Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp61-62

A-7-06(Late News)

Time-Domain Study on Reproducibility of Laser-Based Soft-Error Simulation

Hiroaki Itsuji[1,2], Daisuke Kobayashi[1,2], Nelson E. Lourenco[3], and Kazuyuki Hirose [1,2]

[1] School of Engineering, Univ. of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo 113-8654, Japan
[2] Institute of Space and Astronautical Science, JAXA, 3-1-1, Yoshinodai, Sagamihara, Chuo, Kanagawa 252-5210, Japan
[3] Advanced Concepts Laboratory, Georgia Tech Research Institute,
Central Research Building, 400 10th Street, NW, Atlanta, GA 30332-0250, USA
Phone: +81-42-759-8534, E-mails: h.itsuji@ac.jaxa.jp, hirose@isas.jaxa.jp

Abstract

Studied is the soft error issue, which is a circuit malfunction caused by ion-radiation induced noise currents. We have developed a laser-based soft-error simulation system to emulate the noise and evaluate its reproducibility in time domain. It is found that this system that conforms to the two-photon absorption process can reproduce the shape of ion-induced transient currents, which is not achieved by the conventional single-photon approach. A technique to estimate the initial charge distribution inside the device is also presented.

I. Introduction

Soft-errors in SRAMs are one of the critical problems for today's CMOS device development, as pointed out by ITRS [1]. They are circuit errors that stem from transient current, *i.e.,* flow of charge created by a radiation strike such as a heavy ion and a neutron. They are hence usually evaluated with radiation beams [2, 3], but there are several difficulties such as limited accessibility. Complementary, pulsed-laser based soft-error simulators, which can be installed on a laboratory bench, are drawing attention. The single-photon absorption (SPA) technique has been widely used already, and recently the two-photon absorption (TPA) is eagerly developed for its long penetration depth, which is desired to backside irradiation [4].

An important issue in the laser simulation is the reliability in reproducing ion induced transient pulses, the shape of which, *i.e.,* the current vs. time waveform (*I-t* curve), is important since one now needs time-domain analyses for discussing the soft error probability [5]. So far, to our knowledge, it is not yet demonstrated that laser probes can reproduce ion-induced pulses [6]. In this study, we investigate such reproducibility by using a homemade TPA system, demonstrating for the first time that it reproduces an ion-induced waveform successfully, which is not by SPA, on the other hand. The TPA reproducibility is attributed to controllability of the initial carrier spots. For the first clue to investigate this spot controllability, we present a technique to extract the spatial information of the spot inside the device from the externally observed *I-t* measurements.

II. Developed system for TPA based simulation

We have developed a TPA system as illustrated in Fig. 1. In comparison with the system that is already used at the Naval Research Laboratory [4], our system does not need an optical component for shifting the wavelength of the laser

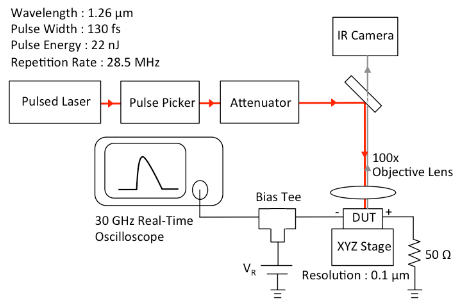

Fig. 1. Developed TPA system for soft-error simulation.

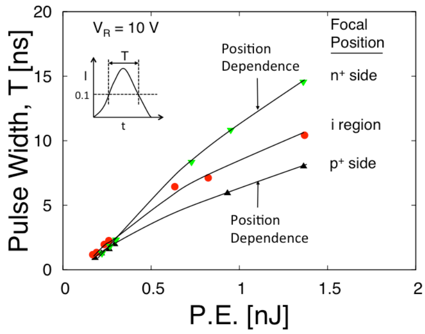

Fig. 2. Measured pulse widths in various conditions.

thanks to our choice of a Cr:Forsterait laser instead for the typical Ti:Sapphire one. This results in further miniaturization of the TPA system. The attenuator is used for controlling the pulse energy (P.E.) while the pulse picker is to adjust the laser repetition rate. The laser beam is focused on the DUT (device under the test) with a 100× microscope objective lens resulting in a 1.1-μm spot size theoretically. A 30-GHz analog bandwidth real-time oscilloscope (Teledyne LeCroy) is installed to record the shape of transient currents. The TPA theory enables to create carriers only near the focal position and to determine its position in an arbitrary depth inside the DUT by moving the DUT on an xyz stage.

III. Reproducibility of TPA based soft-error simulation

The DUT examined in this study is a commercial Si PIN photodiode with a diameter of 450 μm. The PIN photodiode consists of p^+ ($\sim 8 \times 10^{18}$ cm^{-3}), i ($\sim 1 \times 10^{14}$ cm^{-3}), and n^+ ($\sim 2 \times 10^{18}$ cm^{-3}) regions. The thickness of the i region is approximately 15 μm [7]. A 10-V reverse bias was fed to the DUT during the measurements. Fig. 2 summarizes measured pulse widths in various P.E. and positions, *i.e.,* z, which indicates the depth measured from the surface of p^+ region.

