IN-33-CR

149012

45 P.

HAMPTON UNIVERSITY
HAMPTON, VIRGINIA 23668

DEPARTMENT OF PHYSICS

July 14, 1988

NASA Scientfic and Technical
Information Facility
P.O. Box 8757
Baltimore-Washington International
Airport, MD 21240

Dear Sirs:

Please find enclosed 2 copies of the Semi-annual Technical Report for NASA grant NAG-5-929.

Sincerely,

Demetrius D. Venable, Ph.D.
Chairman

Enclosure(s)

cc: Ms. G. Wiseman
Dr. E.G. Stassinoupolos
Dr. L.P. Clark

(NASA-CR-183053) EFFECTS OF COSMIC RAYS ON SINGLE EVENT UPSETS Annual Report (Hampton Inst.) 45 p CSCL 09C

N88-26569

Unclas

G3/33 0149012

(ANNUAL REPORT)

NASA GRANT NAG-5-929

Effects of Cosmic Rays on Single Event Upsets

Hampton University

Department of Physics and Department of Engineering

Hampton, Virginia 23668

Principal Investigators

Calvin W. Lowe
Adebisi O. Oladipupo
Demetrius D. Venable

Faculty Advisor

Thomas N. Fogarty

Technical Monitor

E.G. Stassinopoulos
NASA Goddard Space Flight Center
Greenbelt, MD

July 1988

ABSTRACT

NASA GRANT NAG-5-929

Effects of Cosmic Rays on Single Event Upsets

Hampton University
Department of Physics and Department of Engineering
Hampton, Virginia 23668

In this first annual report, we discuss our efforts at establishing a research program in space radiation effects. The research program has served as the basis for training several graduate students in an area of research that is of importance to NASA. In addition, we have provided technical support for the Single Event Facility Group at Brookhaven National Laboratory.

TABLE OF CONTENTS

Introduction

Complex VLSI circuits are used for control, communication and computing purposes. A continuous trend toward higher integration levels resulting in smaller device geometries makes them more susceptible to several types of radiation damage, when they are submitted to ionizing radiation. The effects range from Single Event Upsets (SEU) and parametric degradation to complete device failure[1]. In sensitive applications such as military systems, nuclear power, and space missions, the device failure may be catastrophic. While the defense community has developed considerable background in Radiation Hardened Integrated Circuit technology for high dose rate exposures, the space community has been concerned with the effects of Natural Space Radiation usually of lower dose rate and different composition.

Over the past several years NASA has shown considerable interest in human resource development of minority graduate students. In response to these concerns a NASA supported International Conference on Natural Space Radiation Effects was held in January 1987. The work presented at this conference served as the basis of much of the research planned at Hampton University under the grant "Effects of Cosmic Rays on SEU" (NAG-5-929) - E.G. Stassinopoulos, NASA Technical Monitor, Goddard Space

Flight Center, T.N. Fogarty, AT&T-Bell Laboratories (BL) Advisor, D.D. Venable, C.W. Lowe, and A.O. Oladipupo, Principal Investigators and V. Zajic and P. Mawanda-Kibuule, Research Assistants.

Through the above contract, the Single Event Facility Group (SEFG) - formed in 1987 as a consortium of several government agencies (NSA, NASA, USASDC, and NRL) receives constant maintenance and upkeep of services from Hampton University at their Single Event Upset Test Facility (SEUTF) at the Brookhaven National Laboratory. As much of the research performed by SEUTF users generates data that is ITAR restricted, none of the people involved in this program at Brookhaven are foreign nationals other than those holding permanent working visas ("green cards").

In order to fully promote the human resource goal of minority graduate research and to allow for investigative projects of greater proportions than any one university can pursue, Hampton University is expanding its role in these areas by such actions as serving as the lead institution for a proposed Minority University Consortium for the Study of Space Radiation Effects on Materials, Devices, and Systems; and is planning to establish an Institute for research and graduate training in space radiation phenomena.

Technical Discussion

Natural Space Radiation is an integral part of the space environment. Typically, cosmic rays consist of charged particles with energies that cover a significantly broader range than any producible on Earth. The International Conference on Space Radiation Effects (NASA JSC, January 1987) reiterated the space environments of concern to be either 1-2 MeV electrons, 1-500 MeV protons, alphas, solar flares, high energy heavy ion, galactic cosmic rays, or some combination thereof. Depending on the flight path, it is also important to consider the effects of trapped electrons and protons in Van Allen radiation belts. An Advanced Solar Proton Prediction Model (PPS-87)[14] was presented at the 6th Annual Symposium on Single Event Effects sponsored by DoD, DOE, and NASA (Los Angeles, April 1988).

Complex VLSI circuits used in space-borne systems for control, communication, and computing purposes are continually bombarded by energetic charged particles. When passing through the devices, the charged particle lose part of their kinetic energy by ionization, and an electron-hole plasma column is formed along the incident particle track. Under the influence of internal electric fields in sensitive depletion regions, the charge may be separated and collected at critical device junctions. This induced charge collection can cause a state change or bit-flip of a particular memory location within the device from the "0" state to the "1" state and vice versa. When the circuit again accesses such a device, no indication of permanent damage is perceived, giving rise to the term "soft error". In general, the amount of energy deposited inside the medium increases with increasing charge of the incident particle. Hence the examination of this phenomena becomes particularly important for highly stripped energetic heavy ions. In some cases, a single ion can cause the device to latch up. The consequence of latch-up can lead to catastrophic failure (burn-out) unless the device power is turned off before burn-out occurs. The critical charge required for SEU was shown to decrease with the square of the feature size, while the collected charge depends primarily on Linear Energy Transfer (LET) and thickness of the sensitive region. Hence, scaling down the dimensions increases the device susceptibility to SEU. Ground based tests of device susceptibility to SEU and burn-out were reported by many authors using charged particle accelerators[2-7] (electrons, protons, and heavy ions) and Cf-252 fission fragments[12-13]. For a given technology, the cross sections were shown to be dependent on LET, bias, and to some extent also on total dose and the type of charged particle radiation.

Accumulated total-dose radiation effects reflect the total amount of ionizing radiation that a device absorbs over long periods of time. Radiation induces oxide and interface charge resulting in gradual electrical parameter degradation such as flat-band voltage shift, transconductance degradation, and threshold voltage shift, and can even lead to complete device failure[8-11, 29-30]. For example, the total dose parametric shifts, including the threshold voltage rebound above the preradiation value when annealed under inversion bias, were confirmed by Diogu et al.[9] and Winokur et al.[10]. Secondary radiation produced by 1 MeV proton bombardment (total dose 1 MRad(Si)) of capped and uncapped NMOS transistors was shown to result in significant parametric degradation (also see Appendix). Recent evidence also suggests a dose rate dependency of failure mechanisms, demonstrated by Winokur et al.[9] for dose rates ranging from 0.10 to 100 Rad (Si)/sec.

The major objectives of the present contract are (a) to establish a graduate research program at Hampton University in which to utilize the Brookhaven Twin Tandem Van de Graaff Heavy Ion Accelerator for SEU research; (b) to develop a computer based model, embodying the results of experimental SEU cross sections data and the known physics of interaction between ionizing radiation and matter; and (c) to develop techniques to reliably predict the SEU susceptibility of VLSI circuits in space applications.

The contract stipulates that the designated Hampton University full-time personnel will spend up to 50% of a man-year per person at the Brookhaven SEUTF. Upon notification from the chairman of SEFG, Hampton University will dispatch the maintenance crew (a post-doc fellow and an electronic technician) one day before any scheduled experiment, in order to check the SEUTF equipment and make sure the system is fully operational. These professionals will be standing by at BNL for the entire duration of the scheduled beam time to perform repairs, if anything should go wrong with SEUTF equipment only. They will not participate in nor assist users with the performance of their experiments, unless the user is Hampton University. The maintenance crew will also shut down the facility after the user has completed his experiment or exhausted his beam time.

Equipment

Having several pieces of needed equipment either on hand from Hampton University's inventory or as loaned items from NSA and AT&T Bell Laboratories, we were able to accomplish a fast start-up. As a result of this experience, device fabrication, irradiation, diagnostic, and computing equipment selected and purchased from our budget has a higher certainty of meeting functional demands.

Some equipment is also available through the AT&T-BL College Gift Program. A summary of pertinent equipment is given below:

1) An AT-compatible PC (640 K RAM) with Microsoft MS-DOS operating system has been purchased. A Cannon PV-1080A Color Printer is on loan from T. N. Fogarty. Most computer modeling is being done on this PC. It will also be used to control compatible equipment through an IEEE-488 Interface Bus.

2. An AT&T Unix PC and an AT&T-478 Printer are donated by AT&T-BL. This computer will be used as a central data base for our research efforts. We also plan to install the MS-DOS operating system on this computer.

3. A HP-4192A LF Impedance Analyzer for CV-test is available in the Department of Engineering at Hampton University. The required T-chuck and probe are on loan from AT&T-BL.

4. A HP-4145B Semiconductor Parameter Analyzer for fast transconductance and threshold voltage measurements was on loan from NSA for a portion of the grant period. An identical item has been purchased

from our budget.

5. A high sensitivity (10^{-16} A) KEITHLEY 617 Programmable Electrometer for charge pumping technique has been purchased.
6. A QUA TECH WSB-10C Waveform Synthesizer Board (approximately 100 nsec risetime) residing in the AT-compatible PC has been purchased and used in preliminary charge pumping experiments.
7. A HP-8112A Pulse Generator, 50 MHz (5 nsec risetime) for the charge pumping technique has been purchased. Our preliminary experiments indicated a need of shorter risetime.
8. A low intensity tutorial X-ray source TEL-X-OMETER 580A with a Cu target (maximum dose rate 0.34 Rad (Si)/sec) is available in the Department of Physics at Hampton University.
9. An American Instruments MAX 3100 X-ray Generator with Cu target, maximum dose rate 650 Rad (Si)/sec), for secondary radiation effects simulation has been ordered from our budget. Our initial estimates indicated a need for higher intensity X-rays.
10. Necessary X-ray monitoring equipment has also been ordered. It will be comprised of a TENNELEC TD 38 SX2 2 mm thick NaI(Tl) detector with a thin Be entrance window, TENNELEC TC 154A preamplifier, and corresponding NIM electronics from EG&G ORTEC:

4001A/4002A BIN/BIN Power Supply

478 2-kV Bias Power Supply

460 Delay Line Amplifier

550 Single Channel Analyzer

661 Ratemeter

480 Pulser

Most of the above NIM modules will be also used in the proposed position annihilation experiment.

11. A HP-1600A Logic State Analyzer for SEU testing is available through AT&T-BL College Gift Program.
12. In addition, a plasma deposition reactor, high-pressure steam oxidation unit, vacuum equipment (updated by three VEECO TG-70 Thermocouple Vacuum Controls from our budget), metallization chamber, and a wet bench are available through the same program. A magnetron sputtering system is on loan from AT&T-BL. The above equipment will be used for in-situ growth of MOS capacitors and amorphous Si.
13. A dedicated beam line at SEUTF utilizing the Brookhaven Twin Tandem Van de Graaff Heavy Ion Accelerator (from 27 MeV protons to 350 MeV Au-197 heavy ions) is available for SEU testing. If neces-

sary, additional beam time may be purchased at the low energy Van de Graaff accelerator at Lehigh University (1 MeV electrons or protons) or at the cyclotron at the University of Texas Medical Center (up to 150 MeV Fe-56 heavy ions).

Phase I Work

Hampton University is currently studying "Effects of Cosmic Rays on SEU" (NAG-5-929). The major objectives of Phase I are listed below:

(1) to assemble a research team, which should supervise graduate and undergraduate student activities;

(2) to coordinate the Hampton University support activities for SEFG and other users of SEUTF at BNL;

(3) to install computer codes for secondary radiation affecting VLSI circuits in space and simulate secondary radiation effects using X-rays;

(4) to develop experimental set-up for diagnostic tools such as CV-tests, fast parametric tests and charge pumping technique;

(5) to test SEU susceptibility of SRAMS by means of computer simulation and using SEUTF at BNL;

(6) to generate and analyze data appropriate for the pursuit of graduate

degrees at the Master of Science level;

(7) to develop capabilities for in-situ growth of Silicides and of hydrogenated Amorphous Si.

