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Comparison of Heavy Ion and Electron-Beam Upset Data for GaAs SRAMs

Prepared by

L. D. FLESNER
Naval Ocean Systems Center

R. ZULEEG
McDonnell Douglas Astronautics Company

and

W. A. KOLASINSKI
The Aerospace Corporation

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QUANG BUI, Lt., USAF
MOIE Program Manager

TYRON FISHER, Capt., USAF
MOIE Project Officer

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We report the results of experiments designed to evaluate the extent to which focused electron-beam pulses simulate energetic ion upset phenomena in GaAs memory circuits fabricated by the McDonnell Douglas Astronautics Company. The results of two experimental methods were compared: irradiation by heavy-ion particle beams, and upset mapping using focused electron pulses. Linear energy transfer (LET) thresholds and upset cross sections are derived from the data for both methods. A comparison of results shows good agreement, indicating that for these circuits electron-beam pulse mapping is a viable simulation technique.

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Preface

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I. INTRODUCTION

Focused electron pulses have been previously employed as a convenient and informative experimental method for investigating the susceptibility of GaAs integrated circuits to single-particle events. The technique has been used to study charge collection processes in discrete devices [1] and for mapping upset-sensitive areas in static random-access memory (SRAM) circuits [2]. It was assumed in those studies that, despite dissimilarities between the ionization produced by energetic ions and by focused electron pulses, that the effects of the two phenomena are sufficiently similar so that useful information is obtained. In this report the assumption is experimentally evaluated. Data for upsets induced in GaAs SRAMs by ion beams are compared with data from upset mapping by focused electron pulses. Good agreement is found both in LET upset thresholds and cross sections. We also briefly discuss the prospects for using focused electron pulses to test Si circuits.

II. EXPERIMENTAL

Figure 1 shows a diagram of the apparatus. Focused 39-kV electron pulses are rastered across a memory cell, with a single pulse applied at each location. The locations at which upsets occur are recorded and correlated with a secondary electron image of the circuit. The pulse duration is held constant at 1 ns, while the charge per pulse, and thus the pulse energy, is varied from map to map. The data provided upset-sensitive area (cross section) versus pulse energy, and sensitive circuit features are identified.

The effective LET of a 39-kV electron pulse in GaAs has been estimated using literature data [3] as follows: in GaAs approximately 60% of the incident energy is dissipated in the initial 2μm. In previous work on charge collection in GaAs FETs [2] we have found that 2μm is an appropriate collection depth for semi-insulating GaAs. Since the pulse energy is simply the beam voltage (39 kV) times the beam current times the pulse duration, all of which are known, the effective LET is estimated simply by dividing 60% of the beam energy by the collection depth of 2μm. The effective LET is combined with the sensitive area versus pulse energy to yield a plot of upset cross section versus LET for comparison with cyclotron test data.

The heavy ion data were taken at the Berkeley cyclotron by personnel of The Aerospace Corporation. A variety of ions and angles of incidence were employed in order to produce charts of upset cross section versus effective LET.

