Local Laser Irradiation Technique for Estimating Single Event Effects Sensitivity

A.I.Chumakov, A.V.Yanenko, A.N.Egorov, O.B.Mavritsky

Specialized Electronic Systems, 31 Kashirskoe shosse, Moscow, 115409 Russia

Abstract

A single event upset and single event latchup thresholds are analyzed in various ICs under local laser irradiation. An approach for estimation of ion-induced SEE thresholds based on local laser irradiation is presented. Comparative experiment and software simulation research are performed at various pulse durations and laser spot sizes. Correlation of single event thresholds under focused and local irradiation is found.

I. Introduction

Single event effects (SEE) are the dominant integrated circuit (IC) failure effects under irradiation of nuclear particles with high energies. The main SEEs in ICs under nuclear particles irradiation are single event upsets (SEU) and single event latchups (SEL).

The modern prediction methods of ion-induced SEU and SEL are based on SEE cross section vs. linear energy transfer (LET) dependence. The main parameter of this dependence is LET threshold. LET threshold determination in accelerator tests is rather complex and expensive. SEU threshold prediction by software simulation requires taking into account a lot of parameters, which are very difficult to identify. Application of picosecond focused laser simulation tests is limited due to various optical effects (reflection, diffraction, metal leads shadowing etc.) and the necessity of IC chip surface scanning in order to locate the most sensitive area [1,2]. Sometimes it is possible to use the uniform laser irradiation. However, the application of this procedure for prediction IC SEL or SEU thresholds has some problems: it is necessary to estimate the influence of adjacent structures and large photocurrent resulting in rail span collapse.

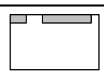
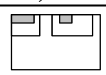
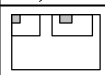
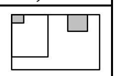
Laser tests limitations can be essentially reduced if so called "local" laser irradiation (with laser spot radius r_p of 10-100 μm) is used instead of focused one. However, the new problems arise, namely the difference in charge collection processes under local and focused laser irradiation. In fact, charge generated by focused laser beam is collected by drift in sensitive volume, while under local laser irradiation the diffusion mechanism of charge collection can play essential role. Moreover, in latter case charge collection by p-n structures adjacent to sensitive volume affects upset threshold. To find out the correlation between these cases it is necessary to perform the upset threshold comparative tests and software simulation research under both focused and local laser beam irradiation with various laser pulse duration, laser spot radius and technological parameters of IC elements.

The main issue of this work is a computer simulation and an experimental investigation of SEU and SEL thresholds under both focused and local laser beam irradiation with various laser pulse duration, laser spot radius and technological parameters of IC elements.

II. Calculation Method

Computer simulations were performed for various semiconductor structures to determine a possibility of local laser irradiation usage instead of focused one. The values of latchup thresholds were calculated in orthogonal n^+-p^+-n-p structures ($x\times y\times z$=40×100×100 μm^3) [3]. Four types of cylindrical symmetry structures ($r\times z$=25×50 μm^2) were chosen for upset threshold analysis (Table 1).

Table 1: Parameters of upset simulated structures

Region	Type of structure			
	n^+-p	p^+-n-p	p^+-n-p	n^+-p-n
Substrate	P, 10^{15}	P, 10^{15}	P, 10^{15}	N, 10^{16}
p-n junctions	N, 10^{19}	P, 10^{19}	P, 10^{19}	N, 10^{19}
Wells	-	N, 10^{18}	N, 10^{18}	P, 10^{18}
Structure view				

2D software simulator ("DIODE-2") with cylindrical and orthogonal symmetries was used. Upset/latchup threshold values were determined under different conditions (radius of laser spot, location of laser stripe, pulse duration etc.).

The dependencies of latchup threshold laser energy versus laser stripe width dx and its location x are shown in Fig.1. The curves are normalized by minimum laser threshold value (J_{lo}).

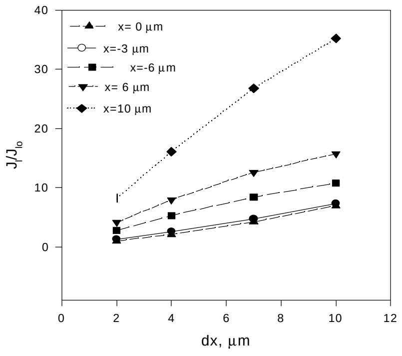


Figure 1: Latchup threshold energy as a function of stripe width and its location

These dependencies can be described as:

$$J_l/J_{l0} \text{ » } k_l\,dx, \qquad (1)$$

where k_l is a proportionality coefficient.