During Phase I, a viable research team has been assembled and is now functional. A Hampton University Graduate Research Program has been established where Master's degree level graduate students are working on this project. Engaged in the research have been: Dr. Thomas N. Fogarty, AT&T-BL Advisor, faculty members Drs. Demetrius D. Venable, Calvin W. Lowe (Physics department), and Dr. Adebisi O. Oladipupo (Engineering Department). Fulltime personnel are Drs. Vladimir Zajic and Paschal Mawanda-Kibuule, Research Assistant Professors, and Christopher M. Humphry, Research Technician.

Three graduate students (Mr. Kurt Kloesel, Ms. Cecily Smith, and Mr. Duc M. Ngo) and several undergraduate students (Ms. Faith Welch, Ms. Alfreda Branch, Mr. Eric Edwards, Mr. G. Hackaday, and Mr. C. Washington) participated in the project, thus fulfilling the human resource goal. The students have been principally becoming familiar with experimental apparatus and procedures. K. Kloesel has been developing his M.S. thesis proposal in the field of charge pumping techniques. C. Smith has switched to ternary semiconductor compound work under a different NASA contract

(C.W. Lowe, Principal Investigator). D.M. Ngo has submitted his thesis proposal "A Target Fragmentation Model for Cosmic Ray Induced SEU" (Dr. Warren W. Buck, Thesis Advisor, Physics Department, and Dr. John W. Wilson, NASA Technical Advisor, NASA Langley Research Center) and has received a NASA Graduate Student Researchers Fellowship (beginning September 1988) to continue his work.

We have provided technical assistance to Drs. E.G. Stassinopoulos and O.O. Van Gunten from SEFG in the set-up and verification of the Brookhaven SEUTF. The maintenance crew, V. Zajic and C. Humphry, has been dispatched to BNL four times in the past year. During the last trip, the crew was allowed to interact with users and perform necessary repairs independently. Two solid state detectors for heavy ions have been calibrated, using some recent data[15-16] to calculate the Pulse Height Defect (PHD), to make possible a fast check of the beam line energy independent of information from the accelerator control room. A lower detector calibration curve shown in fig. 1 allows the measurement of the beam line energy with an uncertainty better than 1% for lighter ions (such as C-12 or Si-28) and 2% for heavier ions (such as I-127). A high quality thin Al-foil for LET measurements was ordered from Goodfellow Metals.

We have begun to develop a computer code for secondary radiation affecting VLSI circuits in space. This work is being done by V. Zajic and D.M. Ngo. A computer code for electron or proton ionization and radiation energy loss embodying the known corrections of Bethe's original formulas[17-18] has been developed (see fig. 2). The code will also calculate the yields of characteristic X-radiation and bremsstrauhlung when completed with reliable formulas for inner shell ionization cross-sections[41] and fluorescent yields. Another computer code for heavy ion electronic and nuclear stopping power and range based on Ziegler's tables[19] was obtained from J.W. Wilson, NASA LaRC. The code has been modified using natural splines to speed up the calculation of range (see fig. 3), completed with reliable data for particle induced inner shell ionization cross sections[20-21] and fluorescent yields[22] (see fig. 4), and consequently used to estimate the PIXE yields (see fig. 5) in VLSI circuit encapsulation:

$$\text{Yield/Fluence} = w_x N \int_0^{E_1} \sigma_x(E) \frac{dE}{\text{LET}(E)}$$

where w_x is the fluorescence yield, σ_x particle induced ionization cross section, and N the density of target atoms[24]. The assessment of the effects of these X-rays on device performance requires additional transport calculations through the encapsulation and the device itself, using data for X-ray absorption coefficients[23] (see also fig. 5). The code will also be used to estimate secondary gamma-radiation yields provided reliable data for inelastic scattering and radiative capture cross sections are obtained. The Cosmic Ray Upset Model (CRUM) developed at NRL to predict SEUs induced in memory devices operating in space has been installed in our AT-compatible PC and compared with the CREME model. Calculated SEU rates exceeded those obtained with the CREME model 1.3 to 1.4 times indicating the former one to be more conservative.

An experimental set-up for computer controlled CV-test for Terman analysis using the HP-4192A LF Impedance Analyzer is being developed by C. Smith, K. Kloesel, C. W. Lowe, and T.N. Fogarty.

Computerization of the HP-4145B Semiconductor Parametric Analyzer to assemble transconductance curves for NMOS devices has been completed by D.M. Ngo, C.W. Lowe, and T.N. Fogarty. A typical curve set is shown in fig. 6. The transconductance is defined as the devices ability to vary drain current (output) in response to gate voltage variation (input), with the drain-source voltage constant:

$$g_m = \left(\frac{\partial I_D}{\partial V_G}\right)_{V_D}$$

The threshold voltage, V_{TH}, can be obtained by drawing an envelope line as shown in fig. 6 and reading the displayed x-intercept value. For the data presented in fig. 6, V_{TH} is 0.78V.

An experimental set-up for the computer controlled charge pumping technique[26-28], using the WSB-10C Waveform Synthesizer and a KEITHLEY 617 Programmable Electrometer, has been developed by K. Kloesel, V. Zajic, and T.N. Fogarty. The experimental arrangement is pictured in fig. 7. When the NMOS transistor is pulsed from accumulation to inversion, electrons flow into the channel. Some recombine with the trapped holes, others are captured by the interface traps. When the transistor is pulsed back into accumulation, the mobile negative charge drifts to the source and drain, but the trapped electrons recombine with the majority of substrate holes giving rise to a current from the substrate. Essential results reported by earlier authors were reproduced, including the proportionality between charge pumping current, I_{CP}, and frequency for a square waveform (fig. 8), measurement of the mean interface state density, and capture cross section using a sawtooth waveform of variable frequency (fig. 9). The interface state density distribution in the lower or upper half of the band gap was determined using variable risetimes or falltimes, respectively (fig. 10). Since we were not able to cover a substantial part of the band gap using the WSB-10C Waveform Synthesizer (approximately 100 nsec risetime) a HP-8112A Pulse Generator 50 MHz (5 nsec risetime) has been purchased.

A low intensity tutorial X-ray source, TEL-X-OMETER 580A, with a Cu target was considered for X-ray simulation of secondary radiation effects on the oxide and interface trapped charge and parametric degradation of MOS devices. Preliminary testing has been done by A.O. Oladipupo, V. Zajic, and C.W. Lowe. The maximum measured dose rate was approximately 0.34 Rad (Si)/sec of Cu K X-rays using a Ni filter to eliminate higher energy bremsstrahlung. The dose rate was also unstable. Therefore, a higher intensity X-ray source as well as X-ray monitoring equipment have been ordered (see Section 2-Equipment).

In order to choose the most suitable application software for SRAM simulation, P. Mawanda-Kibuule with several students (D.M. Ngo, F. Welch, and A. Branch) have compared MICROCAP II, ALLSPICE and P-SPICE. The sensitivity of individual models was tested calculating SEU susceptibility as a function of channel length, carrier mobility, and feedback resistor values (see fig. 11). MICROCAP II does not account for parasitic parameters making the model inappropriate for channel length L < 2 μm, which is some three generations behind the present day 0.8 μm technology.

Out of the three levels of SPICE II, level 1 can be used for quick estimates, level 2 models V_{TH} based on fundamental device physical parameters such as doping density and channel length. There is a long channel and short channel version of this model. Level 3 uses measured device properties such as V_{TH} and g_m. SPICE III has 4 levels, P-SPICE will be suitable for our studies. We also considered the possibility of using SUPREME application software residing on Howard University's 11/780 VAX computer. In order to access it via SIMNET (Historically Black Colleges and Universities (HBCU) simulation network), installation of a land line has been ordered by A.O. Oladipupo.

Amorphous Si is a material of increasing importance for device fabrication. We have also begun to develop plans for a Multichamber In-situ Deposition and Analysis of Amorphous Silicon system[31-37] to be funded under a future grant. Phase I of this project involved design and assembly, of the system, consisting of a low-pressure plasma assisted chemical vapor deposition reactor, quadrupole mass spectrometer, dry oxidation unit, metallization chamber, and an analysis chamber (see fig. 12). The analysis chamber will be fitted with an X-ray Photoelectron Spectrometer (XPS), High Energy Electron Diffraction (HEED) system, and an sputtering ion gun. A linear transfer mechanism will be used to transport specimen between chambers. The integrity of the system will be monitored via a series of ion gauges. An arrangement of the Solid State Radiation laboratory was designed by T.N. Fogarty, C. Humphry, and K. Kloesel using AUTOCAD application software (see figs. 13-14). The same team also modified the electric power line in the laboratory in order to connect the vacuum station and sputtering ion gun. The vacuum station is being set-up by C. M. Humphry, A.O. Oladipupo, and E. Edwards.

In order to maintain close contact with the scientific community engaged in SEU research, we have attended three meetings and presented one paper[30] in the past year:

(1) Single Event Effects Sixth Annual Meeting held in Los Angeles in April 1988 and sponsored by DoD, DOE, and NASA (attended by T.N. Fogarty and V. Zajic);

(2) Spring Meeting of the Electrochemical Society held in Atlanta in May 1988 (attended by P. Mawanda-Kibuule, K. Kloesel, and T. Fogarty);

(3) Virginia Academy of Science 66th Annual Meeting held in Charlottesville in May 1988 and sponsored by the University of Virginia (attended by D.D. Venable, V. Zajic, and P. Mawanda-Kibuule).

A central reference bibliography for the project is being developed by T.N. Fogarty and C.M. Humphry using WORDSTAR 2000 application software installed on the AT&T Unix PC.

Phase II Goals

For the renewal Phase II of our SEU grant we will continue to conduct all aspects of the research currently being undertaken.

(a) we will further develop the computer code for secondary-radiation affecting VLSI circuits in space including secondary X- and gamma-radiation and nuclear fragmentation[25];

(b) we will simulate secondary radiation effects using a high intensity X-ray source, investigate the device parametric degradation using the installed diagnostic tools such as charge pumping techniques, and consider the possibility of such testing at low temperatures;

(c) we will begin testing SEU susceptibility of SRAMS degraded by various dose rates and total dose exposures and compare these to virgin SRAMS. We also plan to conduct tests at the Brookhaven SEUTF for parts identified by other research efforts of Hampton University e.g. radiation resistant gate dielectrics with Fairchild Laboratory, Lehigh University, and future consortium members,[38-41].

(d) Finally, we will investigate the use of positron annihilation as a diagnostic tool for MOS devices radiation damage. The principal idea behind this to is to utilize different life-times for mobile and trapped positrons when irradiating the device with a positron source such as Na-22. The proposed experimental arrangement is shown in fig. 15.

This project is being performed in collaboration with the Science Directorate of the NASA Goddard Space Flight Center, Greenbelt, MD. The NASA GSFC contact for this effort is Senior Staff Scientist and Project Technical Monitor, Dr. E.G. Stassinopoulos, tel. (301) 286-8067. We wish to acknowledge the fruitful discussions with Drs. J.W. Wilson (NASA LaRC) and E.G. Stassinopoulos (NASA GSFC), and the continuing assistance of Dr. Louis P. Clark (NASA Headquarters) to our research and his concerns for promotion of research at HBCUs. It is expected that in the long term Hampton University will establish a research institute to train significant numbers of minority students in the pursuit of this type of work.

References

1. Messenger, G.C. and Ash, M.S., "The Effects of Radiation on Electronic Systems," Van Nostrand Reinhold (1987).

2. Diehl, S.E., et al., "Error Analysis and Prevention of Cosmic Ion Induced Soft Errors in CMOS SRAMS," IEEE Trans. Nucl. Sci. NS-29 (1982), 2032.

3. Brucker, G.J., et al., "The Damage Equivalence of Electrons, Protons, and Gamma-rays in MOS Devices," IEEE Trans. Nucl. Sci. NS-29 (1982).

4. Stassinopoulos, E.G. et al., "The Damage Equivalence of Electrons, Protons, and Gamma-rays in Rad-Had MOS Devices," IEEE Trans. Nucl. Sci. NS-30 (1983).

