200p-

UCID-

16434

This is an informal report intended primarily for internal or limited external distribution. (The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.) This report is not to be given additional external distribution or cited in external documents without the consent of the author or LLL Technical Information Department.

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

TIME RESOLVED DETECTION WITH MOS
RADIATION DETECTORS WITH MEMORY

J. W. Balch

July 5, 1973

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

GB

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REFER QUESTIONS TO: J. W. Balch	LAWRENCE RADIATION LABORATORY	ELECTRONICS ENGINEERING REPORT LIVERMORE, CALIFORNIA	UNIVERSITY OF CALIFORNIA	LER 73-102801
ORIG. J. W. Balch	TIME RESOLVED DETECTION WITH MOS RADIATION DETECTORS WITH MEMORY			DATE 7/5/73
APPROVED <i>[Signature]</i>				PAGE 1 OF 10

SUMMARY

MOS radiation detectors with memory have been used to time resolve a portion of an electron beam pulse from a 704 Febetron. These detectors have the three functions of detection, memory and read-out all integrated into a single device so that time resolved detection can be performed without the requirement of real-time diagnostics. Good agreement (Fig. 5) was obtained between the waveshapes of the time resolved signal of the MOS radiation detector with memory and a real time MOS radiation detector used as a reference monitor of the Febetron's pulse. The time resolution of the detector system was 6.6 nsec. No effort was made to calibrate the output of the MOS detectors with radiation dose.

INTRODUCTION

MOS radiation detectors with memory have been used previously for x-ray time integral detection¹ and for time resolved x-ray detection². In addition to x-rays, these detectors are also known to be sensitive to electrons³. For laboratory development we have found it convenient to use a 704 Febetron pulsed electron beam source of irradiation to investigate time resolved detection with these detectors. Using these MOS radiation detectors we have time resolved a portion of the Febetron's pulse.

The detector system consisted of six MOS transistors (MOSFETs) placed periodically along a tapped delay line as shown in Figure 1. The basis of operation of this detector system with memory² is the voltage dependent radiation sensitivity of MOS devices and their permanent storage of the radiation induced signal. The active region of the devices for both detection and memory is the SiO₂ layer between the metal gate and the silicon substrate. For the detector system of Figure 1, each MOSFET stores a signal that is approximately proportional to the time integral of the product of the radiation dose deposited in its SiO₂ layer and the voltage applied across the SiO₂ during the irradiation⁴. Thus, in Figure 1, if a constant bias-strobe pulse, whose duration is greater than the radiation pulse, is propagated down the tapped delay line coincident with the radiation pulse, each MOS detector will be sequentially turned-on and will store a signal proportional to its integrated radiation dose from the time the detector was turned on until the end of the irradiation. Since each MOSFET is an integral detector, the difference in integrated dose of two adjacent MOSFETs is proportional to the average dose delivered to the detector system in the time interval Δt between their turn-on times.

The physical mechanism of signal storage in the MOS device is positive charge (holes) trapped in the gate oxide. Readout of this radiation induced oxide charge is accomplished by monitoring the threshold voltage shift of the MOSFET's drain voltage versus gate voltage characteristic. For p-channel enhancement mode devices, positive oxide charge shifts the MOSFET's threshold voltage to increasingly negative voltages.

EXPERIMENTAL PROCEDURE

The experimental setup used in these experiments is outlined in Figure 2. All irradiations were performed inside a vacuum chamber at a pressure of about 5×10^{-2} torr. The 704 Febetron produces a pulse of electrons having a maximum energy of 350 keV and a maximum beam energy of 5 joules. The maximum surface dose into aluminum is 2.5 Mrads. In these experiments we used aluminum foil attenuators to reduce the surface dose to an estimated 10^3 to 10^4 rads at the detectors so that we could repeatedly pulse (10-15 pulses) a given set of MOSFETs without driving them into saturation. The pulse width of the Febetron is about 20 nsec at FWHM but has a baseline pulse width of about 60 nsec due to a long low intensity tail.

For the detector system we used six commercial MOSFETs (General Instrument MEM 520 with cans removed) equally spaced around the circumference of a 0.5 inch diameter circle on a P.C. board with 6 nsec lengths of RG 176B delay cable interconnecting their gates as shown in Figure 1. The gate-substrate capacitive loading of the transmission line increased the average time delay between MOSFETs to 6.6 nsec so that during a single irradiation the detector system could time resolve only a $6 \times 6.6 = 33$ nsec portion of the 60 nsec wide Febetron pulse. We chose not to time resolve the entire Febetron pulse during a single irradiation until we were assured by these simpler experiments that the detector system was functioning and was understood adequately.

