The Nonlinear Behavior of P-I-N Diode in High Intense Radiation Fields

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Abstract

The dependence of p-i-n diode ionizing current amplitude vs dose rate is defined using two-dimensional software simulation. It is shown that analyzed dependence becomes nonlinear beginning with relatively low dose rates near 10^7 rad(Si)/s. This effect is connected with the modulation of p-i-n diode intrinsic region by irradiation. As a result the distribution of electric field becomes non-uniform that leads to decrease of excess carriers collection. The ionizing current pulse form becomes more prolonged because of delayed component contribution. It is necessary to take into account when p-i-n diode is used as dose rate dosimeter.

I. INTRODUCTION

The p-i-n diodes are widely used for the measurements of ionizing radiation dose rates. The 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 ionization pulse with the accuracy of several nanoseconds.

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

II. P-I-N DIODE STUDY

The typical p-i-n diode with 380 micrometers intrinsic region thick at 300 V reverse bias was investigated. P-i-n diode cross-section is shown in Fig. 1. 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 dose rates the original software simulator "DIODE-2D" [1] was used. The "DIODE-2D" is the fundamental system of equations two-dimensional solver. 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 dose rate and laser intensity dependency under reverse bias 300 V is presented in Fig. 2. The radiation pulse waveform was taken "Gaussian" with 11 ns duration. One can see that the direct proportionality between current pulse amplitude and dose rate (laser intensity) takes place only at relatively low dose rates (up to 10^7 rad(Si)/s). The ionization distribution nonuniformity connected with laser radiation attenuation does not affect the dependence.

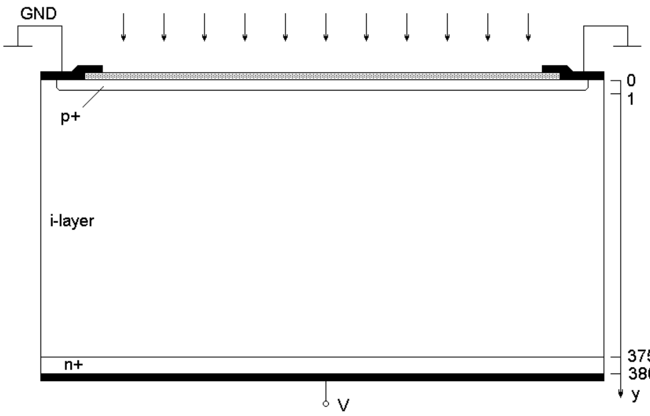


Figure 1: P-i-n diode cross-section

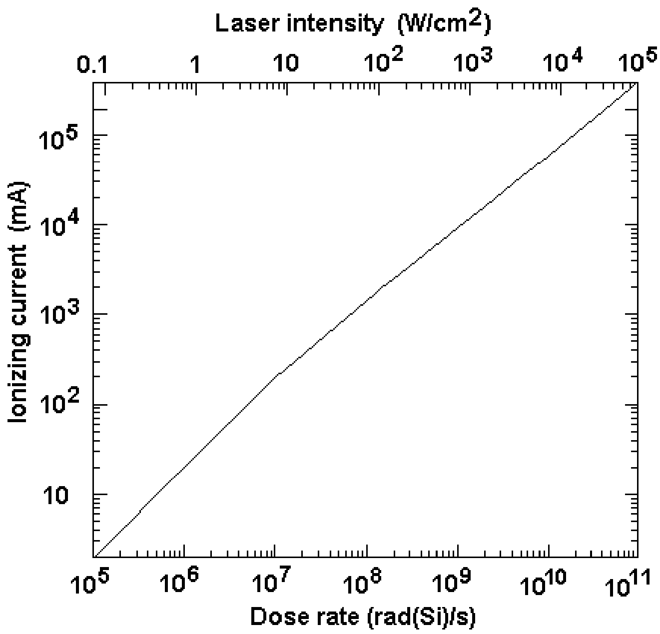


Figure 2: P-i-n diode ionizing current pulse amplitude vs dose rate and laser intensity dependency

The reason of non-linearity is connected with 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 presented in Fig. 3.

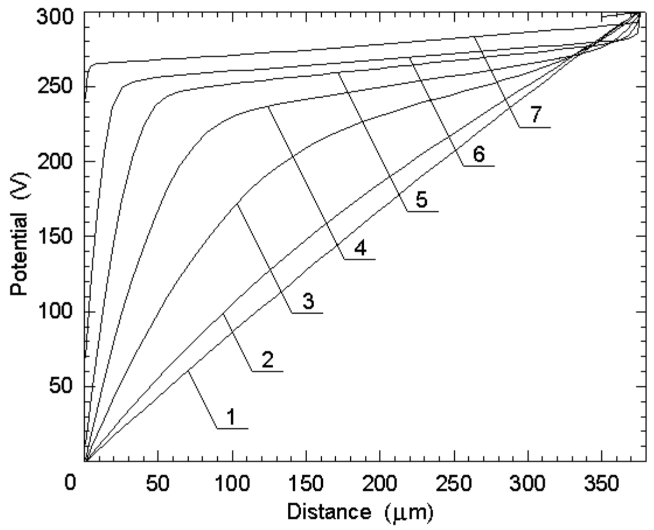


Figure 3: Potential vs distance distributions at time 11 ns for different maximum dose rates: initial (1), 10^7 (2), 10^8 (3), 10^9 (4), 10^{10} (5), 10^{11} (6) and 10^{12} (7) rad(Si)/s

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 dose rate 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 dose not repeat the dose rate waveform.