5. Brucker, G.J., et al., "Recovery of Damage in Rad-Hard MOS Devices during and after Irradiation by Electrons, Protons, Alphas, and Gamma-rays, "IEEE Trans. Nucl. Sci. NS-30 (1983).

6. Peterson, E.L., et al., "Suggested SEU Figure of Merit," IEEE Trans. Nucl. Sci. NS-30 (1983).

7. McNulty, P.J., et al., "Methods of Calculating SEU Rates for Bipolar and NMOS Circuits," IEEE Trans. Nucl. Sci. NS-32 (1985), 4180.

8. Fogarty, T.N., et al., Proceedings of the International Conference on Natural Space Radiation Effects on VLSI Technology, NASA JSC/Prairie View A&M University, January 1987.

9. Diogu, K.K., et al., "Charge Anomaly at MOS Interfaces Submitted to 1 MeV Proton Radiation," op. cit. 8.

10. Winokur, P.S., et al., "CMOS Device Response and Failure Mechanisms in Satellite Environments," op. cit. 8.

11. Okyere, J.G., "Effect of Transistor Sizing on Circuits for Hardening CMOS SRAMS against SEUs," op. cit. 8.

12. Sanderson, T.K., et al., "The Application of Cf-252 Fission Fragments to SEU and Latch-up Testing of VLSI Devices," op. cit. 8.

13. Block, R.C., et al., "An Advanced Cf-252 System for SEU Testing," presented at the 6th Annual Symposium on SEE, DoD/DOE/NASA, Los Angeles, May 1988.

14. Swart, D.F., et al., "Advanced Solar Proton Prediction Model (PPS-87)," op. cit. 13.

15. Ogihara, M., et al., "Systematic Measurements of Pulse Height Defects for Heavy Ions in Surface-Barrier Detectors," Nucl. Instr. and Meth. A251 (1986), 313.

16. Zoutendyk, J.A., et al., "Field Funneling and Range Straggling in Partially Depleted Silicon Surface-Barrier Detectors," IEEE Trans. Nucl. Sci. NS-31 (1984), 1101.

17. Leo, W.R., "Techniques for Nuclear and Particle Experiments," Springer-Verlag (1987).

18. Sternheimer, R.M., et al., "Density Effect for the Ionization Loss of Charged Particles in Various Substances," At. Data and Nucl. Data Tables 30 (1984), 261.

19. Ziegler, J.F., et al., "Stopping Power and Ranges in All Elements," 5 vols., Pergamon Press (1977).

20. Johansson, T.B., et al., "Analytical Application of PIXE, "Nucl. Instr. and Meth. 137 (1976), 473.

21. Cohen, D.D., et al., "K- and L-Shell Ionization Cross Sections for Protons and Alphas," At. Data and Nucl. Data Tables 33 (1985), 255.

22. Bambynek, W., et al., "X-ray Fluorescence Yields, Auger and Coster-Kronig Transition Probabilities," Rev. Modern Phys. 44 (1972), 716.

23. Gerward, L., "Analytical Approximations for X-ray Attenuation Coefficients," Nucl. Instr. and Meth. 181 (1981), 11.

24. Wilson, J.W., et al., "X-ray Production in Low Energy Proton Stopping," NASA Technical Memorandum 100619 (1988).

25. Wilson, J.W., et al., "A Baryon Transport Computer Code," NASA Technical Memorandum 4037 (1988).

26. Groeseneken, G., et al., "A Reliable Approach to Charge-Pumping Measurements in MOS Transistors," IEEE Trans. Electron. Dev. ED-31 (1984), 42.

27. Cilingiroglu, U., "A General Model for Interface-Trap charge-Pumping Effects in MOS Devices," Solid State Electronics 28 (1985), 1127.

28. Saks, N.S., et al., "Generation of Interface-States by Ionizing Radiation at 80°K Measured by Charge-Pumping and Subthreshold Slope Techniques," Proceedings of 1987 Annual Conference on Nuclear and Space Radiation Effects, IEEE/NPSS, July 1987.

29. Fogarty, T.N., et al., "Simulation of Natural Space Radiation Effects on VLSI Technology," Abstract #624, Extended Abstracts 87-2, Electrochemical Society Fall Meeting, 1987.

30. Zajic, V., et al., "Natural Space Radiation Effects on Materials, Devices and Systems," presented at Virginia Academy of Science 66th Annual Meeting, VAS, Charlottesville, May 1988.

31. Roopwah, K., et al., "Properties of Glow-Discharge Intrinsic a-Si:H Submitted to 2 MeV Proton and Electron Radiation," SERI Advanced Photovoltaic Conference, to be published.

32. Mahan, A.H., et al., "Evidence for Microstructure in Glow-Discharge a-Si:H Alloy," Proceedings of the SERI PV AR&D Conference, Denver, May 1986.

33. Maissel, L.I. and Glang, R., "Handbook of Thin Film Technology," McGraw Hill (1970).

34. Vossen, J.L. and Kern, W., "Thin Film Processes," Academic Press (1978).

35. Takagi, T., et al., "An Evaluation of Metal and Semiconductor Films Formed by ionized Cluster Beam Deposition," Thin Films 39 (1976).

36. Coutumas, T.C., Fogarty, T.N., Harshberger, R., and Porter, R., "Plasma Assisted Vacuum Deposition," private communication (1978).

37. Fogarty, T.N. and Frasier, D., "Magnetron Sputtering of Aluminum Alloys and Tantalum Silicide," private communication (1980).

38. Grunthaner, F.J., et al., "Chemical and Electronic Structure of the SiO_2/Si Interface," Material Sci. Rep. 1 (1986), 65.

39. Nishioka, Y., et al., "Dramatic Improvement of Hot Electron Induced Interface Degradation in MOS Structure Containing F or Cl in SiO_2," IEEE Electron. Dev. Lett. 9 (1988), 39.

40. da Silva, Jr., E.F., et al., "Radiation Response of MOS Capacitors containing Fluorinated Oxides," IEEE Trans. Nucl. Sci. NS-34 (1987), 1190.

41. Powell, C.J., Rev. Mod. Phys. 48 (1976), 33.

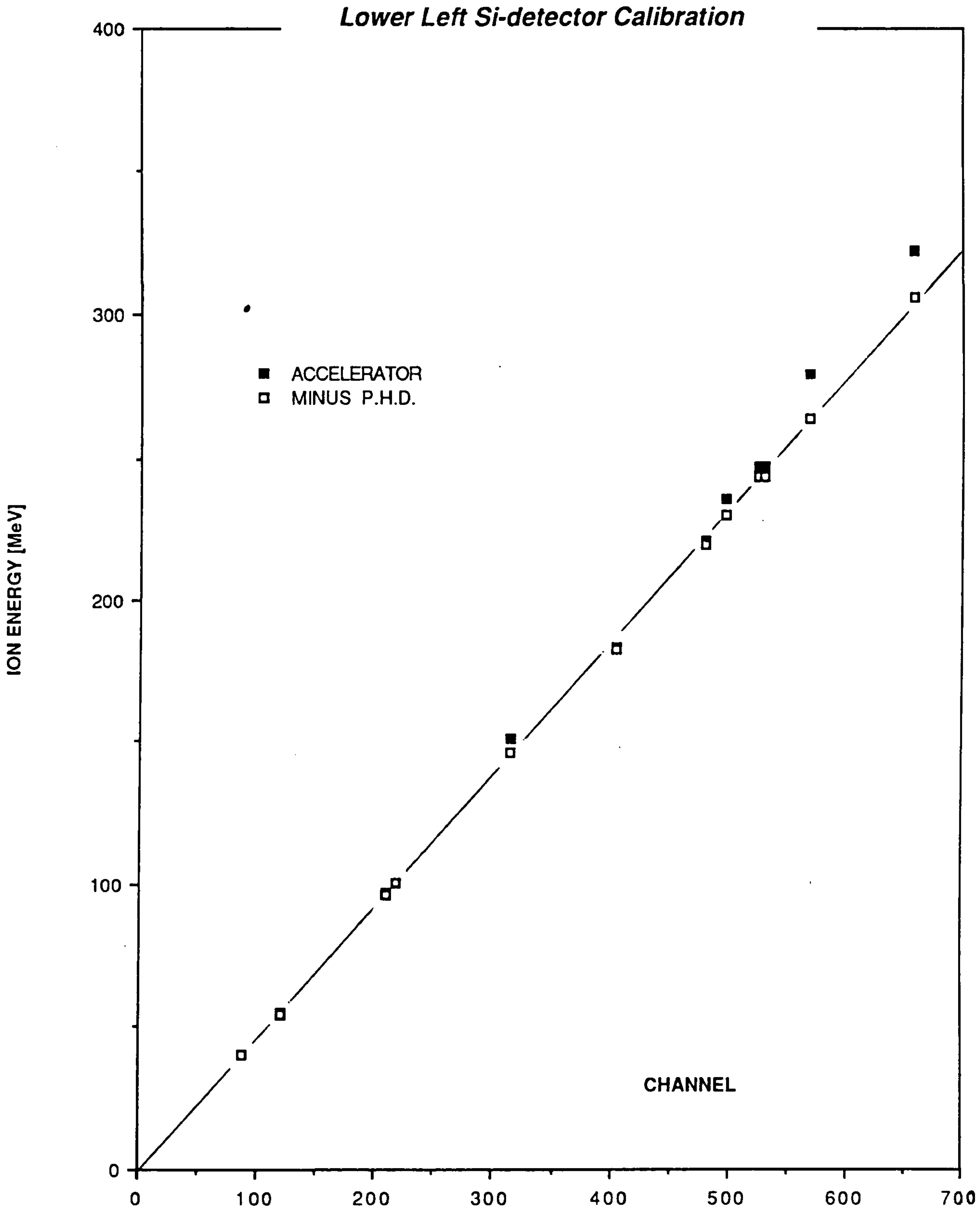


Fig. 1: A heavy ion solid state detector calibration curve measured at the Brookhaven SEUTF using 40 MeV C-12 to 320 MeV I-127 ions.

