# The Behavior of P-I-N Diode under High Intense Laser Irradiation

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*Abstract*

The dependence of p-i-n diode ionizing current amplitude vs 1.06 μm pulsed laser irradiation intensity is investigated. It is shown that the analyzed dependence becomes nonlinear beginning with relatively low laser intensities near 10 W/cm$^2$.

## I. INTRODUCTION

Pulsed laser sources are widely used for dose rate effects simulation in IC's [1]. The Nd:YAG laser with 1.06 μm wavelength is nearly ideal for silicon devices, with a penetration depth near 700 μm [2]. The measurements of pulsed laser irradiation intensity and waveform monitoring may be provided with p-i-n diode. High electric field in its intrinsic region provides the full and fast excess carriers collection. As a result the ionizing current pulse waveform repeats the laser pulse within the accuracy of several nanoseconds.

Possible nonlinear ionization effects may disturb the behavior of p-i-n diode at high laser intensities. Here we present the results of the recent study of typical p-i-n diode using 2D numerical simulation and a pulsed laser simulator with the 1.06 μm wavelength as a radiation source.

## II. P-I-N DIODE STUDY

The typical p-i-n diode with a intrinsic region 380 -micrometers thick at 300 V reverse bias was investigated. P-i-n diode cross-section is shown in Fig. 1. The sensitive area size is 2.3x2.3 mm. The p+ and n+ regions of diode are doped up to 10$^{19}$ cm$^{-3}$.

To investigate the p-i-n diode possibilities at high laser intensities the original software simulator "DIODE-2D" [3] was used. The "DIODE-2D" is the two-dimensional solver of the fundamental system of equations. It takes into account carrier generation, recombination and transport, optical effects, carrier's lifetime and mobility dependencies on excess carriers and doping impurity concentrations.

The calculated p-i-n diode ionizing current pulse amplitude vs laser intensity dependence under 300 V reverse bias is presented in Fig. 2. The radiation pulse waveform was taken as "Gaussian" with 11 ns duration. One can see that the direct proportionality between current pulse amplitude and laser intensity takes place only at relatively low intensities (up to 10 W/cm$^2$). The ionization distribution nonuniformity connected with laser radiation attenuation does not affect the dependence because of relatively low excess carrier density is not enough to sufficiently change the absorption coefficient.

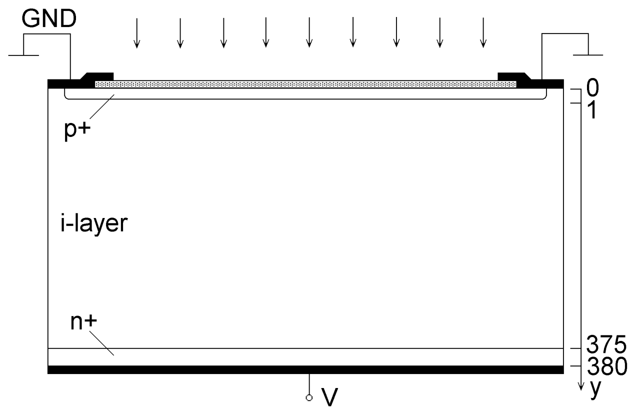



Figure 1: P-i-n diode cross-section

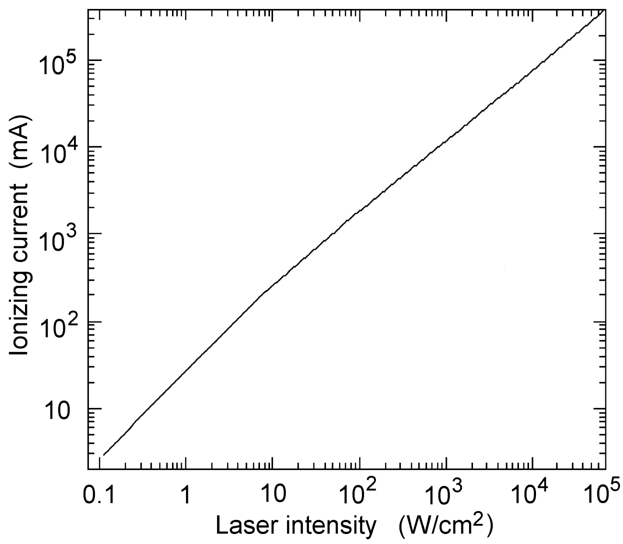
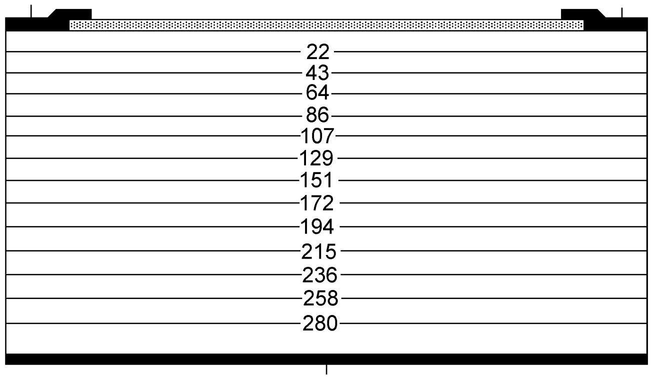



Figure 2: P-i-n diode ionizing current pulse amplitude vs laser pulse intensity dependence

The non-linearity is caused by the modulation of p-i-n diode intrinsic region by excess carriers. Because of low level of initial carriers concentration the modulation takes place at relatively low dose rates. As a result of modulation the distribution of electric field in the intrinsic region becomes non-uniform that leads to decrease of excess carriers collection. This proposal is confirmed by results of potential distribution calculations for different laser peak intensities presented in Fig. 3.

