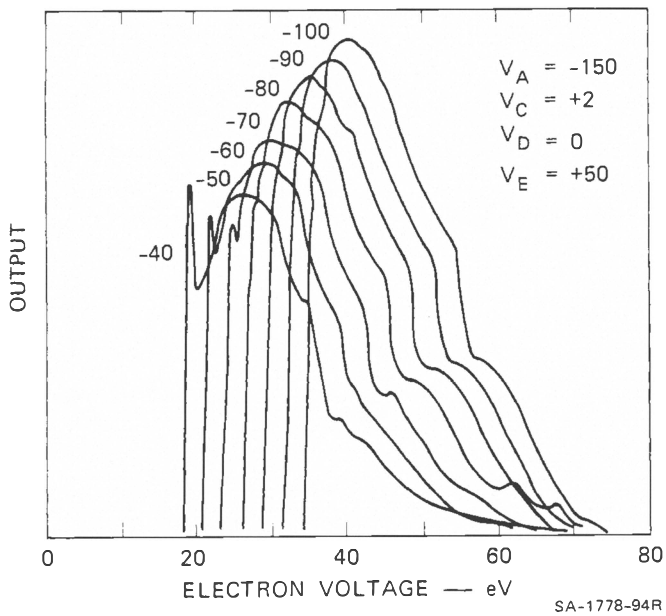

FIGURE 4 MULTIPLIER OUTPUT AS A FUNCTION OF ELECTRON ENERGY WITH V_B AS PARAMETER

are accepted by the multiplier. The passband is approximately 20 V.

Target Usage

In the discussion above, the use of a single mucap for each bit has been indicated. This usage is actually impractical, since it is desirable that a bit location should be determined by the point of incidence of the electron beam on the target, and not by the structure on the target. We therefore make the structure fine in comparison with the beam diameter, and we use maybe nine mucaps for each bit. Occasional missing mucaps do not, therefore, impede operation. In addition, data may be written along a curved path, and raster distortion within reason does not affect performance.

It has been mentioned that readout is partially destructive. Successive reads of the same location will show a signal of decreasing amplitude, until the readout electrons drop below the threshold set by the readout system. An external comparator is also used, to distinguish logically between ONEs and ZEROs. By incorporating a second comparator level into the system, it is possible to detect ONEs that require refreshing. In addition to the reason for decreasing signals given above, there are two further reasons. First, since the target uses surface charge storage, signal is lost with time by leakage along the surface. The initial samples showed a 4-hour storage time. Second, signals may decay because the reading beam has shifted slightly with respect to the actual data location because of some drift in the system. A periodic reading of the complete memory and associated refreshing can therefore ensure that the memory is nondestructive readout (NDRO), that information is not lost through volatility, and that stability between the data and the addressing beam is achieved.

EXPERIMENTAL MODULE

Earlier this year, an experimental EBAM module was delivered to the Air Force Avionics Laboratory, at Wright-Patterson Air Force Base (3). This unit is a single-tube system operating from a memory exerciser which acts as a source of data and addresses for the memory testing operations. The tube, illustrated in Figure 5, consists of an electron gun at the bottom, the latest version of which employs the long-life dispenser cathode; a single electrostatic lens; an electrostatic beam deflector; a readout system; and a storage target plane. The deflector is of the octupole type

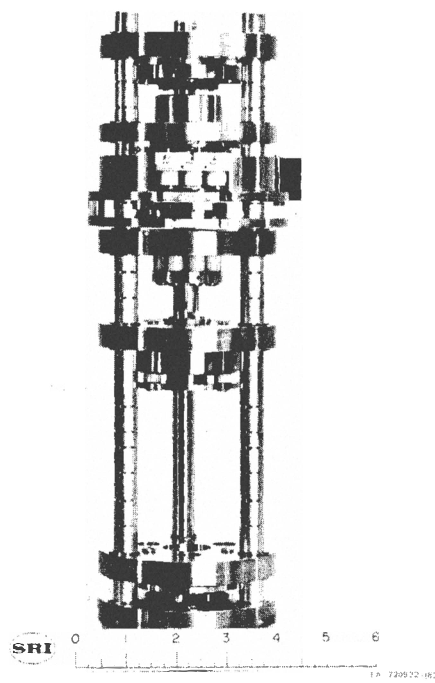

FIGURE 5 EBAM TUBE CONSTRUCTION

developed by the author under an earlier program (4,5). The configuration is illustrated in Figure 6. This deflector, which has eight electrodes, uses a combination of x and y voltages appropriately summed on each of the plates. The advantages are that we are able to select an appropriate field distribution in the x-y plane in order to minimize certain aberrations such as astigmatism. The deflector also has a common center of deflection with equal x-y sensitivities.