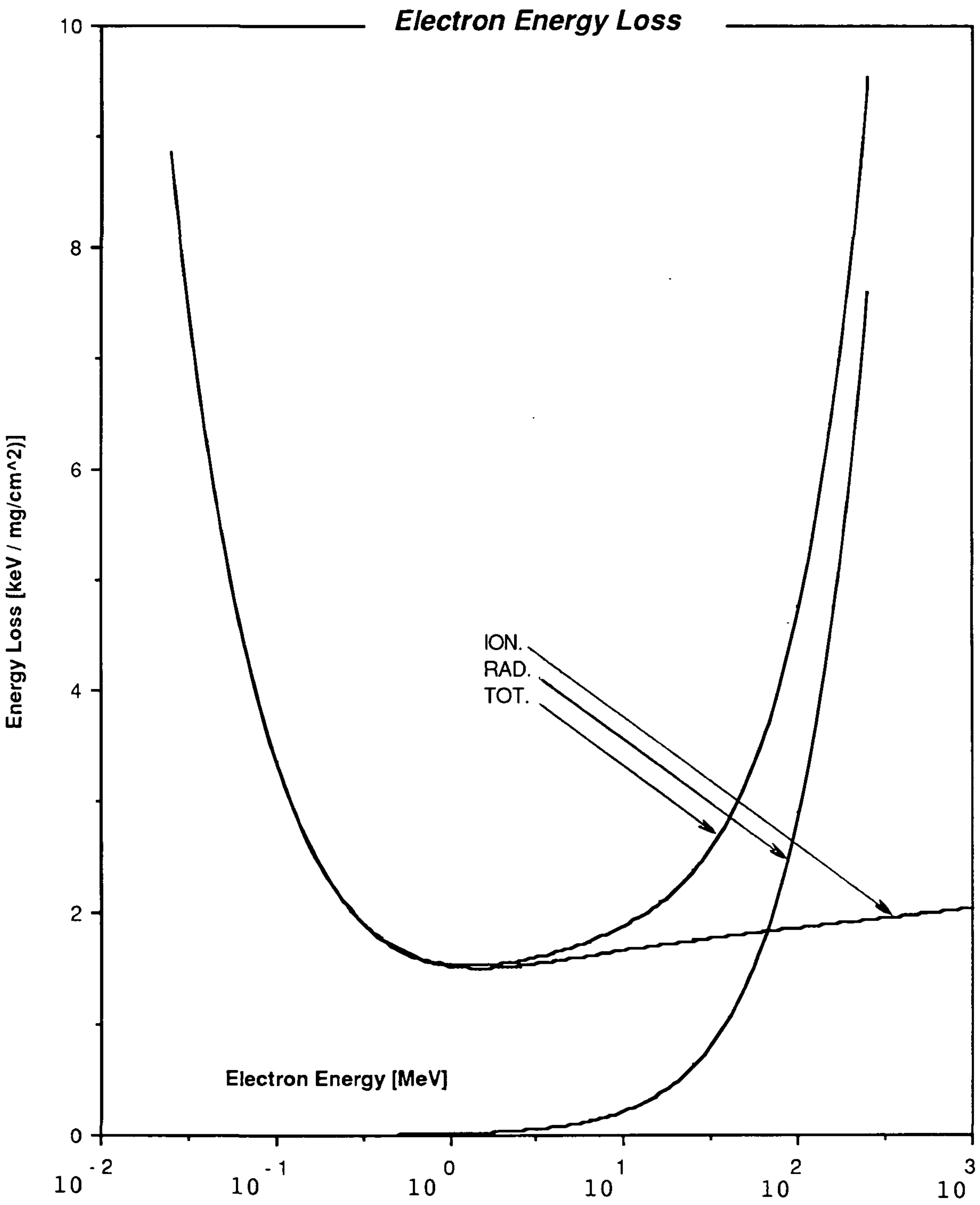
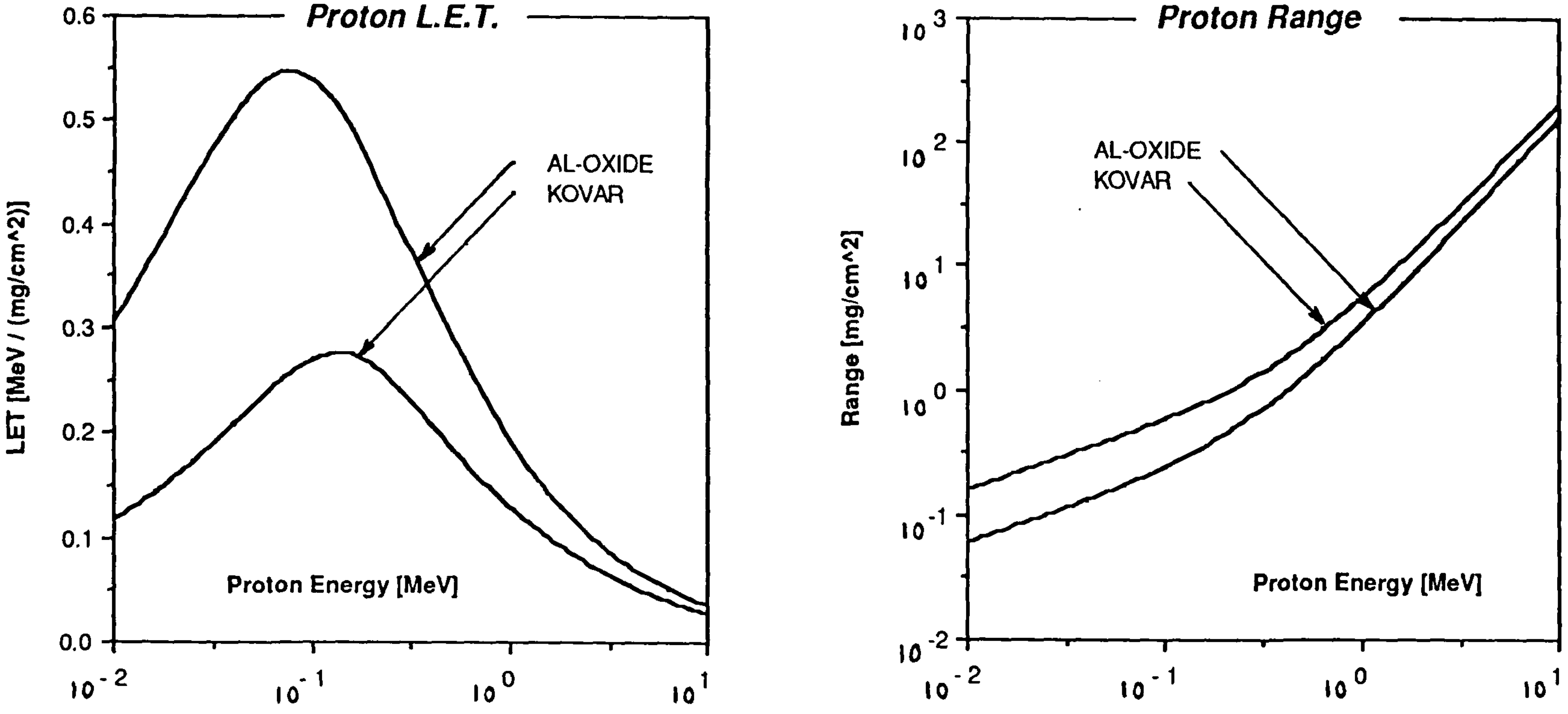


Fig. 2: Calculated ionization and radiation energy loss for electrons in Al-oxide.

$$\text{Range} = \int_{0}^{E_p} dE \,/\, \text{LET}\,(E)$$



(A) (B)

Fig. 3: Calculated stopping power (A) and range (B) for protons in Al-oxide and Kovar.

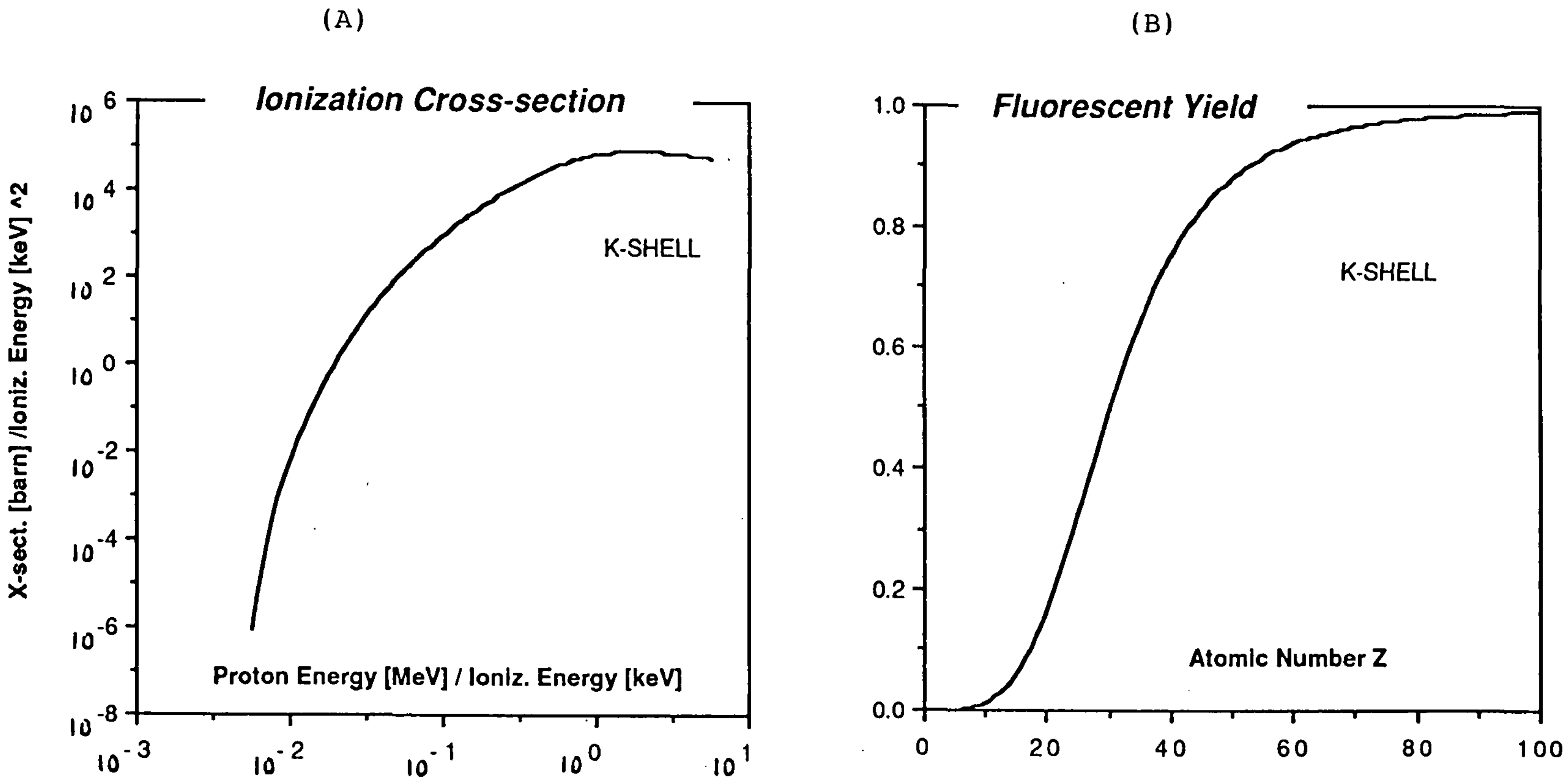


Fig. 4: A universal curve for experimental proton induced K-shell ionization cross sections (A) and K-shell fluorescence yields.

