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A pulsed nanosecond IR laser diode system to automatically test the Single Event Effects in the laboratory

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Abstract

A pulsed nanosecond IR laser diode system to automatically test the Single Event Effects in laboratory is described. The results of Single Event Latchup (SEL) test on two VLSI chips (VA_HDR64, 0.8 and 1.2 μm technology) are discussed and compared to those obtained with high-energy heavy ions at GSI (Darmstadt). © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Single Event Effect (SEE) is an effect induced by a single particle or ion that can cause a permanent high current path (Single Event Latchup, SEL), a bit flip (Single Event Upset, SEU) or a stuck bit (Single Hard Error) [1]. As circuit dimensions are scaled down, the individual circuit nodes requires less charge to be upset, hence, many integrated circuits operating in avionics and in space have been found to become more susceptible to SEE induced by energetic particles such as protons or charged heavy ions [2]. The increasing trend towards the use of Commercially available Off The Shelf (COTS) [3] products instead of radiation hardened parts in space requires additional SEE testing on ground to ensure that the commercial parts will meet the mission requirements.

Our goal is to produce a tool for the qualitative evaluation of Device Under Test (DUT) response to SEL/SEU in laboratory. This tool will allow us to detect unsuitable devices, thus reducing the number of components to be tested with heavy ion beams. Our results have shown that the thorough understanding and control of crucial system parameters such as surface reflections, pulse size and duration, and the laser beam intensity could give quantitative informations on SEL/SEU thresholds which can be compared with results of ions beams.

In the following we describe an infrared-pulsed laser diode system to test SEE in the laboratory,

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emphasizing both the advantages and limitations of the pulsed laser technique. The results of SEL test on two VLSI chips (VA_HDR64 [4], 0.8 and 1.2 μm technology), which will be used in front-end electronics of the Antimatter Magnetic Spectrometer (AMS) experiment are compared to those obtained with high-energy (200–800 MeV/nucleon) xenon, gold and uranium ions at GSI (Darmstadt).

2. IR-pulsed laser system

This system is capable of delivering large number of pulses with adjustable intensities across a DUT over its entire surface and perform online calibration in a fully automatic manner. The design of the system has been done by considering the following parameters:

- modularity, the capability of using its parts also for the heavy ion beam tests (i.e. SELDP, see below);
- the capability of fast screening of components; and
- cost effectiveness.

Since the physics of ion-semiconductor and photon-semiconductor interactions are different, the charge distributions generated by laser light and by heavy ions may lead to different amount of charge collected and subsequently different results for SEE measurements. In order to have a radial charge distribution as similar as possible to the one produced by a heavy ion particle, good beam focusing and relatively long penetration depths are required. In order to minimize the two photon absorption (TPA) phenomenon effect (i.e. non-linear absorption at high laser intensities) two parameters to be controlled are the laser wavelength and the laser pulse width [5]. Our choice for wavelength of 913 nm is a good compromise to reduce by a factor 100 the TPA (with respect to wavelengths near band gap, i.e. $\lambda = 1.13$ μm for silicon) and provide a sufficiently long penetration depth (≈ 27 μm).

The numerical simulation results [6] have shown that the SEL energy threshold values dependence on pulse width varies by up to 10% for pulse widths between 10 ps and 1 ns and then increase smoothly. At our pulse width of 15 ns the overestimation of the laser energy with respect to the 10 ps pulse width is a factor of $1.8 \pm 10\%$. After the application of this correction factor to the SEL energy threshold calculation, the results have shown a good agreement with those obtained with heavy ions. This opens the possibility of using a laser diode giving the simplicity in design and cost effectiveness of such a system.

The knowledge of surface reflections from the DUT is another important parameter to control, since it determines the effective amount of light that enters into the DUT. We measured the DUT's surface reflections by calculating the ratio between the light collected by a photodiode placed at a given angle, first by a totally reflecting surface and then by the DUT; we found that the ratio of incident light penetrates the DUT is 0.70 with a relative error of 5%. For our wavelength, the quantum efficiency of silicon ($0.95 \pm 5\%$) and thermal losses for silicon (only $0.83 \pm 3\%$ of energy survives) are well known quantities [7].

