USE OF DIFFUSED LASER IRRADIATION TO IMPROVE DOSE RATE SIMULATION ADEQUACY

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Abstract

A diffused laser irradiation was used to improve laser simulation adequacy of dose rate effects in silicon IC’s with high metallization density. The conversion of coherent output laser irradiation into the diffused one was performed by specialized homogenizer. Test structures with various metallization coverage were designed. Numerical simulations together with laser tests were performed in order to clarify the advantage of diffused laser irradiation before coherent one.

1. INTRODUCTION

The laser simulation of dose rate effects is based on laser beam capability to ionize IC's semiconductor structures [1]. Associated shadowing effects have been investigated in details [2,3]. It was shown that the metal coverage reduces the simulation adequacy if coherent laser irradiation is used. The influence of shadowing on latch-up threshold in this case was analyzed in [4].

A way to improve dose rate laser simulation adequacy was proposed in [5]. The approach is based on the application of noncoherent (diffused) laser radiation that reduced metallization shadowing effects. The optical model of diffused laser radiation interaction with IC semiconductor structures and appropriate software simulator were presented. It was shown that in the case of diffused laser irradiation the ionizing effect is defined by average metallization coverage of structure and the adjacent area.

In this work we applied the diffused laser irradiation to dose rate ionizing current and latch-up simulation. The specialized test structures were manufactured to experimentally estimate the advantage of diffused laser irradiation before coherent one.

2. TEST STRUCTURES DESCRIPTION

Two structure sets (TSCPHXX and TSCLUXX) are manufactured in conventional 2-μm bulk CMOS process. A structure's cross-section is presented in Fig. 1. Each structure includes well-substrate p-n junction (48x78 μm) with strip contacts and various metallization coverage. Contact region size is 2x2 μm. The structure set TSCLUXX is similar to TSCPHXX but with different disposition of highly doped regions in order to form SCR (latch-up). The structural parameters are: p-substrate is B doped up to 12 Ω·cm. The 6 μm n-well is P doped up to 1700 Ω/ . The 0.6 μm p+ and 0.35 μm n+ regions are doped up to 110 Ω/ and 40 Ω/ consequently.

The structures TSCPHXX have four leads: two anodes (A1 and A2) and two cathodes (K1 and K2) and structures TSCLUXX have leads: base and emitter of parasitic p-n-p transistor (B1 and E1) and emitter and base of parasitic n-p-n transistor (E2 and B2).

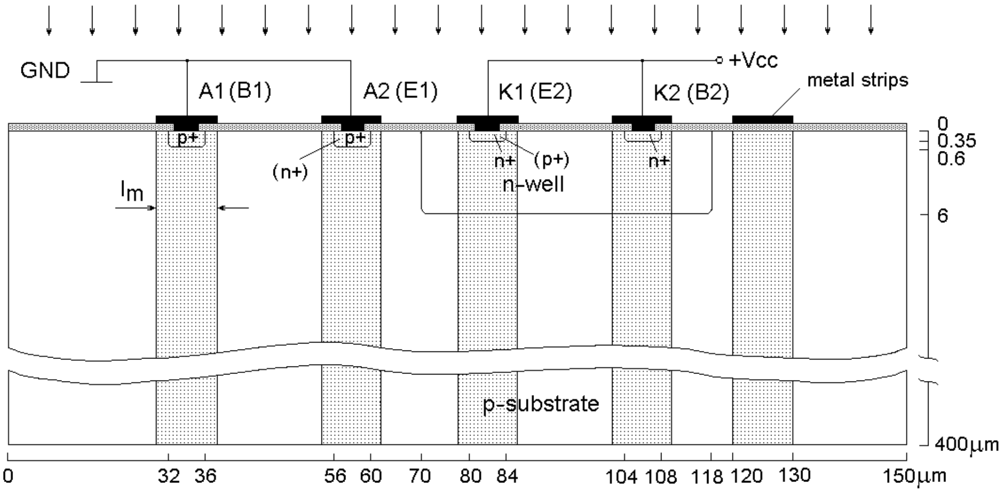


Figure 1. TSCPHXX (TSCLUXX) test structures cross-section

Various test structures have the individual metal strip widths. Metal strip parameters of the structures are summarized in Table 1.