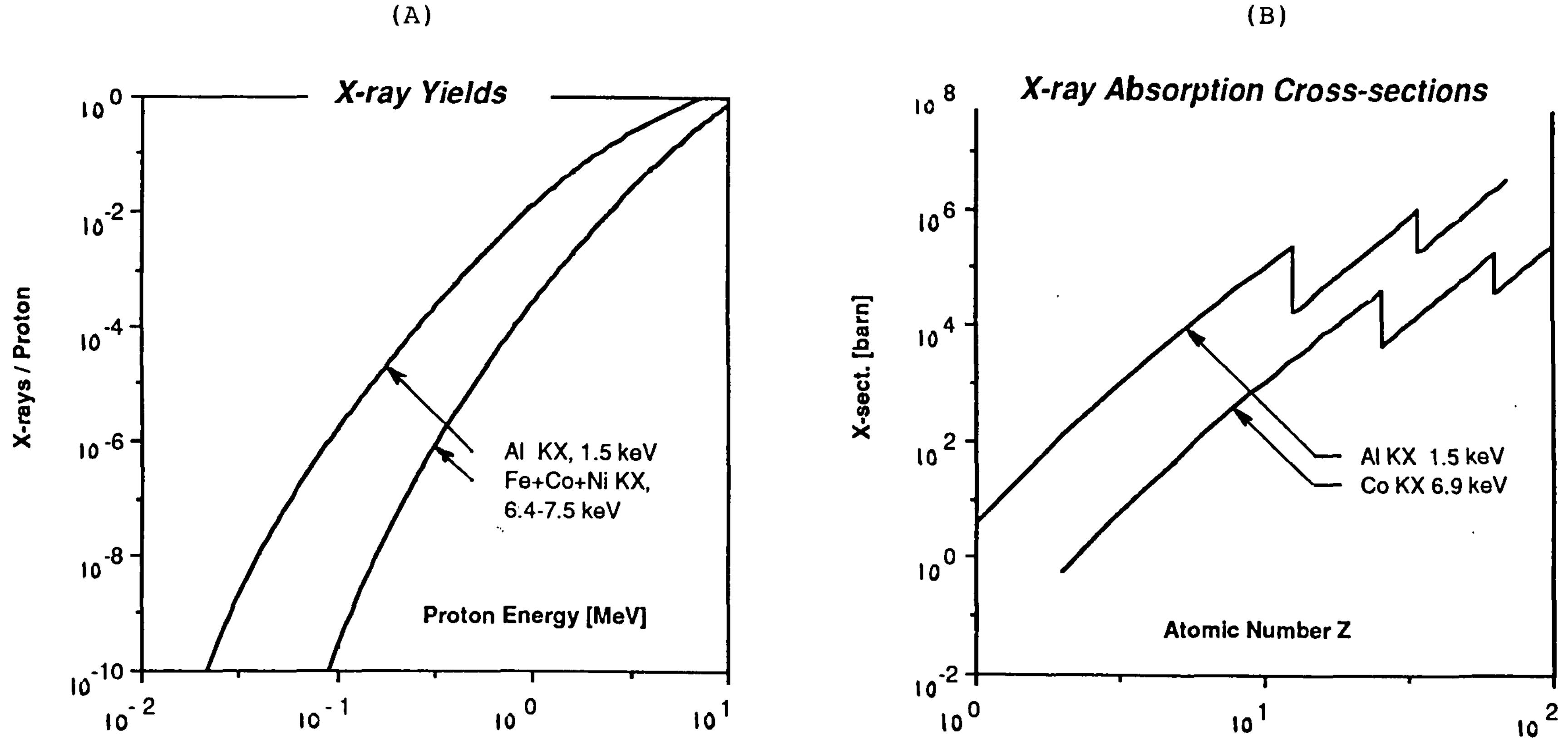
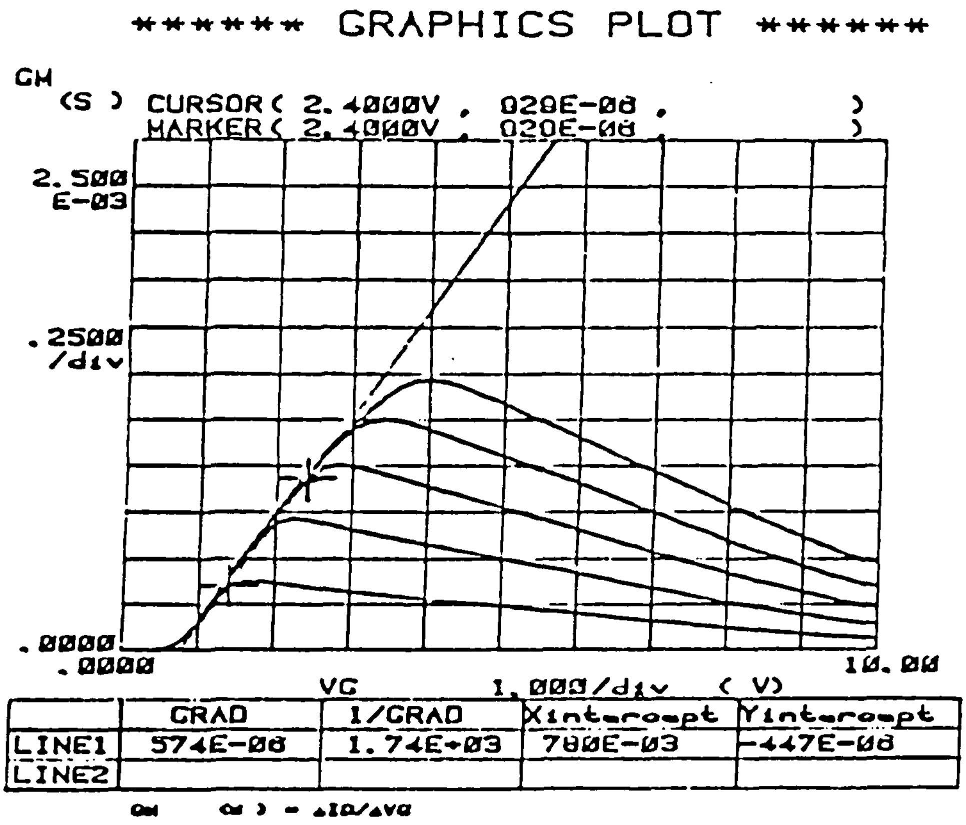


Fig. 5: Calculated yields of proton induced Al KX-rays in Al-oxide and Fe+Co+Ni KX-rays in Kovar (A). Analytical fits for Al and Co KX-ray absorption cross sections (B).



	GRAD	1/GRAD	Xintercept	Yintercept
LINE1	574E-08	1.74E+03	780E-03	-447E-08
LINE2				

Fig. 6: Transconductance measurement of a MOSFET transistor. The measured threshold voltage equals 0.78 V as explained in the text.

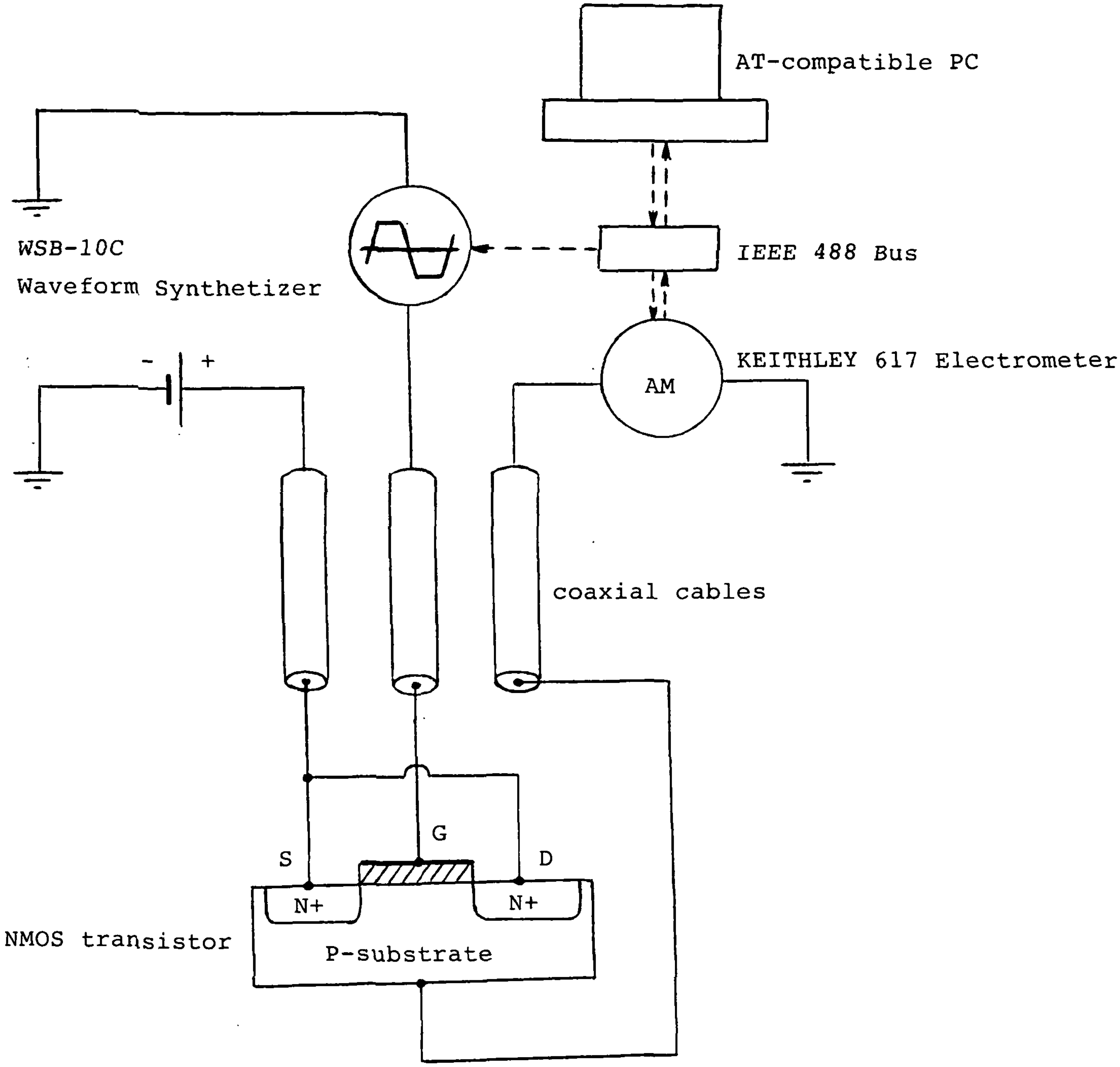


Fig. 7: Experimental set-up for the charge pumping technique. WSB-10C Waveform Synthetizer will be replaced by HP-8112A Pulse Generator.

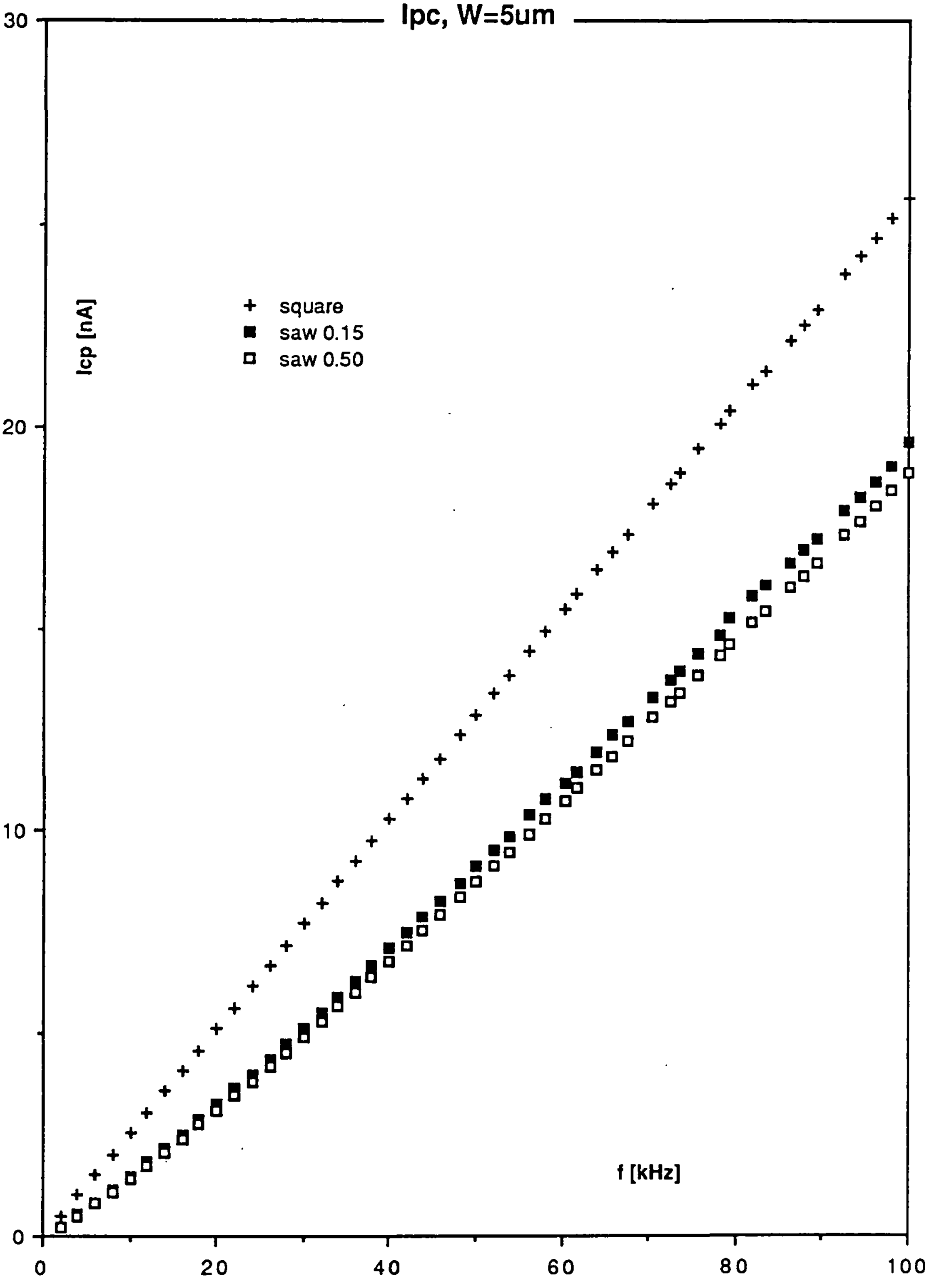


Fig. 8: Charge pumping current as a function of frequency for one square and two sawtooth waveforms (rise times 0, 15, and 50 % of the period).