2.1. Setup description

The setup consists of an externally triggered laser module mounted on a vertical axis including a polarizer, a beam splitter and a microscope objective. A fraction of the beam is deviated by the beam splitter and sent along a secondary axis to a photodiode which is used to monitor and calibrate the beam intensity on the DUT. An X–Y motorized translator stage is located under the primary axis on which the DUT is mounted. The translator is operated by high-precision motors controlled via a PC card. A similar motor is used to rotate the polarizer in order to adjust the energy of the laser pulses.

The power is supplied to the DUT by a custom module called Single Event Latchup Detector and Protector (SELDP) [8]. This module has two other important features that are the detection and the counting of SEL (SEUs are detected via software) and the protection of the DUT from possible damage.

An interface card placed in SELDP provides the connection with a DAQ card located in a PC. Through this interface it is possible to send, receive

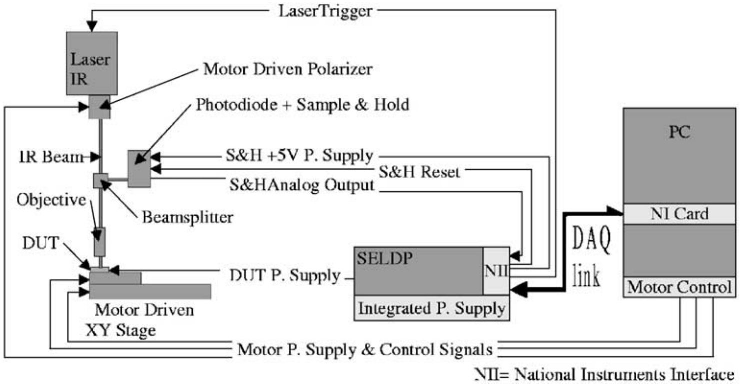

Fig. 1. Block diagram of the setup.

Table 1
Setup main components specifications

Laser diode	$\lambda = 913$ nm, 15 ns wdt, 20 W @peak, 10 kHz prf.
Polarizer	Ext. rat. 10^{-5}
Beamsplitter	Ratio = 0.5
Objective	100×, 12 mm WD
X–Y tran. stage	5 cm travel, 0.5 μm rpt.
Photodiode	0.5 A/W sens., 50 Ω load

and sample both digital and analog signals thus allowing the full control of SELDP, laser module and photodiode via PC (See Fig. 1). This card has also NIM output pulses to interface with NIM/CAMAC logic.

The DUT protection is achieved by a circuit which compares the input currents with previously set threshold values (about two times the typical input current of DUT). As the currents go over threshold, a SEL counter is incremented and the power supply is switched off within 100 μs for a programmable time ranging from 1 ms to 99 s. The SELDP module is completely programmable and easy to transport for use in different environments, e.g. during ion beam tests.

The details on the components used for the setup are listed in Table 1.

3. Test procedure and results

We performed SEL tests on two VA_HDR64, 64 channel low-noise/low-power, high dynamic range, charge sensitive preamplifier-shaper VLSI circuits, designed as a part of the front-end electronics of the AMS Silicon Tracker and produced with 0.8 and 1.2 μm technology. To predict the SEE rates of a given electronics device during a mission, we need the knowledge of the device dimensions, the amount of the material surrounding it, the orbit parameters (altitude, latitude, period, duration, etc.) and the SEL Cross-Section (CS) as a function of the Linear Energy Transfer (LET). To evaluate the SEL CS vs. LET we define a scanning matrix on DUT surface (10 × 10 grid cells). At the center of each cell, we then deliver a fixed number of laser pulses (100 pulse) of known intensity (energy) and record the number of SEL occurrences. The cross-section is calculated using:

$$\sigma = \frac{\mathrm{NbSel}}{\mathrm{IntFlux}} \frac{\mathrm{SampledArea}}{\cos(\theta)} \tag{1}$$

where IntFlux is the total number of laser pulses delivered during the scan, NbSEL is the total number of SEL occurred in the scan, θ is the incidence angle (in our case $\theta = 0$). The relative uncertainty on CS is about 20% (mostly determined by the grid matrix size and the sample of pulses in each cell). The corresponding LET value is then calculated as

$$\mathrm{LET} = \frac{E}{\rho_{\mathrm{Si}} d_{\mathrm{Si}}} \tag{2}$$

where ρ_{Si} is the density of silicon, d_{Si} is the penetration depth of laser radiation in the silicon bulk, for which the energy release in silicon is linear at 95% C.L.; E is the energy released in the silicon bulk.