Table 1. Test structures metallization parameters (S_{pn} is p-n junction square S_m is p-n junction metallization square).

Test structure	Metallization strip width l_m, μm	Metallization coverage, S_m/S_{pn},%
TSCPH2 (TSCLU2)	2	8.3
TSCPH6 (TSCLU6)	6	25
TSCPH12 (TSCLU12)	12	50
TSCPH18 (TSCLU18)	18	75
TSCPH22	22	91.7

The minimum and maximum shadowing cases are presented in Fig.2. The last strip to the right does not shadow the p-n junction and its width is equal to 10 μm for all structures.

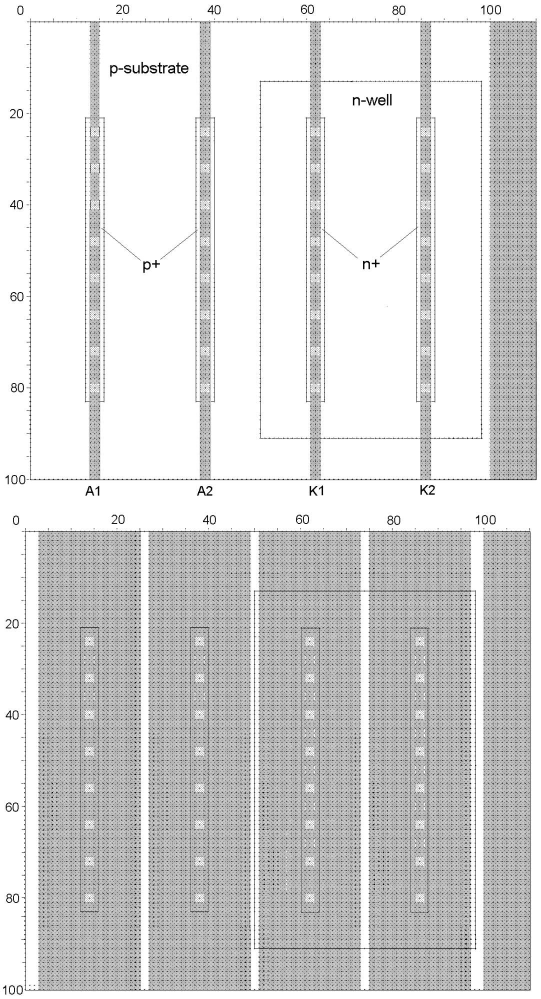


Figure 2. TSCPH2 (top) and TSCPH22 (bottom) test structures view

3. NUMERICAL AND EXPERIMENTAL COMPARATIVE RESULTS

In order to perform the test structures transient analysis the "DIODE-2D" software simulator was used which is the two-dimensional solver of fundamental system of equations taking into account the electrical and optical processes including multireflection and free carrier nonlinear absorption [3]. The numerical simulator optical model was modified in order to take into account the diffuse feature of laser radiation.

Pulsed laser simulator "RADON-5E" with 1.06 μm wavelength and 11 ns pulse width was used [6]. The simulator was supplied by homogenizer that converts purely coherent parallel laser irradiation into diffused mode. The laser pulse maximum intensity was varied from $6{\cdot}10^2$ up to $2.1{\cdot}10^6$ W/cm^2 with laser spot size covering the entire chip. The ionizing current transient response was registered with "Tektronix TDS-220" digital oscilloscope.