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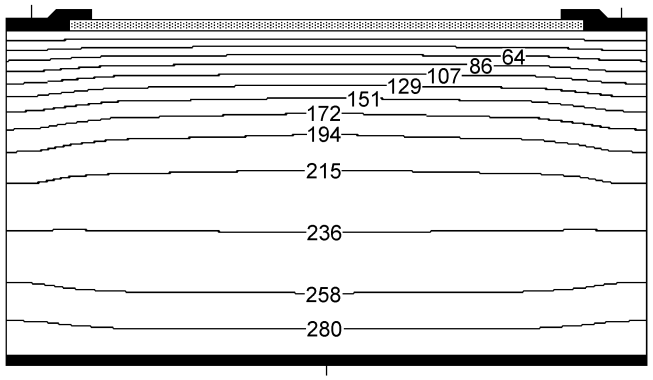


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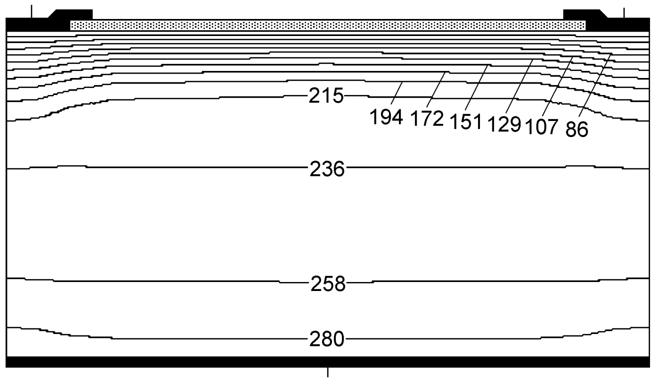



c)

Figure 3: Potential distributions at time 11 ns for different maximum laser intensities: initial (a), $10^2$ (b) and $10^3$ (c) W/cm$^2$

The behavior of p-i-n diode becomes similar to that of ordinary p-n junction with prompt and delayed components of ionizing current. The prompt component repeats the laser intensity waveform. The delayed component is connected with the excess carriers collection from regions with low electric fields. As a result, the ionizing current pulse form becomes more prolonged and doesn't repeat the laser pulse waveform.

Fig. 4 shows the normalized calculated ionizing current pulse waveforms for different maximum laser intensities. At relatively low intensity the current pulse waveform repeats the appropriate laser pulse waveform. At high intensities we see the delayed components.

The non-linear nature of behavior and prolonged reaction must be taken into account when p-i-n diode is used as a laser intensity and waveform dosimeter.

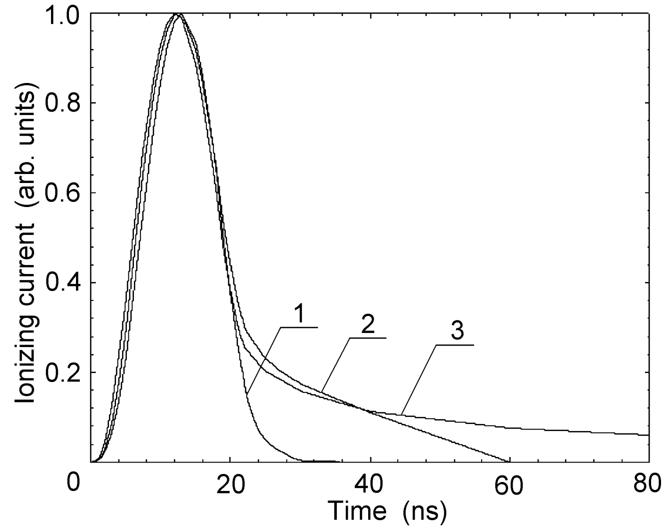



Figure 4: Normalized calculated ionizing current pulse waveforms for different maximum laser intensities:10 (1), $10^2$ (2) and $10^3$ (3) W/cm$^2$

## III. Numerical to Experimental Comparative Results

The numerical results were confirmed by experimental measurement of p-i-n diode ionizing reaction within a wide range of laser intensities.

The pulsed laser simulator "RADON-5E" with the 1.06 μm wavelength and 11 ns pulse width was used in the experiments as a radiation source [4]. 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. It provides in silicon the equivalent dose rates up to $10^{12}$ rad(Si)/s. The p-i-n diode ionizing current transient response was registered with the "Tektronix TDS-220" digital oscilloscope.

