Influence of Temperature on Pulsed Focused Laser Beam Testing

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Abstract

Temperature dependence of radiation-induced charge collection under 1.06 and 0.53 µm focused laser beams is investigated in experiment and numerical simulation. The essential sensitivity of collected charge to temperature was obtained only for 1.06 µm wavelength.

I. INTRODUCTION

The focused laser sources are widely used for single event effects (SEE) investigation [1-3]. Laser simulation of SEE is based on the focused laser beam capability to induce local ionization of IC structures. A wide range of particle linear energy transfer (LET) and penetration depths may be simulated varying the laser beam spot diameter and wavelength.

The temperature dependence of the laser absorption coefficient in semiconductor affects the equivalent LET and must be accounted for when devices are tested at temperature range [4]. In order to estimate the influence of temperature on SEE laser testing parameters we have analyzed the temperature dependence of charge collected in test structure p-n junction.

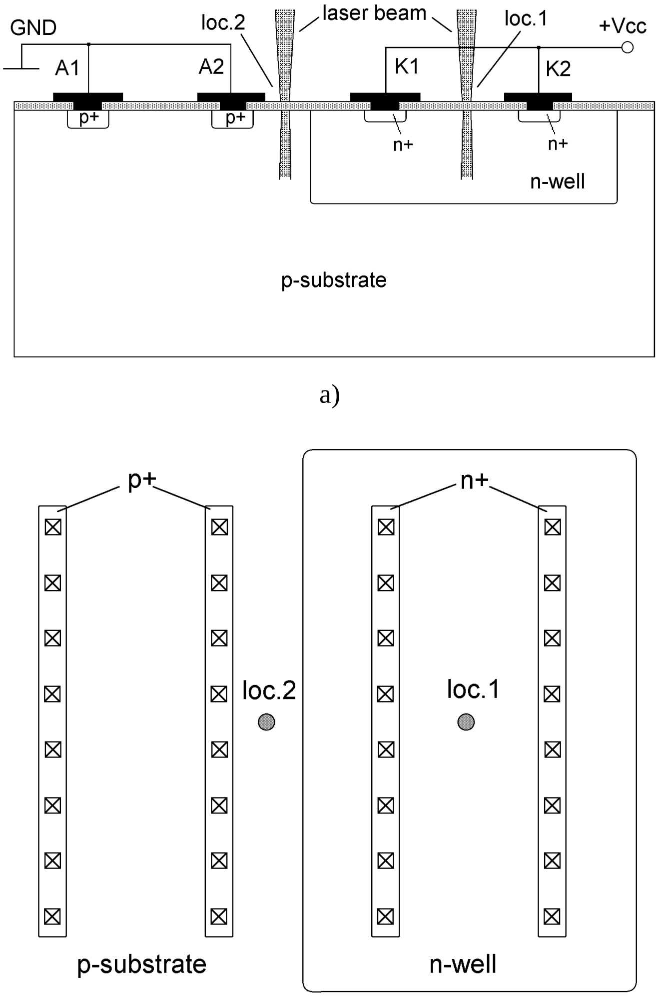
In the present study we used a pulsed laser with 1.06 and 0.53 µm wavelengths as a source of focused ionization. The measurements of p-n junction collected charge were performed in the temperature range from 22 to 110 °C for two laser beam spot positions. It was found the essential influence of temperature on collected charge for 1.06 µm wavelength and the negligible dependence under 0.53 µm laser beam.

This effect is associated with the strong temperature dependence of light absorption in silicon when the photon energy is near the bandgap [5]. The numerical simulations with the “DIODE-2D” 2D software simulator confirmed this assumption.

II. EXPERIMENTAL DETAILS

The experiments were performed using the original "PICO-2E" pulsed solid-state laser simulator (Nd^{3+} passively mode-locked, basic wavelength $\lambda = 1.06$ µm, laser pulse duration $T_p \approx 8$ ps) as a source [6]. The simulator was used in basic ($\lambda = 1.06$ µm) and frequency-double ($\lambda = 0.53$ µm) modes with laser spot diameter of 5 µm.

The investigated test structure is manufactured in a conventional 2 µm bulk CMOS process and includes well-substrate p-n junction (48x78 µm) with narrow (2 µm) metallization strips to have a maximum free surface [7]. The p-n junction collected charge temperature dependence was measured under laser irradiation for two laser beam locations as shown in Fig. 1. The first is located within the n-well (location 1) and the second is localized out of junction area (location 2).



a)

b)

Figure 1: Cross-sectional (a) and top (b) views of the test structure

The internal chip temperature was monitored with an additional forward biased p-n junction test chip. The experimental set-up and temperature monitoring procedures are described in [8]. The temperature uncertainty was near 5%. The test structures were under 5 V bias. The ionizing current transient response and collected charge were registered with a "Tektronix TDS-220" digital oscilloscope.

III. NUMERICAL TO EXPERIMENTAL COMPARATIVE RESULTS

In order to perform a collected charge analysis of test structure in a temperature range the "DIODE-2D" software simulator was used. This is a two-dimensional solver of a fundamental system of equations that was modified to include a temperature dependent laser absorption coefficient. It takes into account the electrical and optical processes including free carrier nonlinear absorption [9].

The temperature dependencies of semiconductor parameters such as band gap and intrinsic carrier density were taken into account in accordance with [10]. The bulk mobility temperature dependence is described by the function $(T/300)^{-2.33}$ for electrons and holes, where T is the Kelvin temperature. As for low level density carrier lifetimes their temperature dependencies were modeled by a power law $(T/300)^2$. The Auger recombination coefficients were taken slightly increasing with temperature in accordance with a 0.2 power law.