To know what portion of the Febetron pulse we were time resolving with the MOS detectors with memory, we experimentally observed when the MOSFETs were "turned-on" with respect to the Febetron pulse. This was done by monitoring on a dual channel oscilloscope in the Add Mode the bias-strobe pulse at the end of the detector's transmission line and the response of a separate real time MOS radiation detector to the entire Febetron pulse. Knowing when the last MOSFET on the transmission line was turned on with respect to the Febetron pulse and the time delay between MOSFET's, we could determine when each MOSFET was "turned-on". Figures 3a, 3b and 3c respectively, show typical waveforms of (1) the monitor signal of a real time MOS radiation detector, (2) the bias-strobe pulse observed at the end of the transmission line, and (3) the simultaneous display of the above two signals using the oscilloscope's Add Mode to show the time relationship between the Febetron pulse and the bias-strobe pulse.

The bias-strobe pulse was monitored at the end of the transmission line by the x20 attenuator signal pickoff shown in Figure 1. The bias-strobe pulse was generated by an avalanche transistor pulse circuit which was triggered by a signal from the pulse voltage monitor (PVM) of the 704 Febetron. The bias-strobe pulse had a voltage of either 5 or 12 volts, a pulse width of 60-100 nsec and a measured rise time at the end of the transmission line detector of about 2 nsec. The fall time of the pulse was relatively long, as shown in Figure 3b, but this is unimportant so long as the bias pulse width is wider than the radiation pulse being detected. The relative time positions of the bias-strobe pulse with respect to the Febetron pulse could be varied by changing the delay cable length between the PVM output and the Trigger Input of the avalanche transistor pulse generator (see Figure 2). The electronics were fast enough that the bias-strobe pulse appearing at the first MOSFET of the detector's transmission line could be advanced 11 nsec ahead of the Febetron pulse. Less than 2 nsec jitter was observed between the bias-strobe pulse and the Febetron pulse for successive shots.

The monitor signal shown in Figure 3a was obtained from the circuit of Figure 4. The monitor signal is the voltage developed across R_1 and the 50Ω impedance of the coax signal cable by the ionization currents that flow from the d.c. biased real time MOS radiation detector (also a MEM 520 MOSFET). A major portion of the ionization currents is due to electrons ionized in the MOSFET oxide and swept out of the oxide into the metal gate and from there through the external circuit -- C_s and R_1 . Therefore, the signal observed across R_1 was used as a reference waveform of the instantaneous charge storage in the oxide and, thus, is representative of the waveform to be time resolved. The monitor MOSFET was located on the same P.C. board used to hold the six MOSFETs of the transmission line detector system.

To achieve time resolved detection with the MOSFET radiation detector with memory, we found it necessary to carefully select discrete MOSFETs with equal radiation sensitivities. This was done by irradiating at a 5 V d.c. radiation bias some 30-40 MOSFETs, six at a time, to categorize their threshold voltage shifts. Typical threshold voltage shifts for these irradiations of 10^3 to 10^4 rads were 0.5 volts. From this categorization, six MOSFETs with comparable radiation sensitivities would be selected and given a series (1-4) of subsequent irradiations at 5 V d.c. radiation bias to see how close they tracked. If for these subsequent irradiations the six MOSFETs had equal threshold voltage shifts, ± 25 mV, they would be used for the time resolved experiments.

RESULTS

The time resolved signals shown below for the MOS radiation detector with memory are plotted as the difference in threshold voltage shifts of adjacent MOSFETs on the transmission line. These sketches show only the relative shape of the time resolved signal. At present, we have made no attempt to relate the threshold voltage shifts to absorbed dose. The threshold voltage shifts of the individual MOSFETs were obtained from measurements of threshold voltage immediately before an irradiation and within three minutes after an irradiation.

For each time resolved experiment an oscilloscope waveform like that of Figure 3c was obtained showing the relative time position of the Febetron pulse and the bias-strobe pulse of the MOS radiation detector with memory. Using these waveforms the time resolved data obtained from the MOS radiation detector with memory was plotted as a function of time relative to the signal of the real time MOS radiation detector. Figure 5 shows several resulting waveforms with the time resolved data plotted as bar graphs below sketches of the typical radiation pulse shown in Figure 3a as seen by the monitor signal detector. Negligible variation of the shape of the monitor signal was observed, although its amplitude did vary from shot to shot. The waveforms of Figures 5a and 5b were obtained with two different groups of six MOSFETs each.

The shape of the MOS time resolved data shown in Figure 5 corresponds to the monitor signal waveform, particularly the locations of the peak of the signal and the leading edge of the pulse. The variation in amplitude of the MOS time resolved waveform from one shot to another was due to many factors--principally, the variation of Febetron output and the decreasing radiation sensitivity of MOSFETs that were repeatedly irradiated.