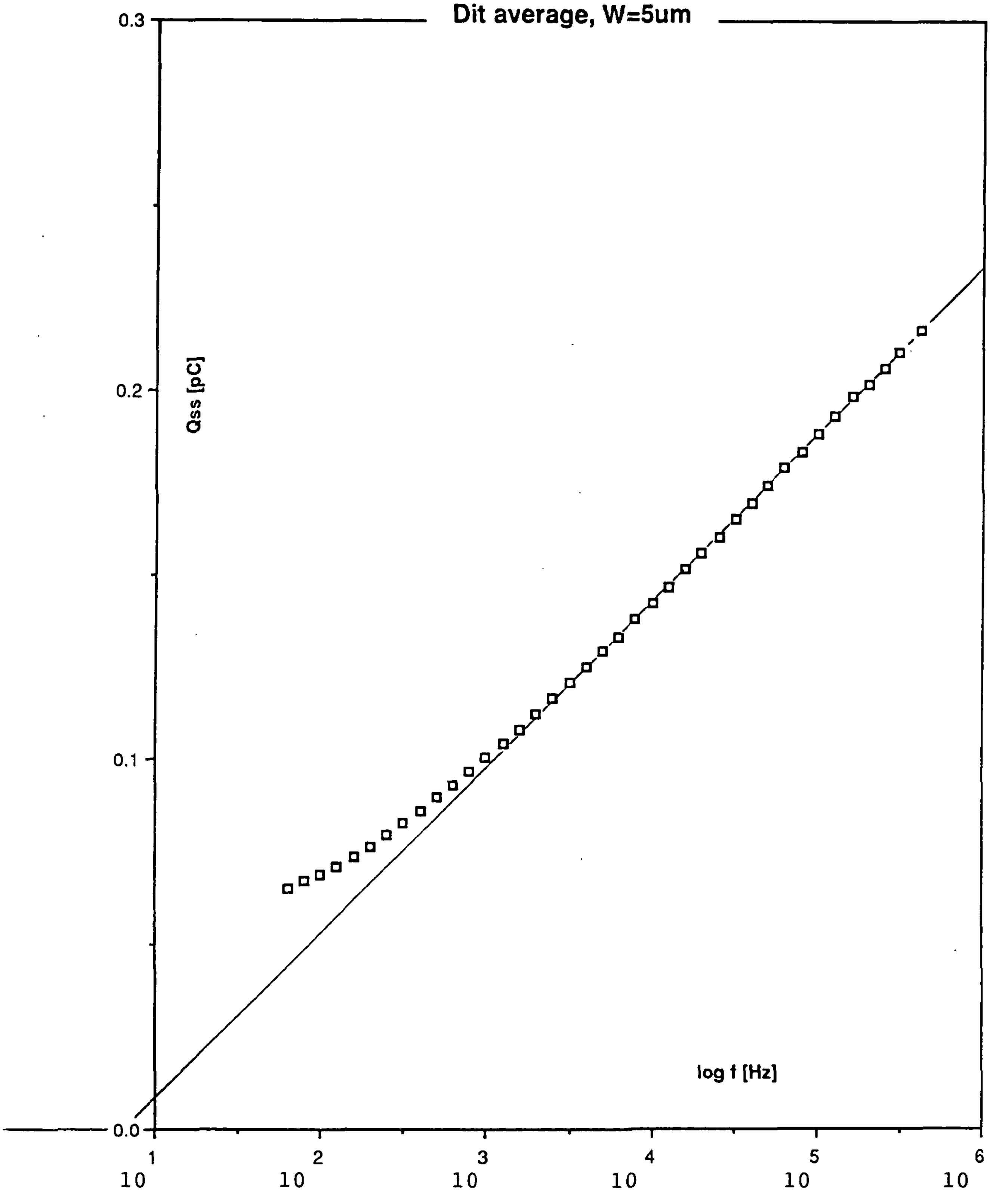


Fig. 9: A charge recombining per cycle ($Q_{ss} = I_{CP}/f$). The slope is proportional to the mean interface trap density and the extrapolated frequency to electron and hole capture cross sections.

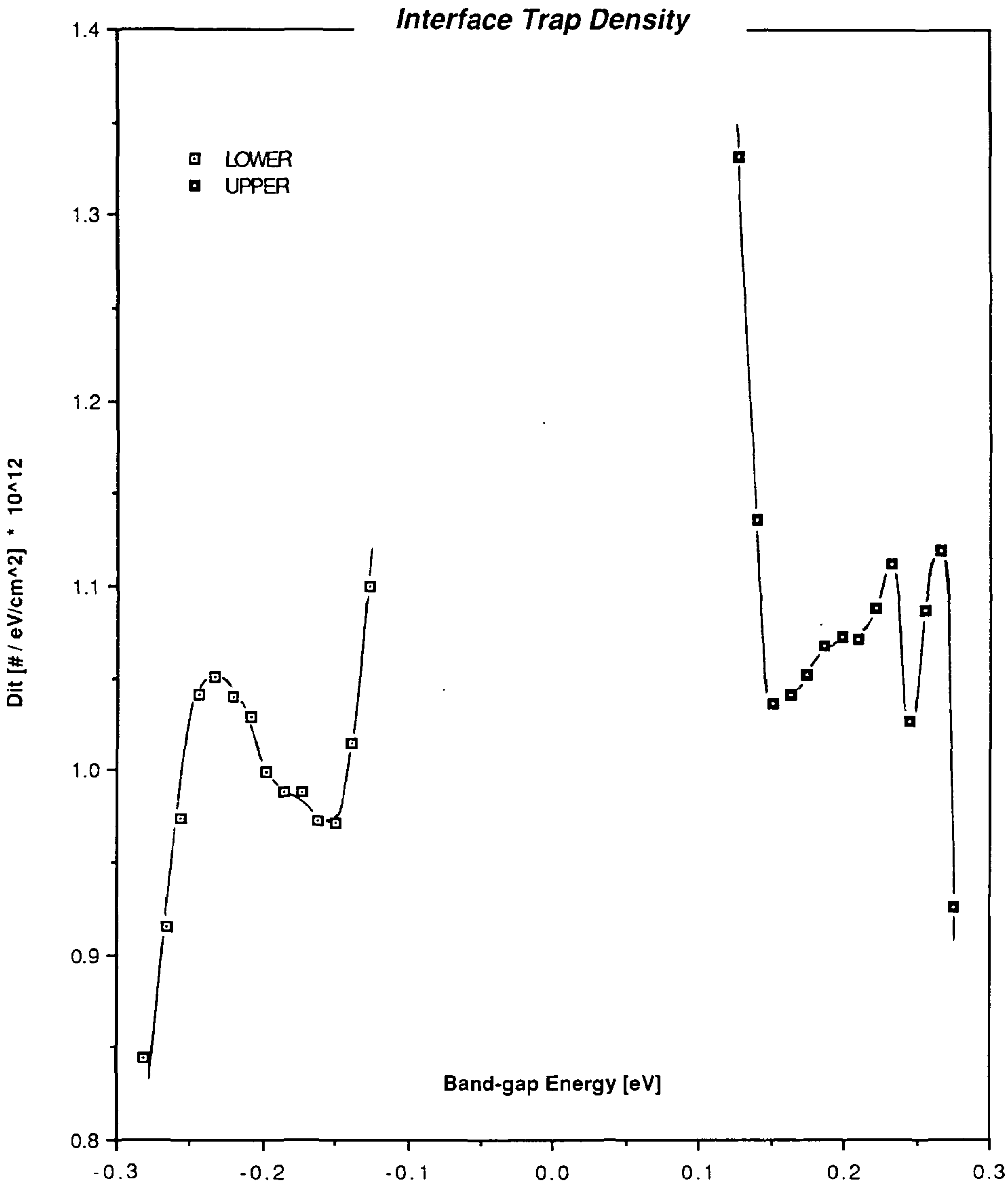


Fig. 10: Interface trap density distribution in the lower and upper halves of the band gap as measured by varying rise and fall times, respectively.

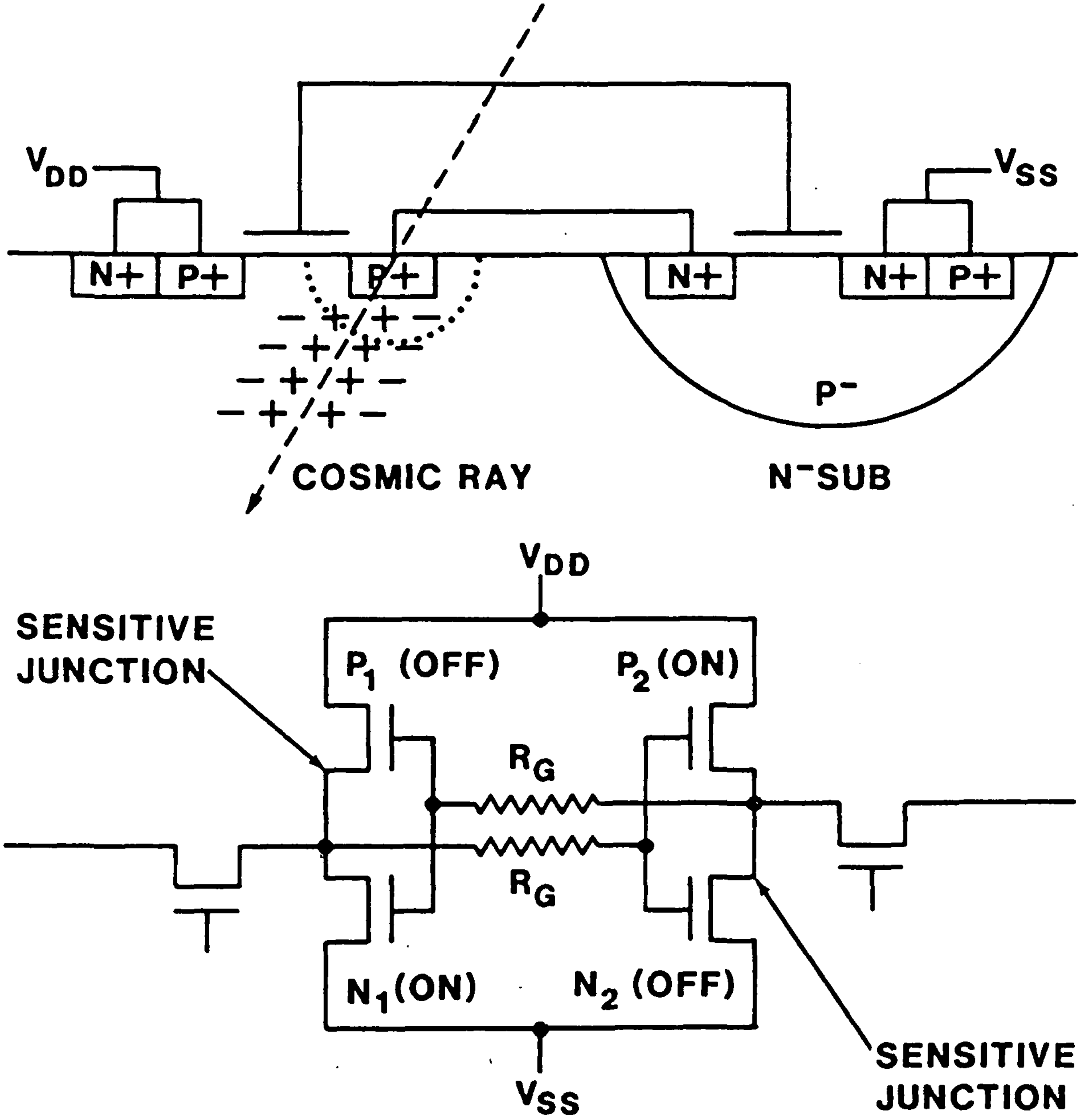


Fig. 11: SEU of a SRAM cell hardened by feedback resistors.