The "PICO-2E" laser simulator pulse energy has a fluctuations from pulse to pulse. To reduce the variations of laser pulse energy on accuracy the monitoring of every pulse was performed. The numerical and experimental results are presented as a dependences of SEE sensitivity coefficient $K_q = \Delta Q/W$ versus temperature. Here ΔQ is a collected charge in pC and W is a laser pulse energy in nJ.

The SEE sensitivity coefficients vs temperature, both measured and calculated at laser beam location 1 are presented in Fig. 2 for the case of 0.53 µm wavelength. This range of wavelengths is far from bandgap and light absorption coefficient is practically insensitive to temperature. The theoretically predicted slight temperature dependence may be connected with the competition of two mechanisms: increase of minority charge carriers lifetime and decrease of their mobility with temperature.

The pulse-to-pulse variation of laser energy during 0.53 µm wavelength experiment was in the range from 0.5 to 1.08 nJ. The 2-order linear regression of experimental data is presented in Fig. 2 by dashed line.

The SEE sensitivity coefficient vs temperature, both measured and calculated at laser beam location 1 are presented in Fig. 3 for the case of 1.06 µm wavelength.

This wavelength is near the bandgap edge and light absorption coefficient is very sensitive to temperature. The theoretical prediction gives the approximately doubling of collected charge in the range from 22 to 110 °C. The experimental results show that SEE sensitivity increases at least three times in this temperature range. This difference between measured and simulated results may be explained by uncertainties of laser absorption coefficient temperature dependence near the edge of silicon fundamental band-to-band absorption zone.

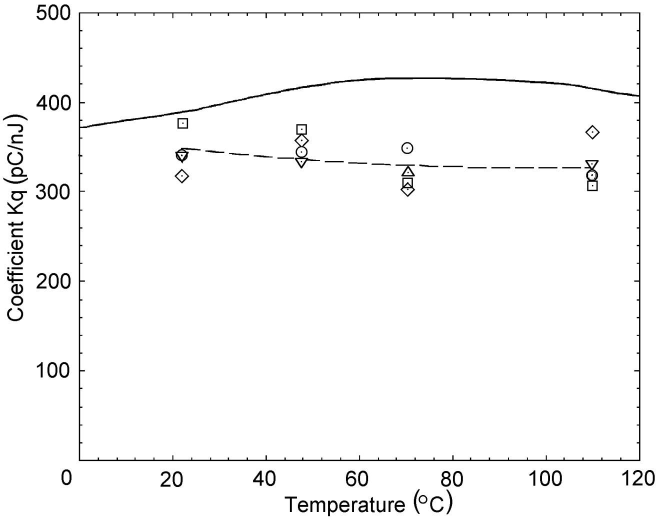


Figure 2: Numerical (lines) and experimentally determined (dots) test structure SEE sensitivity coefficient vs temperature at laser beam location 1 for 0.53 µm wavelength

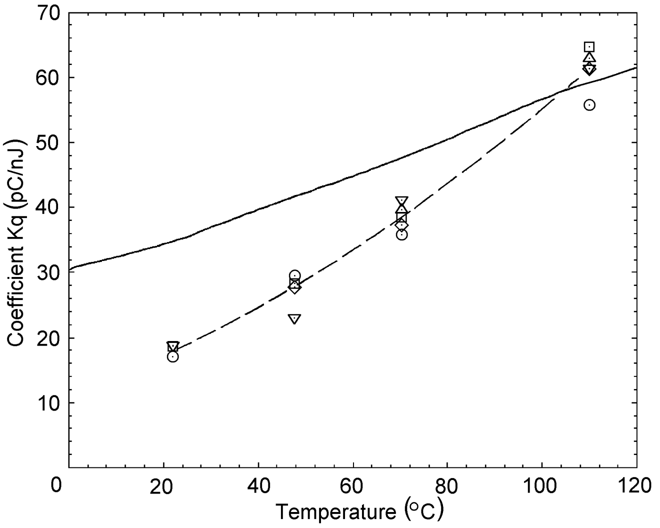


Figure 3: Numerical (lines) and experimentally determined (dots) test structure SEE sensitivity coefficient vs temperature at laser beam location 1 for 1.06 µm wavelength

The pulse-to-pulse variation of laser energy during 1.06 µm wavelength experiment was in the range from 2.3 to 4.5 nJ per pulse.

The experiment and calculations for laser beam location in other surface points (both inside and outside of p-n junction) give the similar results.

The obtained results are in a good agreement with those described in our previous paper [5] for dose rate effects simulation with non-focused 1.06 µm laser irradiation. The collected charge temperature dependence under focused laser beam is similar to that of ionizing current amplitude under non-focused nanosecond laser pulse.

IV. CONCLUSIONS

Temperature dependence of charge collection in silicon IC's under 1.06 and 0.53 µm focused laser beams was investigated in application to Single Event Effect simulation in CMOS test structure.

It was shown that in the case of 0.53 µm laser irradiation the temperature practically does not affect the collected charge because of slight laser absorption coefficient temperature dependence in this range. The theoretically predicted variations of collected charge may be explained by carrier lifetime and mobility temperature dependences.

In the case of 1.06 µm laser irradiation the theory and experiment have shown the essential growth of collected charge with temperature. It is corresponds with strong laser absorption coefficient temperature dependence for photon energy near the bandgap. The theoretical prediction gives the approximately doubling of collected charge in the range from 22 to 110 °C. The experimental results show that SEE sensitivity increases at least three times in this temperature range. The difference between measured and simulated results may be explained by uncertainties of laser absorption coefficient temperature dependence near the edge of silicon fundamental band-to-band absorption zone.

The results obtained prove that the temperature dependence of the laser absorption coefficient in semiconductor affects the equivalent LET and must be taken into accounted in devices SEE selection for LHC electronic.

V. REFERENCES

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