The comparative p-i-n diode ionizing current pulse amplitude vs laser intensity dependencies under 300V reverse bias are presented in Fig. 5. The upper limit of laser intensity is restricted by p-i-n diode failure possibility.

One can see that the experimental results confirm the non-linear behavior of p-i-n diode at intensities above $10^1$ W/cm$^2$. The reduction of reverse voltage increases the non-linear effects.

As for the distortion of pulse waveform at high laser intensities it was also confirmed. The experimental p-i-n diode current pulse waveforms are represented in Fig. 6. At the maximum intensity 1.3 W/cm$^2$ the current pulse waveform repeats the laser irradiation one. At an intensity of 27 W/cm$^2$ we can see prolonged behavior though this intensity corresponds to only 3,4 $10^7$ rad(Si)/s equivalent dose rate.

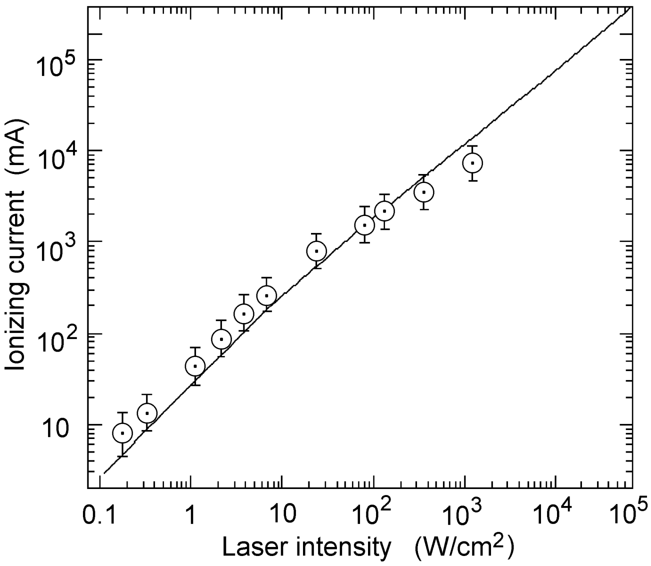
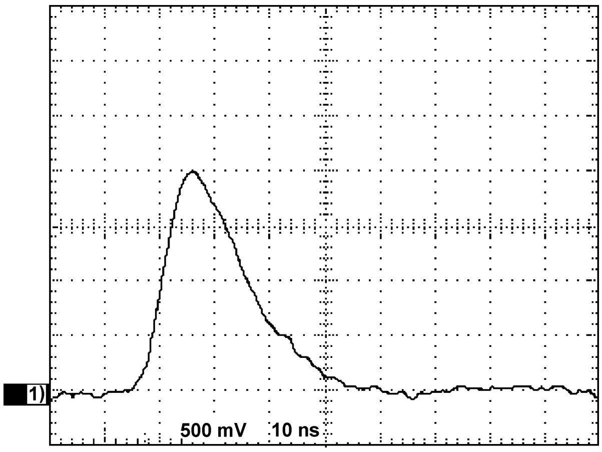
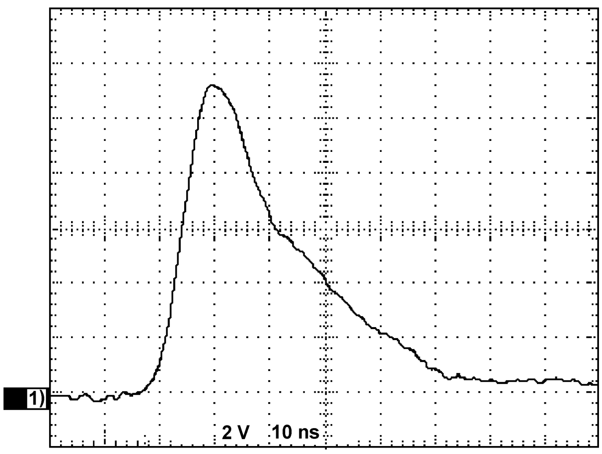



Figure 5: Numerical (line) and experimentally determined (dots) p-i-n diode ionizing current amplitude vs laser intensity




a)




b)

Figure 6: P-i-n diode ionizing current waveforms under laser pulses with 1.3 (a) and 27 (b) W/cm$^2$ maximum intensities

## IV. CONCLUSION

The simulation and experiments under p-i-n diode structure have shown that linear dependence between pulsed laser intensity and ionizing current pulse amplitude is valid only at relatively low intensities up to 10 W/cm$^2$. In the field of high intensities this dependence becomes non-linear and ionizing current increases more slowly than laser intensity. The ionizing current pulse form becomes more prolonged and does not repeat the laser pulse waveform.

The non-linear nature of behavior and prolonged reaction must be taken into account when p-i-n diode is used as a laser intensity and pulse waveform dosimeter in LHC experiments.

## V. REFERENCES

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