The similar calculations were performed for upset threshold estimation (Fig.2). One can estimate laser threshold energy J_s from calculations as:

$$J_s / J_{s0} \text{ » } A_l/A_s, \qquad (2)$$

where A_s is a sensitive p-n junction area, A_l is an effective laser irradiated local area: $A_l = \max(A_s, p\cdot r_l^2)$, r_l is a laser spot radius, J_{s0} is focused laser threshold value for single event upset (SEU).

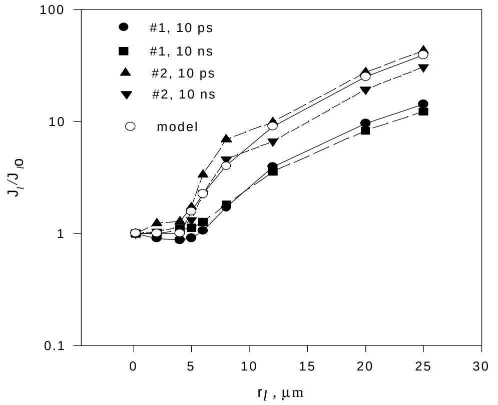


Figure 2: Normalized laser threshold energy as a function of laser spot for two pulse duration and for the first and the second structures

III. Experimental Description and Results

Two types of laser simulators (“PICO-2E” and “RADON-5E”) have been used as the radiation sources [3]. The first one generated picosecond pulses with $T_p \approx 10$ ps and l=1.055 µm. “RADON-5E” was used to generate nanosecond laser pulses with T_p=12 ns and l=1.064 µm. For both laser simulators the wavelength conversion to the second harmonic was performed by non-linear KTP crystal. Conventional focused optical system was used for focused and local laser irradiation procedures. Radius of local laser spot r_l far from focal point was determined as:

$$r_l = h_f \cdot R_l/f, \qquad (3)$$

where h_f is the distance between focal point and chip surface, R_l is incident laser beam radius and f is a lens focal length.

The devices under test were special CMOS test structure TSCLU, CMOS RAM 537RU6 (4K×1) and TTL RAM 541RU1 (4K×1).

The threshold laser energies for these devices were determined under focused, local and uniform irradiation for various values of wavelengths, pulse durations and beam locations.

We carried out comparative experimental and computer simulation research of latchup threshold energy as a function of laser beam location, pulse duration, power supply voltage and wavelength. A good qualitative correlation between experimental data and computer simulation results was found. The experimental data for TSCLU test and software simulation results [4] gave similar threshold energy dependencies vs. focused laser beam location.

The main efforts were concerned with research of latchup and upset threshold differences between focused, local and uniform laser irradiation. The experimental dependencies of laser threshold energy for 541RU1 (upset) and 537RU6 (latchup) are shown in Fig.3. One can see three typical ranges. Laser energy is the practically constant in the first range (I, focused laser irradiation) (Fig.4). The range (II) is cuncerned with local laser irradiation where the curve gradient is constant. The last range (III) corresponds to the uniform laser irradiation.

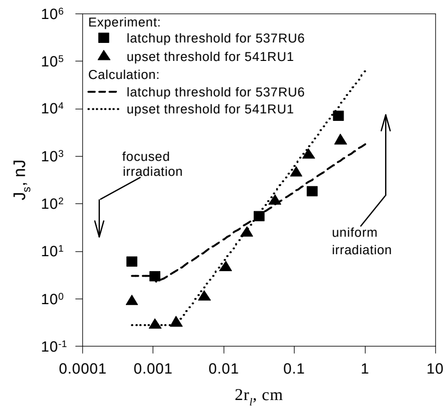


Figure 3. Experimental data of latchup and upset laser threshold energy vs. laser spot diameter for 541RU1 and 537RU6

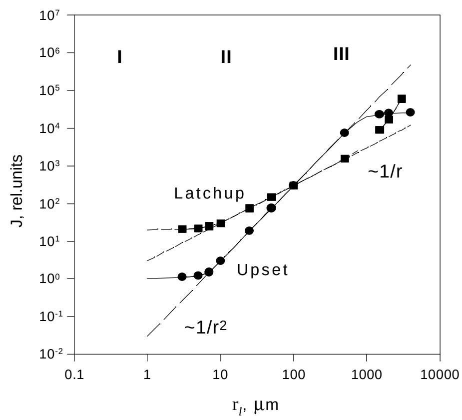
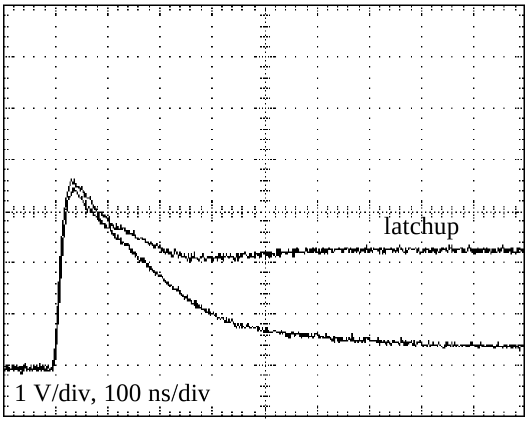