Single-event upsets in GaAs complementary enhancement-mode junction field-effect transistor static random-access memories (C-EJFET SRAMs) fabricated by the McDonnell Douglas Astronautics Company were studied. Fabrication processes and cell design have been described elsewhere [4]. Data for two 1-kilobit SRAM circuits, designated A and B, are presented.
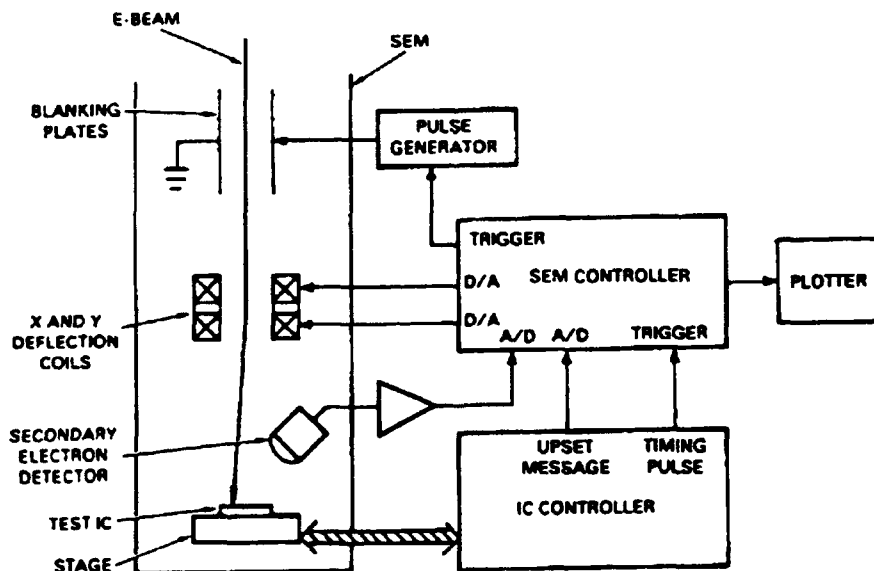

Figure 1. Diagram of experimental apparatus for upset mapping by focused electron pulses.

III. RESULTS

Typical data for SRAM A are illustrated in Figure 2. The dashes show the circuit metallization pattern derived from the secondary electron image, and the X's show where electron pulses produce upsets. Three maps are shown for three increasing pulse energies. In map (a) one upset is observed, and this corresponds to the threshold at which the circuit becomes sensitive. In map (b) multiple upsets are seen, and the cross section is estimated from the area which is proportional to the number of upsets. The region in which the upsets are occurring is identified by comparing the metallization image with the cell layout, and is found to be the region between the gate and drain of the off-state switching transistor. In map (c) a second upset region is also observed, which is associated with the off-state load transistor. Although the transistor gates are essentially transparent to the electron pulse, other metallization lines attenuate the beam and produce shadowing which reduces the apparent sensitive area. In the data shown below, no correction for metal shadowing was made.

In Figure 3 electron pulse data are compared with cyclotron data for SRAM A. The LET at which upsets begin is more clearly defined for the electron pulse data. There are two reasons why this would be expected. Nuclear recoil effects can produce upsets for what would be a nominally low LET. This is because the recoil nucleus is more massive than the incident ion, and therefore has a higher LET. Also, since the cyclotron testing is an average over 1024 cells, atypical cells could contribute small cross sections at low LET. For example, one cell responding with a cross section of 10^{-6} cm^2 will give a cross section of 10^{-9} cm^2 per cell when averaged over 1000 cells. In the electron pulse testing, atypical cells were sometimes observed. These cells had a preferred state and would preferentially switch to the preferred state at a lower threshold than that at which typical cells would toggle. The significance of such atypical cells is that if circuit uniformity can be improved, then LET thresholds will approach the highest level attainable for the circuit design. The capability for determining such effects is a principal advantage of focused electron pulse mapping.