The laser simulation calculated and experimental data of well-substrate junction ionizing current amplitude vs. metallization coverage of TSCPHXX test structures under V_{cc}=5V are presented in Fig.3. One can see the better agreement of the diffused model calculation curve with test data. The usage of homogenizer improves the laser intensity uniformity within chip area and decrease the influence of metallization shadowing on test structure ionizing current. For TSCPHXX test structure set when metallization coverage increase from 8.3 to 91.7% (11 times) the ionizing current amplitude decrease only from 10 to 5 mA (2 times) at laser intensity $9.7{\cdot}10^3$ W/cm^2.

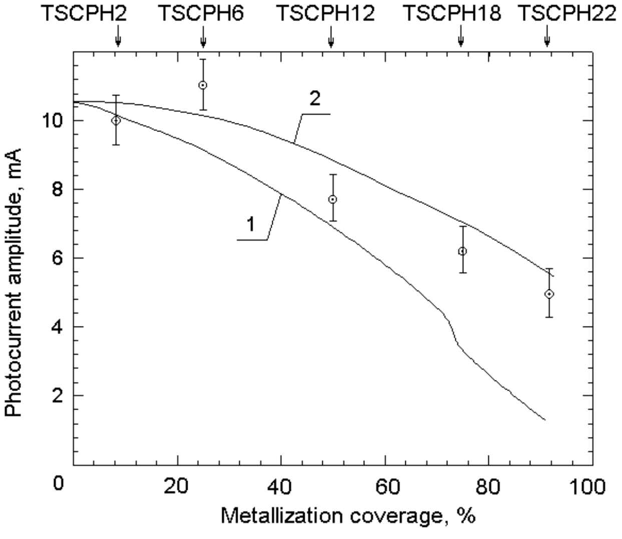


Figure 3. Theoretical (curve) and experimental (dots) test structures photocurrent amplitudes vs. metallization coverage at laser intensity $9.7{\cdot}10^3$ W/cm^2: 1- coherent model; 2 - diffused model

The comparison between theoretical and experimental data for TSCLU2, LU6, LU12 and LU18 test structures under V_{cc}=5V is presented in Fig. 4. One can see that diffused laser irradiation model provides the better agreement with experimental data.