In Figure 5b note the rapid rise of the MOS time resolved signal coincident in time with the leading edge of the Febetron pulse. For this series of shots the first two MOSFETs of the transmission line detector had been biased on before the radiation pulse at $t = -11$ nsec and $t = -4.4$ nsec with respect to $t = 0$ being the beginning of the Febetron pulse. The 15 - 20 mV of signal registered by these first two channels of the transmission line detector is essentially the noise level of the system and can be explained by the variation in radiation sensitivity of these MOSFETs.

We did not time resolve the falling edge of the Febetron pulse because of a lack of suitable MOSFETs with comparable radiation sensitivities. We did not try to thermally erase the signals on any MOSFETs and reuse the devices. Past experience has shown that the stored signals (charges) of these particular MOSFETs do not easily erase thermally.

CONCLUSION

We have obtained good agreement between the waveshape of the Febetron pulse as detected by a real time MOS radiation detector and that detected by an MOS radiation detector system with memory. The important point to note is that we experimentally observed when each MOSFET was biased on with respect to the Febetron pulse and that the stored signals in MOS radiation detectors with memory yielded a waveform whose leading edge and peak occurred at the proper time with respect to the Febetron pulse.

The time resolution of these experiments was limited to 6.6 nsec by choice. The maximum time resolution of these systems is limited to about 1-2 nsec by the rise time of the avalanche pulse generator and the bandwidth of the tapped delay line. Presently work is underway to develop higher resolution systems. For detection of pulses of 1-3 nsec or less an integrated silicon system that uses microstrip delay lines on silicon substrate is being investigated. This latter system will have a potential time resolution of about 0.1 nsec. For detection of wider pulses (1-20 nsec), a hybrid integrated circuit system that uses microstrip delay lines on ceramic substrates is 80% completed. This hybrid system presently has a time resolution of 1.5 nsec, and with improvements a time resolution of 1 nsec or less is expected.

Further development areas of the detector system include (1) integration of the MOSFETs onto a single silicon chip so that higher spatial resolution is possible and so that all the detector elements have uniform radiation sensitivities, (2) development of techniques for controlled erasure of the stored charge so that devices may be reused, (3) calibration of the detectors for pulsed irradiations and (4) a study of oxide charge decay within a fraction of a second after irradiation.

J. W. BALCH
Electronics Engineering Department

J. W. Balch

K. MAYEDA
Electronics Engineering Department

K. Mayeda (J.P.)

Copy to:

G. A. Armantrout
T. A. Boster
T. Burgess
J. Carothers
D. Ciarlo
L. L. Cleland
L. Coleman
P. Ebert
E. Fischer-Colbrie
W. Gieri
T. Huen
R. Kalibjian
L. Koppel
V. R. Latorre
E. Lafranchi
W. Krupke
L. Loquist
G. Longerbeam
C. McConaghy
H. McDonald
W. Mead
J. R. Morton
R. Rossman
R. Rufer
J. N. Shearer
V. L. Smith
H. W. Van Ness
C. E. Violet
J. C. Watson
R. Wichner
R. Wyman
Patent Engineering

References:

- (1) D. R. Ciarlo, et al., UCRL-73222, Oct. 8, 1971.
- (2) R. Kalibjian, et al., UCRL-73493, Feb. 16, 1972.
- (3) J. R. Szeden and J. E. Sandor, Appl. Phys. Lett. Vol. 6, pp. 181-182, May 1, 1965.
- (4) J. P. Mitchell, IEEE Electron Devices, Vol. ED-14, pg. 764, Nov. 1967.

Figure 1. Schematic of MOS radiation detector system with memory.

Figure 2. Experimental arrangement used for irradiations.

(a)

(b)

(c)

- Figure 3. Signals monitored during irradiations.
- (a) Response of a real time MOS radiation detector to the Febetron pulse. Approximate waveform to be time resolved.
 - (b) Bias-strobe pulse measured at the end of the transmission line of the MOS radiation detector with memory. Attenuation x20.
 - (c) Simultaneous display of (a) and (b) above showing time relation between the Febetron pulse and the bias-strobe pulse at the end of the transmission line.

Figure 4. Schematic of circuit used to obtain the response of a real-time MOS radiation detector.

Figure 5. Time resolved signals of MOS radiation detectors with memory relative to Febrtron pulse.

(a) Sketches of a typical monitor signal obtained with a real-time MOS radiation detector (see Fig. 3a).

(b) & (c) Bar graphs of time resolved signals obtained with two MOS radiation detector systems with memory.

DISTRIBUTION

LLL Internal Distribution

TID File

3

External DistributionDivision of Technical Information, Ext.
Oak Ridge, Tennessee

2

Captain Glenn Doughty
Air Force Weapons Lab
Technology Division
DYX
Albuquerque, New Mexico 87117

1

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."