The cross sections for the two testing techniques compare well, considering that no correction has been made for metal shadowing of the electron pulses. An estimate by inspection of the area shadowed suggests that the correction would be less than 50%. This is because the gate metal is thin enough not to cause significant shadowing, and because the most sensitive regions are between the gate and the drain, rather than under the drain metal for crossover lines. Figure 4 shows data for SRAM B. This circuit displayed a higher LET upset threshold and a lower cross section. These data also indicate good agreement between the two testing methods.
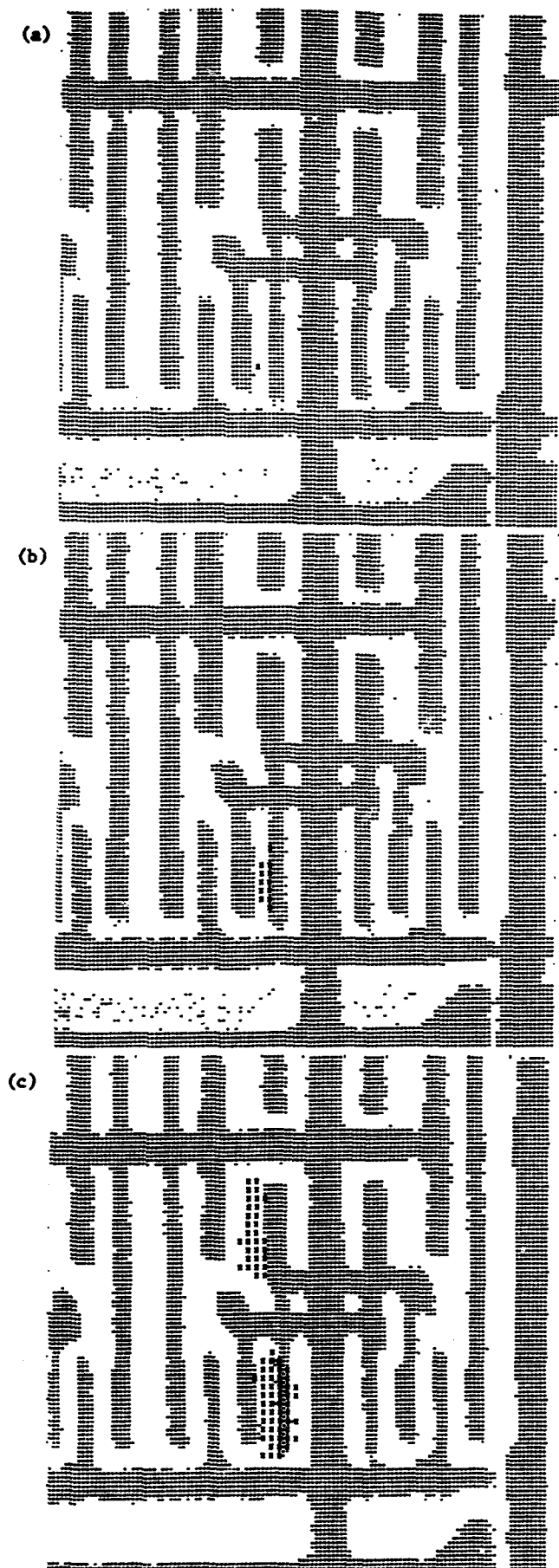
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(a)

(b)

(c)

Figure 2. Typical electron pulse data for SRAM A. Maps (a), (b), (c) were made with effective LETs of 2.1, 2.8, and 6.3 MeV/mg/cm^2, respectively. The dashes show the metallization pattern derived from the secondary electron image, and the X's show the locations at which upsets occurred.