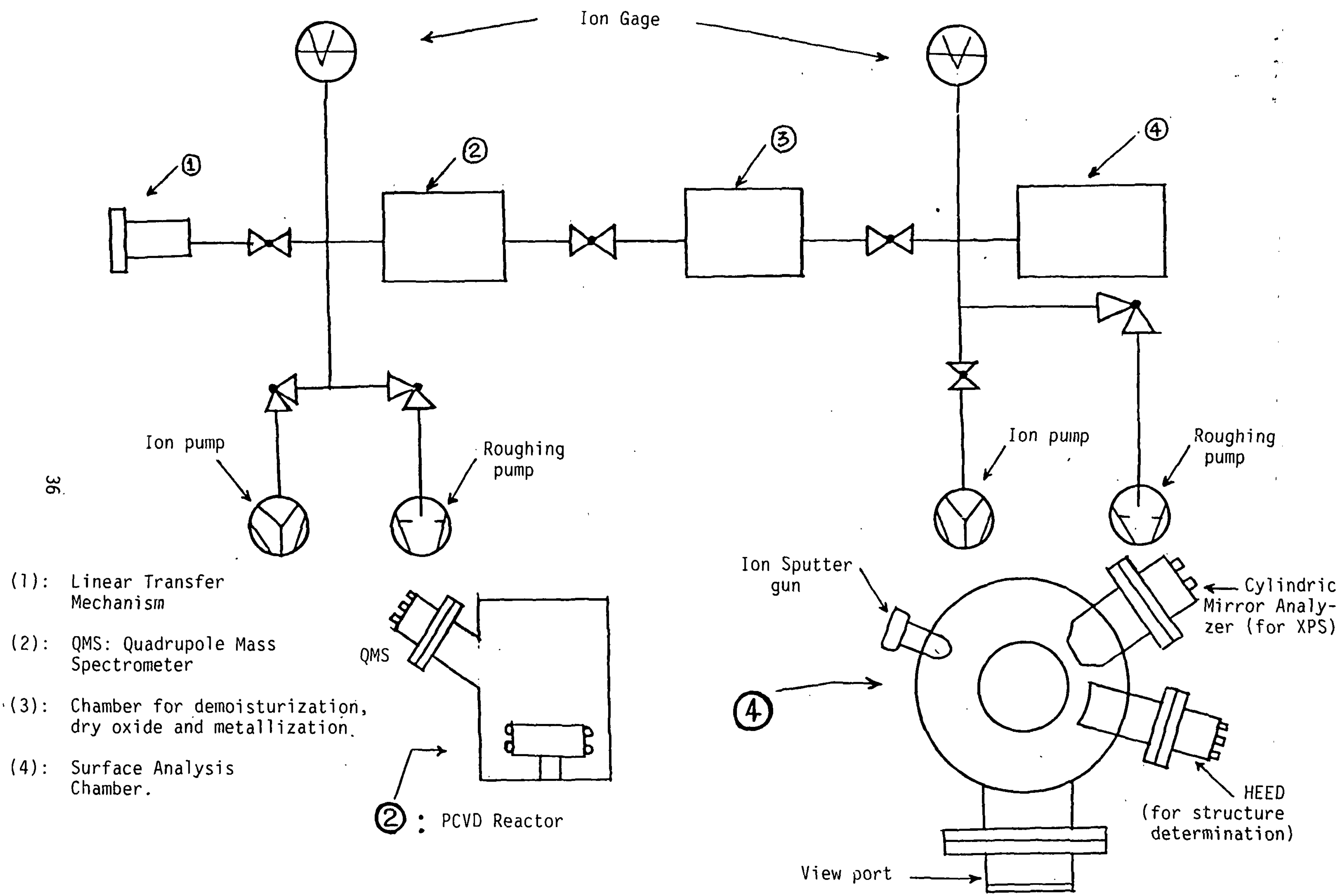


Fig. 12: Proposed experimental set-up for growth and analysis of amorphous Si.

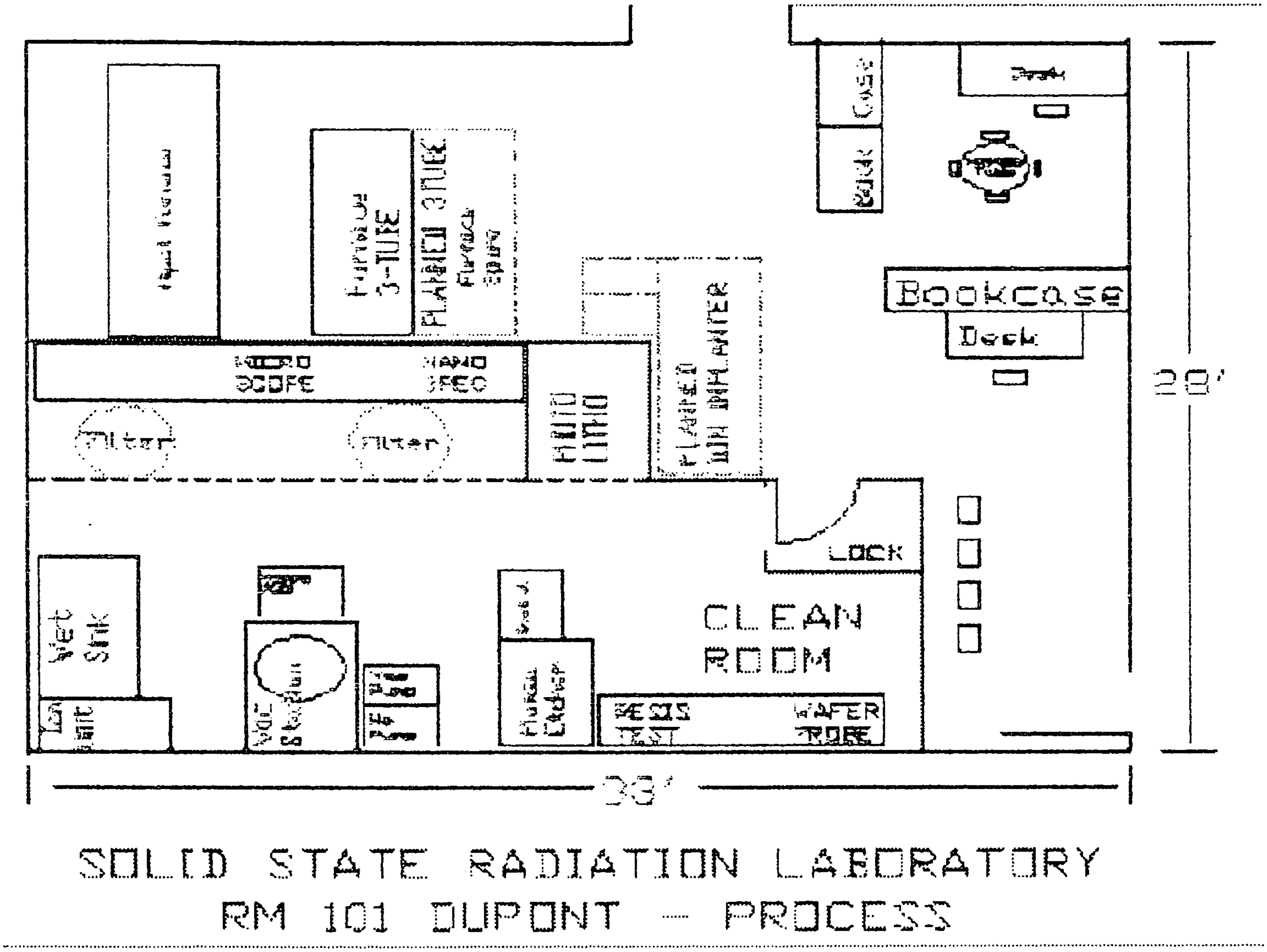
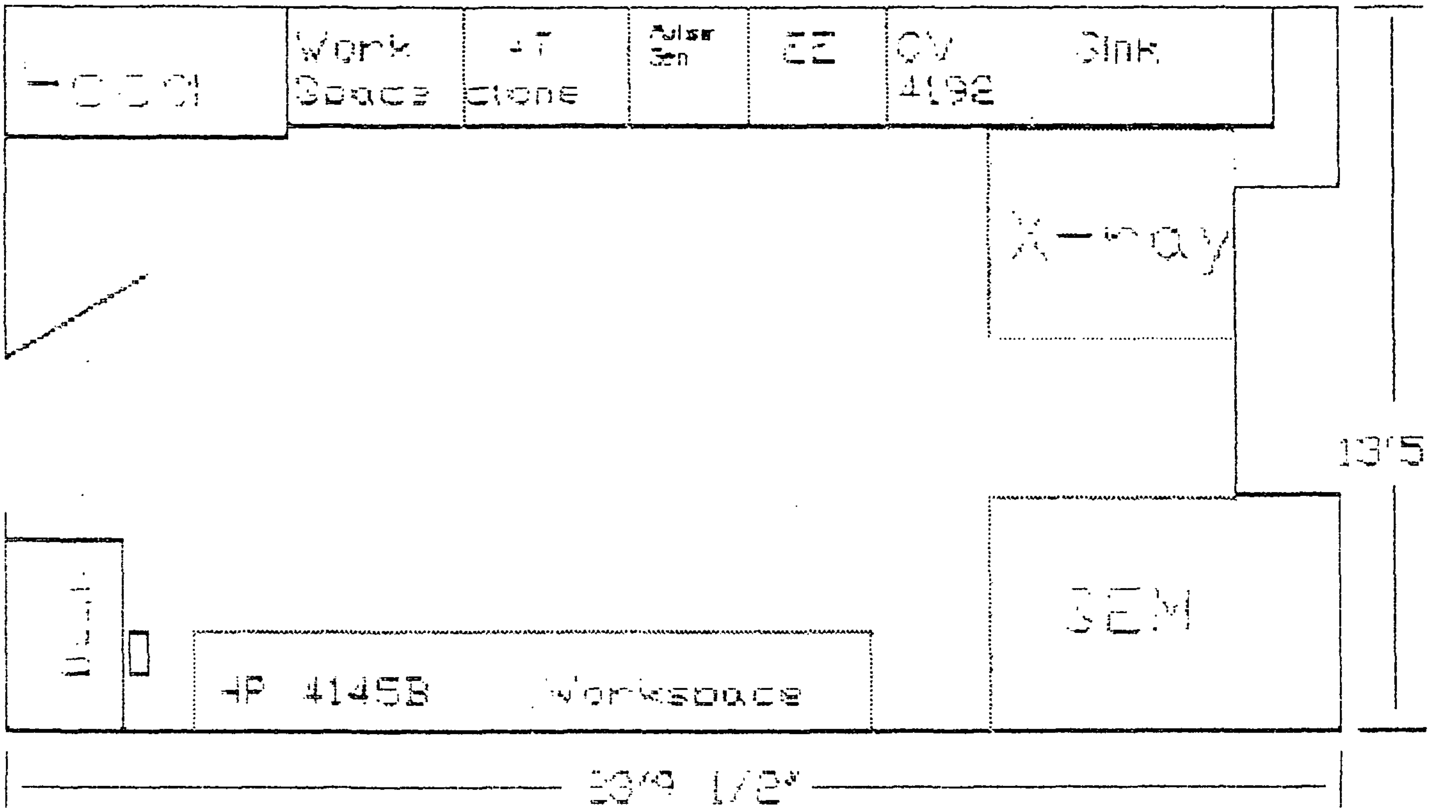


Fig. 13: Arrangement of the Solid State Radiation Laboratory at Hampton University (Room 101, DuPont building).



SOLID STATE RADIATION LABORATORY
TEST & MEASUREMENT
RM 504 OLIN ENGINEERING BLDG.

Fig. 14: Arrangement of the Solid State Radiation Laboratory at Hampton University (Room 504, new building).

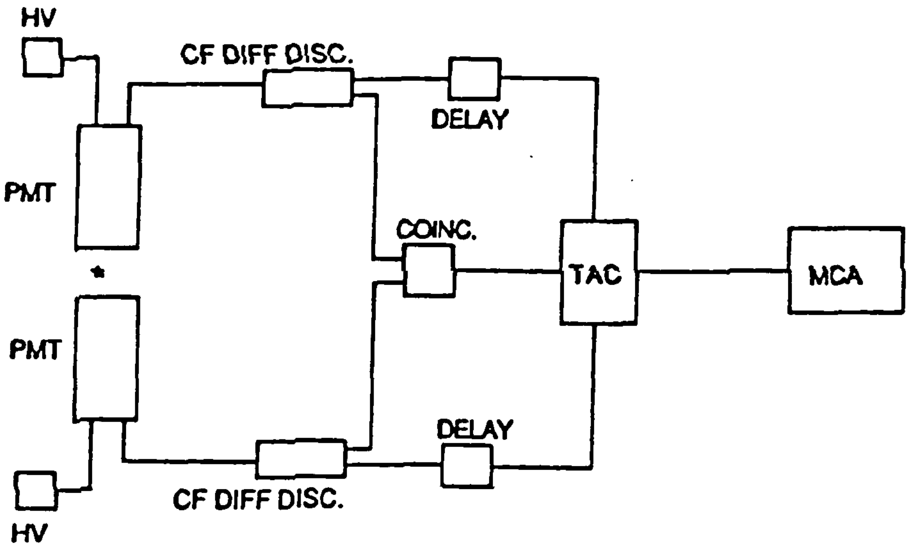


Fig. 15: Proposed experimental set-up for the positron anihilation experiment.