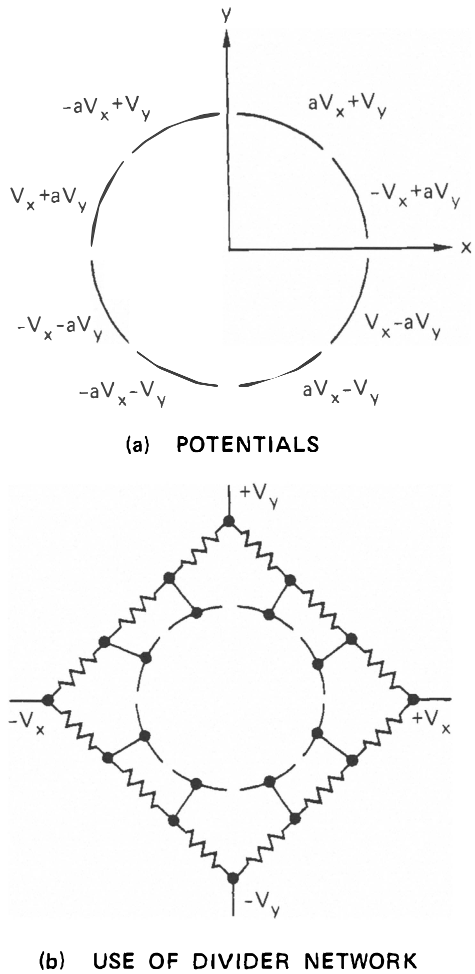

FIGURE 6 REQUIRED VOLTAGE DISTRIBUTION FOR THE OCTUPOLE DEFLECTOR

The targets are prepared by using electron beam lithography to define the mucaps. Exposures of an array of dots are made in parallel by using a screen lens technique, originated by Eugene R. Westerberg (5,6). An appropriate electrical deflection permits multiple exposures to be made to fill in the spaces in the original set.

The raw output signals from a string of ONEs and ZEROs is illustrated in Figure 7. Early testing of this module prior to delivery indicated an error rate of better than 1 in 10^9. Work still remaining to be done includes a more thorough characterization of such effects as read-around ratio and a better understanding of the factors controlling target life. At present, target life appears to be limited by an organic film present on the target from fabrication.

ACKNOWLEDGMENTS

The author gratefully acknowledges the support of the USAF Avionics Laboratory (7) and the help of the following individuals: J. S. Moore, who worked closely with him on the project; P. R. Thornton, for many valuable inputs; C.C. Hartelius, for fabricating the media; E.R. Westerberg, for many ideas and for assistance with the screen lens; and D. Limuti and J. Clark for assistance with the electronics.

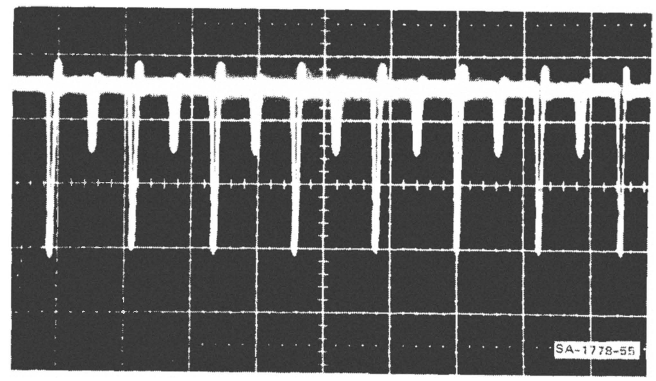

FIGURE 7 PERFORMANCE OF READOUT AMPLIFIER ON THE MEMORY. Analog output 1 0 1 0 . . .

REFERENCES

(1) F.C. Williams and T. Kilburn, "A Storage System for Use with Binary-Digital Computing Machines," PROC. IEEE (London) Part III, Vol. 96, pp 81-100; March 1949.

(2) S.Y. Wong, "High Density Williams Storage," IRE TRANS. ELECT. COMP. Vol. EC-4,No. 4, pp 156-158; Dec. 1955.

(3) J.Kelly and J.S. Moore, "The Development of an Experimental Electron Beam Addressed Memory" PROC.IEEE 1974 National Aerospace and Electronics Conf., NAECON 74, p. 55.

(4) L.N. Heynick, ed., "High-Information-Density Storage Surfaces," 17th Quarterly Rept. ECOM Contract DA 28-043 AMC-01261(E), SRI Proj. 5444, Stanford Research Institute, Menlo Park, Calif. Oct. 1969.

(5) L.N. Heynick, ed., "High-Information-Density Storage Surfaces," Final Report.ECOM-01261-F, Contract DA 28-043 AMC-01261(E), SRI Proj. 5444, Stanford Research Institute, Menlo Park, Calif. June 1970.

(6) E.R. Westerberg and L.N. Heynick, "Electron Image Projection Techniques for Surface Acoustic Wave Device Fabrication," PROC. CONF ON ELECT. DEVICE TECH. pp. 6-12; May 1973.

(7) J.Kelly and J.S. Moore, "Electron-Beam-Addressed Memory Research" USAF Technical Rept. AFAL-TR-74-176, AD-785403; Aug. 1974.