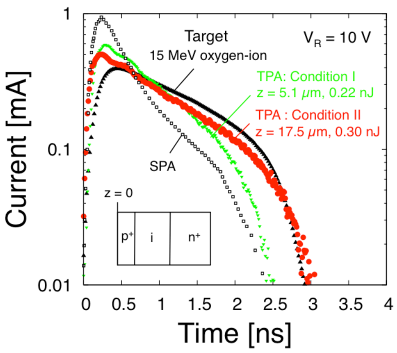

Fig. 3. Comparison of transient currents induced by oxygen-ion [7], SPA [6], and TPA.

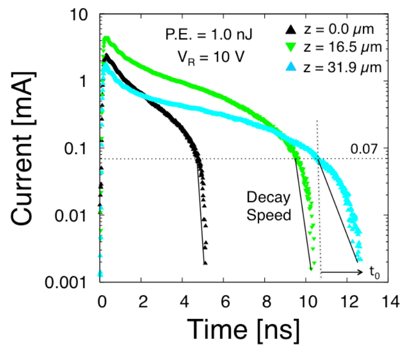

Fig. 4. TPA induced transient currents at three focal positions.

Here, we define the pulse width as the temporal duration where the current exceeds 0.1 mA. This figure implies that we can control the pulse width by changing P.E. and focal position. This controllability is the key to reproduce the transient pulse, as demonstrated in Fig. 3, in which the TPA simulation in the condition "I" reproduces the 15-MeV O-ion-induced transient current (after [7]) successfully while not the condition II. This figure also shows an SPA result, which delivers undesired large difference.

IV. Estimation of the initial carrier spot size

The revealed high reproducibility of TPA is attributed to the controllability of the initial carrier-spot structure (size and position). For the first step to confirm this, we have developed a technique to extract the spatial information of the spot from the measured *I-t* curves. Fig. 4 shows the curves at P.E = 1.0 nJ. We have found that the measured pulses exhibit various decay speeds (rates). In this regard, we have analyzed the decay component, *i.e.,* focusing the region where $I \le 0.07$ mA. Fig. 5 shows the extracted decay tails; the horizontal axis shows the elapsed time (t_0) since I reaches 0.07 mA. This figure reveals that the decay tails distribute in a limited range between the "fast" and "slow" boundaries. This fact is clearly demonstrated in Fig. 6, where this decay rate map exhibits three regions: the two constant regions of "fast" and "slow", and the transition region. This z-dependent evolution of the decay rate is attribute to the position of generated carriers. It is already known that when charge is created inside n^+ region, transient currents exhibit a slow tail [7]. Hence we assume that the "slow" decay corresponds to the case where the charge is all created inside the n^+ region while "fast" the case where the charge is all created inside the i region, since it provides a large electric filed. In other words, the length of the transition region is expected to represent the carrier spot size, *i.e.*, ~15 μm from Fig. 6. This value is the same as one reported in Ref. [8], which also extracted but with a different approach, reporting the value of 16 μm in the similar experimental condition. Interestingly, our analysis (Fig. 6) has revealed that P.E. is not a critical parameter to describe the decay-rate evolution. Although the reason behind it is not clear yet, it might provide a new clew for further understand of soft error phenomenon. We are conducting device simulation analysis in this regard.

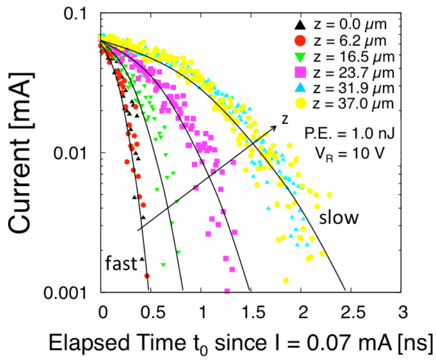

Fig. 5. Decay tails (Magnified view of Fig. 4).

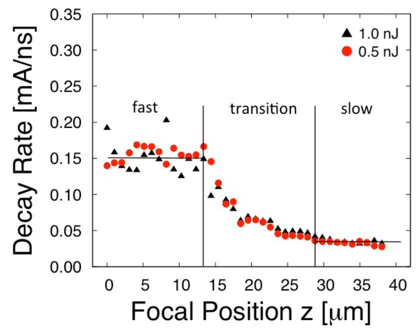

Fig. 6. Decay rate of the transient currents as a function of z.

V. Conclusion

We have developed a TPA system for soft-error simulation and investigated its reproducibility. It is found that the TPA simulation can reproduce the shape of ion-induced currents by controlling the focal position and the pulse energy. We have also presented a technique to estimate the initial charge distribution inside the device from the transient currents externally observed.

References

[1] ITRS: http://www.itrs2.net/. [2] K. Hirose *et al., IEEE Trans. Nucl. Sci*, **49** (6) 2965, 2002. [3] D. Kobayashi *et al., IEEE Trans. Nucl. Sci*, **61** (4) 1710, 2014. [4] D. McMorrow *et al., IEEE Trans. Nucl. Sci*, **49** (6) 3002, 2002. [5] K. Hirose *et al., IEEE Trans. Nucl. Sci*, **51** (6) 3349, 2004 [6] J. S. Laird *et al., IEEE Trans. Nucl. Sci*, **53**, (6) 3312, 2006. [7] S. Onoda *et al., IEEE Trans. Nucl. Sci*, **53** (6) 3731, 2006. [8] E. Faraud *et al., IEEE Trans. Nucl. Sci*, **58** (6) 2637, 2011.