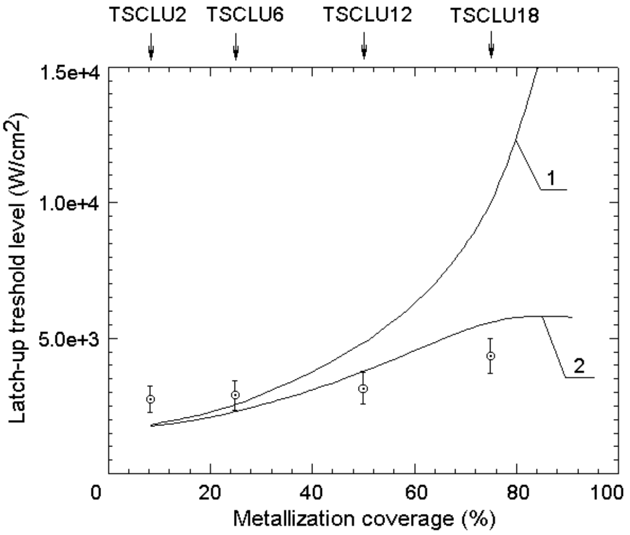
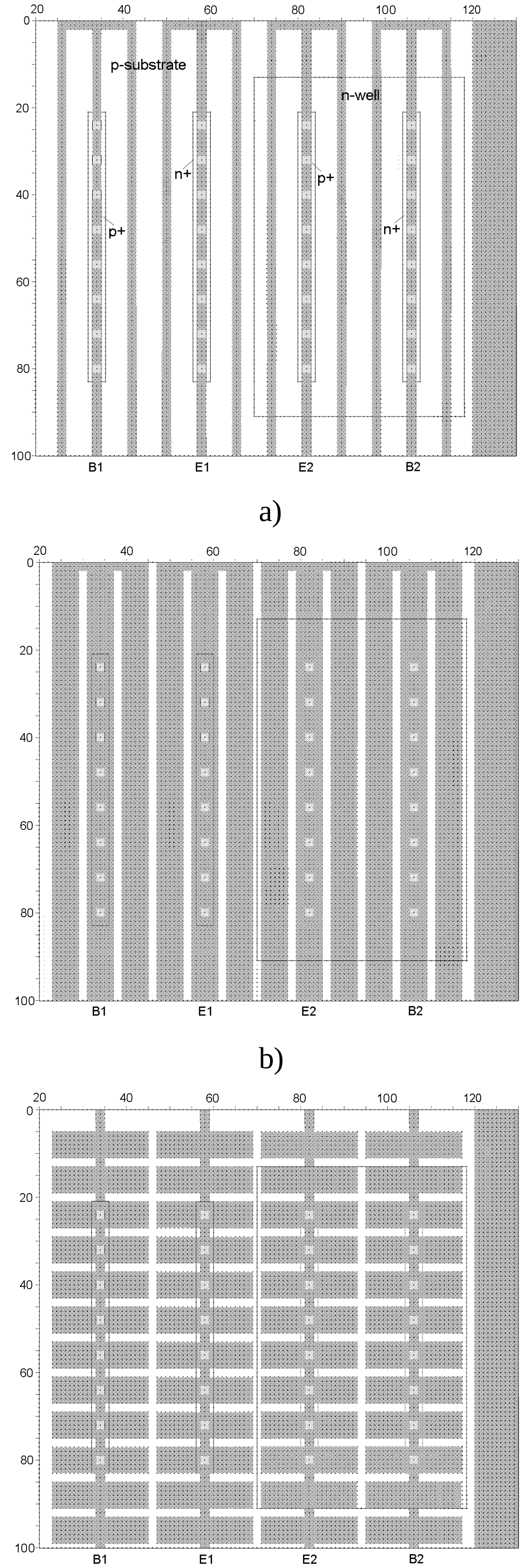


Figure 4. Theoretical (curves) and experimental (o) test structures latch-up levels vs metallization coverage: 1 - coherent model; 2 - diffused model

The experimentally defined TSCLU18 and TSCLU2 test structures latch-up levels equal to $4.3 \cdot 10^3$ and $2.7 \cdot 10^3$ W/cm^2 accordingly. The ratio of latch-up thresholds does not exceed 1.7 when metallization coverage increase from 8.3 to 75 % (9 times). It can be explained by nonparallel feature of diffused irradiation and by contribution of reflected irradiation from chip bottom [5].

However the numerical estimation for diffused model gives 3.38 value of the ratio. The difference between numerical and experimental values may be explained by contribution of light refraction and scattering in passivation layers, SiO_2 and Si neglected under calculation. These factors tend to improve laser ionization uniformity and decrease the difference latch-up thresholds.

To investigate the influence of metallization shape on latch-up threshold level the structures TSCLU23, LU63 and LU18b were designed additionally. They have the individual metal strip topologies shown in Fig. 5. It was found that maximum difference in latch-up thresholds in experiments did not exceed 3% between TSCLU6 and LU23 structures, 5% between TSCLU18 and LU18b structures and 10% between TSCLU18 and LU63 structures. This difference is within the accuracy of laser intensity dosimetry and so the structure pares listed above may be considered as equivalent under diffused laser irradiation.



a)

b)

c)

Figure 5. TSCLU23 (a), TSCLU63 (b) and TSCLU18b (c) test structures view

The reasons of diffused laser irradiation advantage may be explained on the base of optical model. A homogenizer converts the coherent output laser radiation into the diffused radiation of finite-size source as shown in Fig.6. It causes the mixing of various laser modes and permits the nonparallel radiation to partially penetrate under metallization. The additional effect is due to the reflection of the nonparallel laser beam from the substrate's bottom (see Fig. 6). As a result the laser radiation can penetrate under metallization from backside and reduce the ionization nonuniformity.