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Figure 3. Comparison of the upset cross section per cell versus effective LET for heavy ions (o) and focused electron pulses (x). The data shown are for SRAM A.
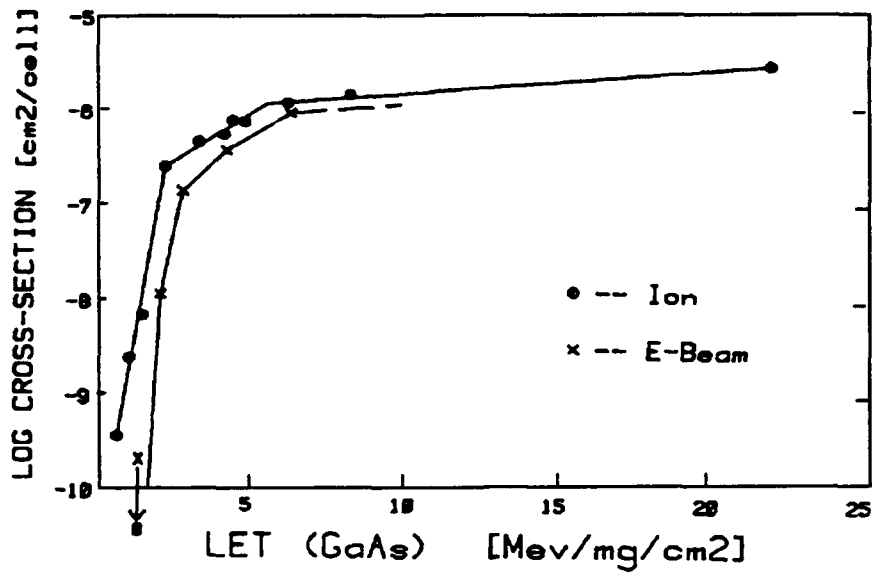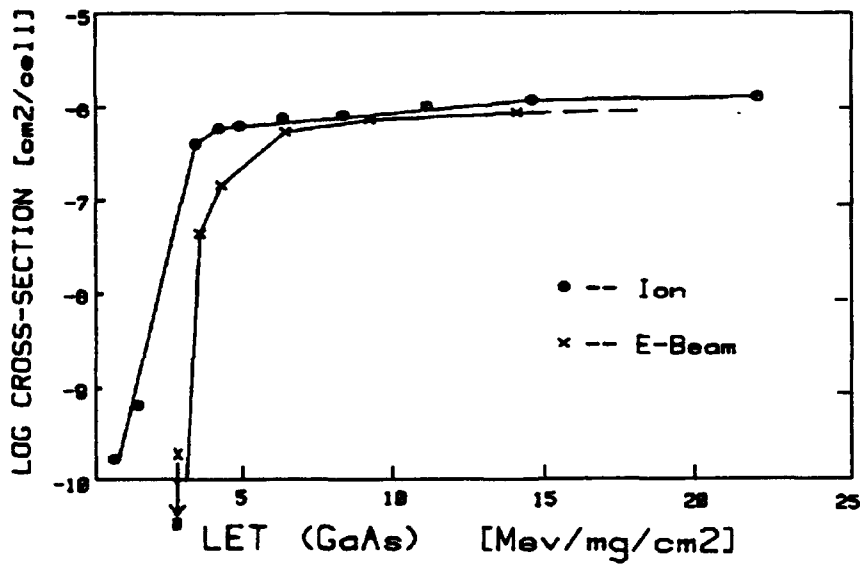

Figure 4. Comparison of the upset cross section per cell versus effective LET for heavy ions (o) and focused electron pulses (x). The data shown are for SRAM B.

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IV. SUMMARY

The data presented in this report indicate that focused electron pulses provide a reasonable simulation of single-particle events for the circuits tested. Similar experiments with heterojunction GaAs SRAMs are in preparation. The method could be applied to Si circuits without necessarily causing total dose degradation, but whether the accuracy of the simulation would also be satisfactory for Si circuits is speculative. We suggest that an experimental answer to the question is desirable, and work directed to this purpose is planned.

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APPENDIX

The insensitivity of GaAs devices to total dose degradation is a considerable convenience for upset testing, whether by ions or by electron pulses. Since Si circuits are generally more sensitive to degradation by ionizing radiation, it is interesting to speculate regarding the feasibility of electron pulse testing for Si. The advantages of spatial mapping, and the ability to synchronize pulses with circuit timing would greatly facilitate testing of Si integrated circuits.

If one wished to employ an equivalent LET of 100 MeV/mg/cm^2, with pulses spaced at 1 μm, the energy delivered for each map dataset would be 10^{10} MeV/mg. This equals 1.6 x 10^5 rad per map, which would not be prohibitive, since circuits with total dose tolerances well in excess of this value are most likely to be of interest. Some caution would be required in order to make multiple maps at increasing LET, if the same circuit elements were to be repeatedly exposed.

Imaging of the circuit for upset registration could be done either optically or by low-energy scanning electron microscopy.

TECHNOLOGY OPERATIONS

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