After implementing the normalizations discussed in Section 2, the effective energy release over incident energy at DUT surface ratio is calculated to be 33%, indicating that one third of the incident laser energy penetrates the DUT. The maximum relative error on this ratio is estimated to be about 23% by summing up the uncorrelated errors of each correction factor (surface reflections, Si quantum efficiency, Si thermal losses, pulse width), while the rms error is 12%.

In Fig. 2 are shown the results of our laser test in comparison with those obtained at GSI using ^{129}Xe, ^{197}Au and ^{238}U ion beams (energy range 200–800 MeV/nucleon) for the 1.2 and 0.8 μm technology. We observe similar LET thresholds values for both ion and laser tests. The LET threshold is defined as the minimum LET value to cause an effect [9], corresponding to the first non zero value of CS. The calculations details and the results of tests carried out under ion beam at GSI (Darmstad) are discussed elsewhere [10].

4. Discussions and conclusions

The advantages of the laser technique are:

- spatial information because of the small beam spot size and the precision on determination of the beam spot position;
- the capability of synchronization with the circuit clock so that SEE measurements can be performed as a function of timing;
- non-destructive; and
- cost and ease of operation.

The limitations of this technique are:

- inability of laser light to penetrate metal and plastic packages. The latter problem can be

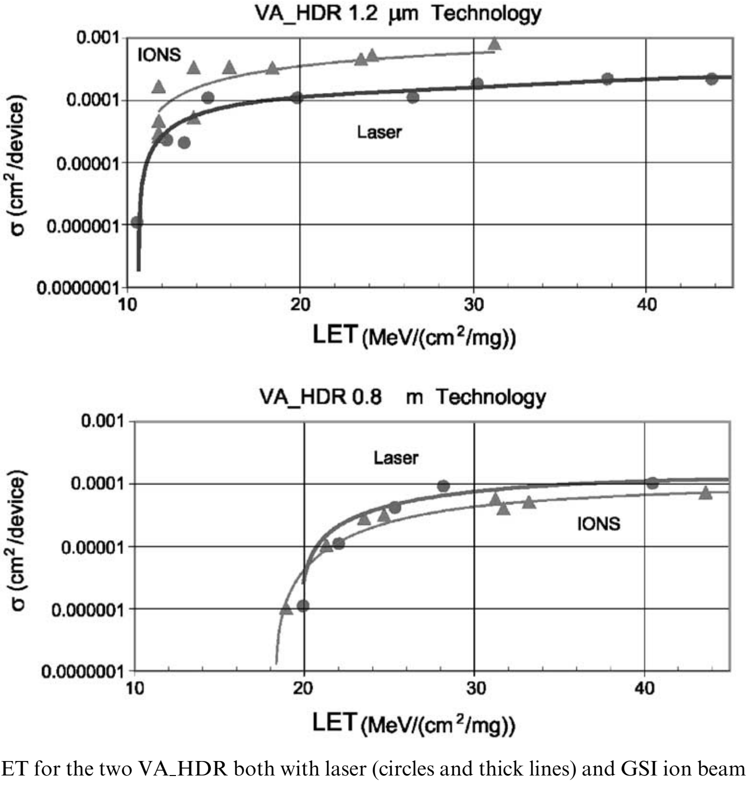

Fig. 2. Cross-section vs. LET for the two VA_HDR both with laser (circles and thick lines) and GSI ion beam (triangles and thin lines).

solved through proper delidding of plastic parts prior to test; and

- no direct measurement of SEE threshold since ions and light do not interact in the same way.

Two VLSI chips were tested using heavy ion beams and nanosecond-pulsed diode laser. The results are in good agreement validating the nanosecond laser technique and the approach used to calculate the cross-sections and corresponding LET values. The systematic errors are well identified and can be reduced by decreasing the scanning grid cell dimensions and increasing the number of pulses used for each grid cell. The development of our system for SEU testing is underway. The collected data will be stored in a component database for future use and comparison. This laser system is a powerful tool providing valuable screening information about the radiation hardness of the components in a fast and cost effective way.

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