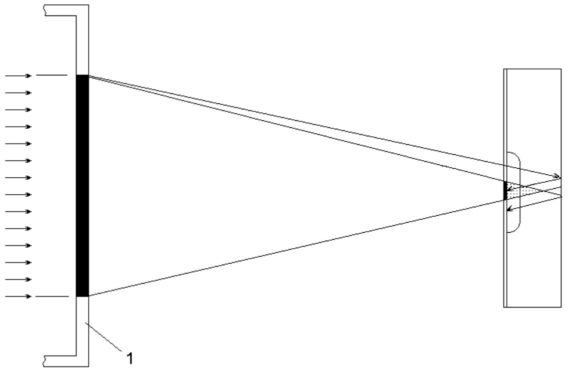


Figure 6. The shadow creation and backside reflection in the case of diffused laser radiation formed by a homogenizer (1)

4. CONCLUSIONS

A method for improving of dose rate simulation adequacy based on the application of noncoherent (diffused) laser radiation was applied and adopted to p-n junction ionizing current and CMOS latch-up threshold estimation. The diffused irradiation was supplied by specialized laser simulator "RADON-5E" with homogenizer. Numerical simulation results were verified against experimental data under specialized test structures with individual metallization coverage and topology.

It was found that usage of homogenizer improves the laser intensity uniformity within chip area and decrease the influence of metallization shadowing on CMOS latch-up threshold. For TSCPHXX test structure set when metallization coverage increase from 8.3 to 91.7% (11 times) the ionizing current amplitude decrease only from 10 to 5 mA (2 times). As for TSCLUXX structures when metallization coverage increase from 8.3 to 75 % (9 times) the latch-up threshold level increase only from $2.7 \cdot 10^3$ to $4.3 \cdot 10^3$ W/cm^2 (1.7 times).

The measured difference between latch-up thresholds of structures with equal metallization coverage and different topology did not exceed 3 - 10%.

Obtained results demonstrate the advantage of diffused laser irradiation for dose rate effects simulation in highly-metallized IC's.

5. REFERENCES

[1]. D.H.Habing, "Use of Laser to Simulate Radiation - induced Transients in Semiconductors and Circuits", *IEEE Trans. Nucl. Sci.*, Vol. NS-12, No.6, p.91-100, December 1965.

[2]. M.Jonsson, S.Mattsson, "Transient Radiation Response of VLSI Circuits: Shadowing Effects and Pulse Widths Dependence in Laser" *IEEE Trans. Nucl. Sci.*, Vol. NS-38, No.6, p.1429-1433, December 1991.

[3]. A.Y.Nikiforov, P.K.Skorobogatov, "Dose Rate Laser Simulation Tests Adequacy: Shadowing and High Intensity Effects Analysis", *IEEE Trans. Nuc. Sci.*, Vol. NS-43, No.6, p.3115-3121, December 1996.

[4]. P.K.Skorobogatov, A.Y. Nikiforov, B.A.Ahabaev "Laser Simulation Adequacy of Dose Rate Induced Latch-up", in *Proceedings of the 4th Europ. Conf. "Radiations and Their Effects on Devices and Systems*, Cannes, France, Sept. 15-19, 1997, pp.I21-I23.

[5]. P.K.Skorobogatov, A.Y.Nikiforov, A.A.Demidov "A Way to Improve Dose Rate Laser Simulation Adequacy", *IEEE Trans. Nuc. Sci.*, Vol. NS-45, No.6, December 1998.

[6]. A.Y.Nikiforov, O.B.Mavritsky, A.N.Egorov, V.S.Figurov, V.A.Telets P.K.Skorobogatov, S.A.Polevich "RADON-5E" Portable Pulsed Laser Simulator: Description, Qualification Technique and Results, Dosimetry Procedure", in *1996 IEEE Radiation Effects Data Workshop Record*, Indian Wells, July 15-19, 1996, pp. 49-54.