Figure 4. Typical dependences of threshold energy on local spot radius

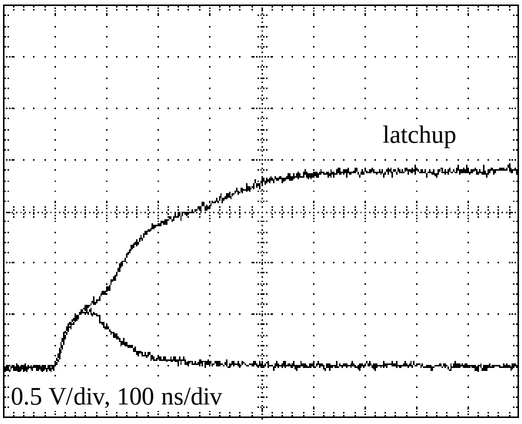
IV. Discussion

As a rule there is not correlation between focused and uniform threshold laser energies. This is attributed to the decrease of IC effective power supply voltage under uniform irradiation (rail span collapse [5]). In this case the upset threshold energy decreases and latchup threshold energy increases.

Really, we can see a large difference in the responses of 537RU6 supply currents under laser irradiation with various laser spot diameters (Fig.5). Though the values of steady latchup current are identical, the time responses under



a) Diameter of laser spot equals to 1.8 mm



b) Diameter of laser spot equals to 0.32 mm

Fig.5. Time response of supply current in 537RU6 under local laser irradiation with pre-latchup and latchup laser energies

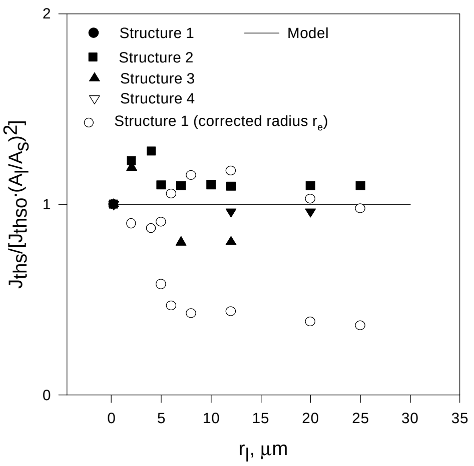


Fig.6. Relative upset threshold energy as a function of laser spot radius (computer simulation)

irradiation with large and small laser spot diameters very much differ. Therefore, it is possible that latchup can be observed under focused laser tests (SEL) while there is no latchup under uniform irradiation.

It is necessary to point out the correspondence between focused (I) and local threshold laser energies (II). Local laser energy is proportional to laser spot radius (1) for latchup and to laser spot area for upset.

To check out the last assumption we carried out additional computer simulation. The comparative results of computer simulation and upset thresholds estimation using equation (2) are shown in Fig.6. One can see good correlation between all results except for structure #1. Apparently, it is explained by the influence of diffusion and funneling effects which may cause the incorrect determination of A_s. Therefore, the suggestion that a sensitive area exactly corresponds to p-n junction area has to be modified. Computer simulation results show that A_s may be calculated using spot radius determined as a boundary between regions (I) and (II) (Fig.2). Such correction was done for structure #1. One can see that the results in this case exhibit better correlation (Fig.6).

The last conclusion allows us to estimate the sensitive area (SEL and SEU cross section) from laser threshold energy dependence vs. laser spot radius. Obtained values of cross section for 541RU1 and 537RU6 correlate with the experimental data.

Previous results were concerned with the laser beam located in the center of a sensitive element. Sometimes it is very difficult to determine a sensitive element. So, one can locate laser beam outside this area (or sensitive area may be located under metal leads). It is impossible to determine SEU or SEL threshold using focused laser beam only. However, the use of local irradiation gives us a chance to do it.

V. Conclusion

2D computer analysis of focused, local and uniform laser irradiation of IC structures was performed for SEU and SEL threshold energies estimation. The correlation of local laser thresholds energy with SEU and SEL threshold was obtained. Comparative experimental researches of test structures and RAMs using focused, local and uniform laser beam for two wavelengths (1.06 µm and 0.53 µm) and two pulse duration (10 ps and 12 ns) was carried out. The approach based on the determination of local laser threshold energy taking into account the ratio of sensitive area to local irradiated area was proposed for SEL and SEU threshold energy prediction.

VI. Reference

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