Abstract No. 624

SIMULATION OF NATURAL SPACE RADIATION EFFECTS ON VLSI TECHNOLOGY

T.N.Fogarty,C.Herman*,K.Diogu & F.Wang**
AT&T-BL,RM.1B206,555 Union Blvd.
Allentown,Pa.18103
*NASA-JSC,Houston,Tx.
**Prairie View A&M Univ.,Prairie View,Tx.

As space station was added to the NASA program, concern for the effect of low dose rate, relatively low energy particles and their secondary radiation over long exposure time has grown. With the increased compaction of design in VlSI systems concern for size effects has also increased. (1,2,3)

In this study(4) NMOS structures and equivalent CV test structures were submitted to one Mev. Proton and Electron radiation. Conventional parametric analysis using a HP-4145b as well as CV testing were applied before and after radiation. Considerable annealing immediately following removal from radiation.(within 3000 sec.) This is due to rapid hole transport. Even when the device is completely shielded from Protons by the(Kovar) encapsulation, secondary radiation including Fe,Ni,&Co Kα characteristic emmission causes considerable damage.(See fig 1&2) Normally after radiation the flatband voltage shifts in a negative direction. All components of Qss, Qot+Qf+Qit have positive charge.However if the device is biased to inversion negative charge is observed at the interface causing "REBOUND" of the Vfb. This confirms earlier work by Winokur et al(5) with Co 60 radiation.(fig.3)The Charge Pumping Technique allows determination of Dit, the density of interface states,in relation to the location in energy space. Thus it can be ascertained that one possible cause of negative charge is the filling of states in the upper half of the bandgap.(4a,b) Winokur (fig,5) also points out a dose rate dependence with timing failure more prevalent at lower dose rate.

Another aspect of the problem is the SEU, Single Event Upset, a non permanent bit flip caused by a charged particle passing through a critical region of a Mos SRAM changing from 0 to 1 or 1to 0 when Qcrit is reached. Diehl et al(8)have demonstrated that novel circuit design can eliminate SEU in SRAM, & Okyere has analized size effects in(fig.6) relation to SEU.(9) Because holding time, alpha particle & SEU are related in RAM the authors propose that those process variables such as the use of epi efficient gettering treatments will reduce stacking faults and also increase Alpha particle resistance.

While MOS-VLSI will account for large portion of Silicon device area used in space, amorphous aSI:H utilized in photovoltaic & display device may rival the area of single Silicon used. Good photovoltaic aSi:H was deposited by Plasma Assisted LPCVD and submitted to 2 Mev Electron and Protons.Film is ascertained by ESR & IR before and after exposure to radiaton. (10,11) The ESR spin density has been related to dangling bonds in Amorphous Silicon. The IR adsorption in the region of wavenumber 2000 cm-1 is indicative of intrinsic aSi:H while the peak at 2070 is believed to be caused by microvoids. IR may be more sensitive to electron damage than spin density.

This work was partially supported by NASA NAS9-17136 and by SERI.

References:

1.Messinger,G.C.& ASH,M.S. The Effect of Radiation on Electronic Systems" Van Nostran Reinhold,published 1987.
2.Fogarty et al;Proceedings of NASA/Prairie View A&M Conference on Natural Space Rad. & VLSI Technology.To be published July 1987.
3.Sanderson,T.K;et al;"The Application of Californium 252 Fission Particles to SEU and Latch-up Testing in VLSI Device op.cit.2.
4.Diogu,K.K;et al;"Charge Anomoly at MOS Interfaces Submitted to 1Mev Proton Radiation"op.cit2.
5.Winokur,P.S;et al "CMOS Device Response and Failure Mechanisms in Space Satellite Environments"op.cit.
6.Cilingiroglu,U;"A General Model for Interface-Trap Charge Pumping Effects in MOS Devices"Solid State Electronics 28,1127,1985.
7.Groeseneken,G;et al;"A Reliable Approach to Charge-Pumping Measurements in MOS Transistors" IEEE Transactions on Electron Devices.ED-31,42, 1984.
8.Diehl,S.E;et al;"Error Analysis and Prevention of Cosmic Ion-Induced Soft-Errors in Static CMOS RAMS"IEEE Transactions on Nuclear Science,NS-29, 2032,1982.
9.Okyere,J.C;"Effect of Transistor Sizing on Circuits for Hardening CMOS SRAM Against Single Event Upsets"op.cit.2.
10.Roopwah,K;et al;"Properties of Glow-Discharge Intrim a-Si:H Submitted to 2Mev Proton and Electron Radiation"SERI Advanced Photovoltaic Conference.To be published Fall 1987.
11.Mahan,A.H;et al;"Evidence for Microstructure in Glow Discharge a-SiC:H Alloys" Proceedings of SERI PV AR&D Conference,Denver,May 1986.

ORIGINAL PAGE IS
OF POOR QUALITY

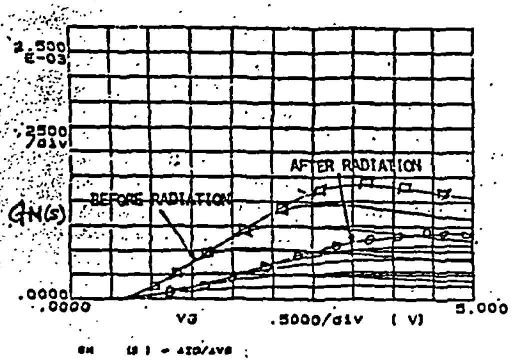


Figure 1: Transconductance versus gate voltage (Encapsulation off —Proton damage)

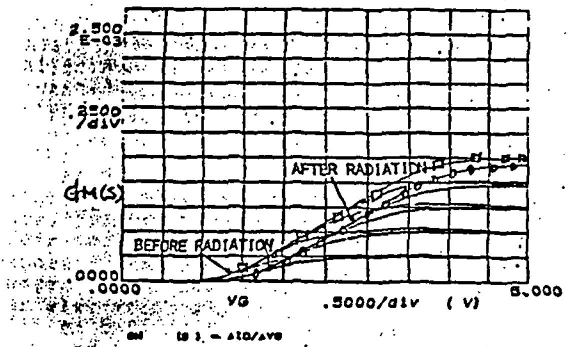


Figure 2. Transconductance versus gate voltage (Encapsulation on —Secondary radiation)

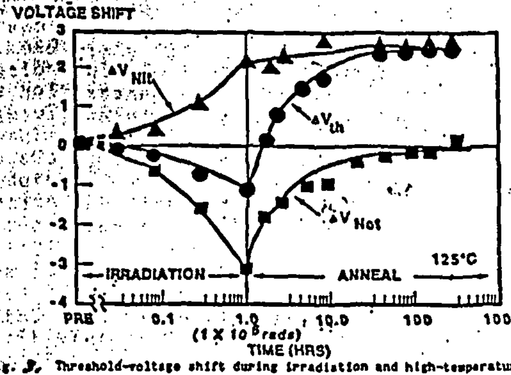


Fig. 3. Threshold-voltage shift during irradiation and high-temperature anneal separated into the shift due to oxide-trapped charge and interface traps. A 10-V bias was applied between gate and substrate during irradiation and anneal. #2

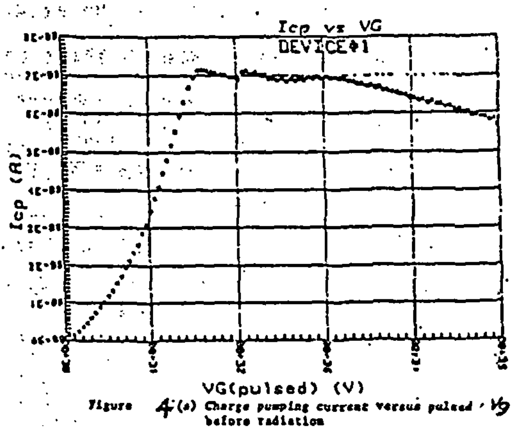


Figure 4(a) Charge pumping current versus pulsed Vg before radiation

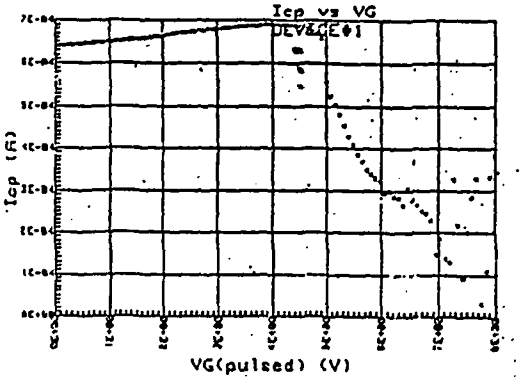


Figure 4(b) Charge pumping current versus pulsed Vg after radiation

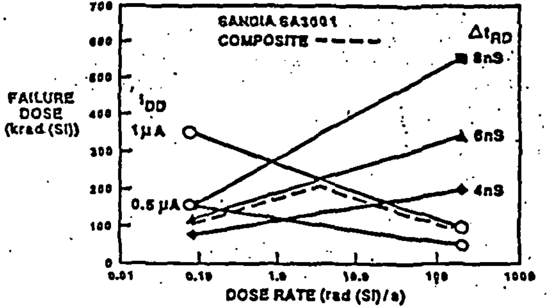


Fig. 5 Failure dose versus dose rate for Sandia SA3001 2K SRAMs.

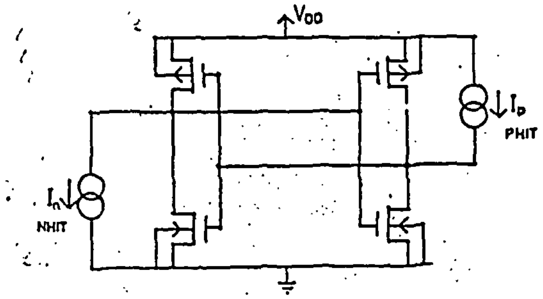


Fig. 6 CURRENT SOURCE MODEL FOR PARTICLE HIT

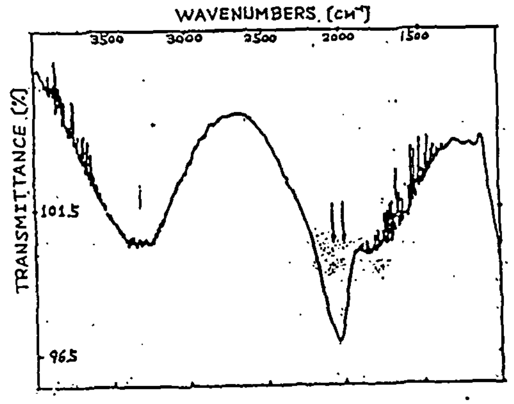


Fig.7 IR-Transmittance for a Good a-Si:H

ABSTRACT

NATURAL SPACE RADIATION EFFECTS ON MATERIALS, DEVICES, AND SYSTEMS. V. Zajic, T. N. Fogarty, P. Mawanda Kibuule, and C. W. Lowe, HAMPTON UNIVERSITY, HAMPTON, VA 23668. Scaling down devices and systems has increased concern for SEU (soft errors) in VLSI circuits. SPICE and CRUM simulation, and experimental results seem to confirm this. In this paper, the effects of total dose, dose rate, rebound phenomenon, and secondary radiation on materials, devices, and systems will be discussed. The effect of parametric degradation, due to prior total dose irradiation, on SEU will be investigated at the new SEFG-SEU Test Facility at BROOKHAVEN. (Supported by the Grant from NASA NAG 5-929)

Presented at the VIRGINIA ACADEMY OF SCIENCE 66th Annual Meeting, CHARLOTTESVILLE, May 1988. (Sponsored by the UNIVERSITY OF VIRGINIA)