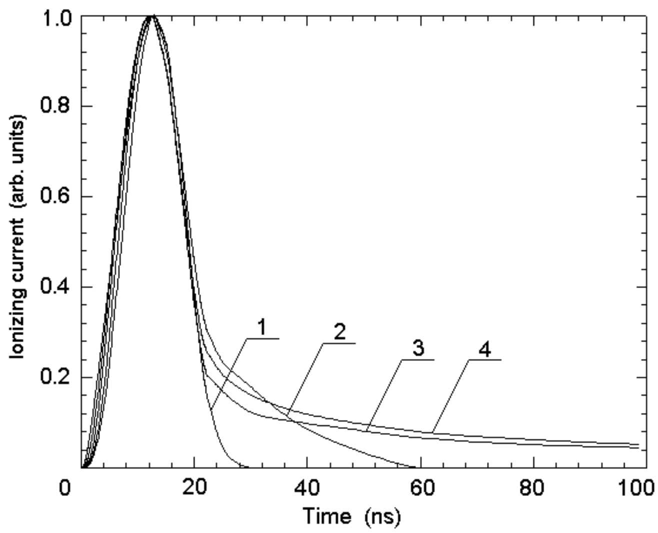


Figure 4: Normalized calculated ionizing current pulse waveforms for different maximum dose rates: 10^7 (1), 10^8 (2), 10^9 (3) and 10^{11} (4) rad(Si)/s

Fig. 4 depicts the normalized calculated ionizing current pulse waveforms for different maximum dose rates. At relatively low dose rate the current pulse waveform repeats the appropriate radiation pulse waveform. At high dose rates we see the delayed components.

The non-linear character of behavior and prolonged reaction must be taken into account when p-i-n diode is used as dose rate dosimeter.

III. Numerical to experimental comparative results

The numerical results were confirmed by experimental measurement of p-i-n diode ionizing reaction in wide range of ionizing radiation dose rates.

Pulsed laser simulator "RADON-5E" with 1.06 μm wavelength and 11 ns pulse width was used in the experiments as a radiation source. 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 "Tektronix TDS-220" digital oscilloscope.

The comparative p-i-n diode ionizing current pulse amplitude vs laser intensity dependencies under reverse bias 300 V are presented in Fig. 5.

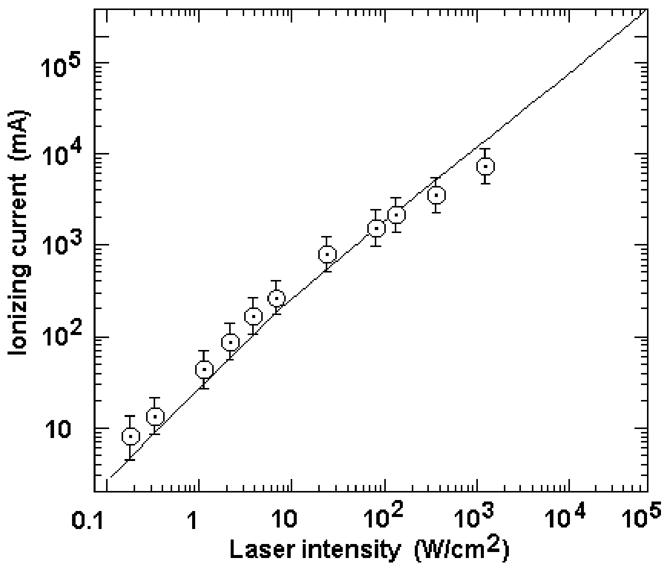
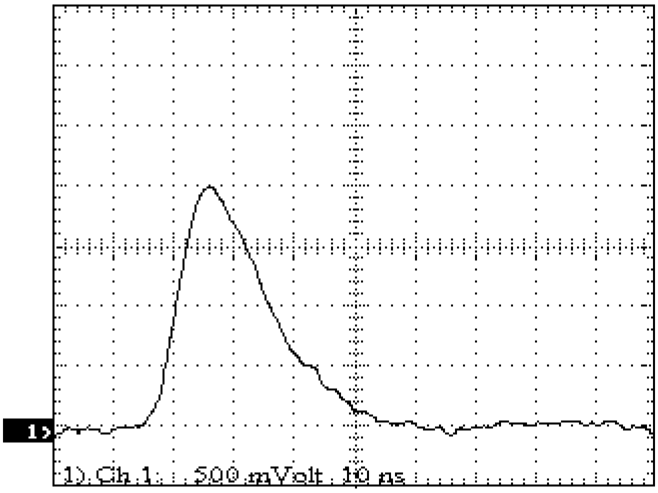


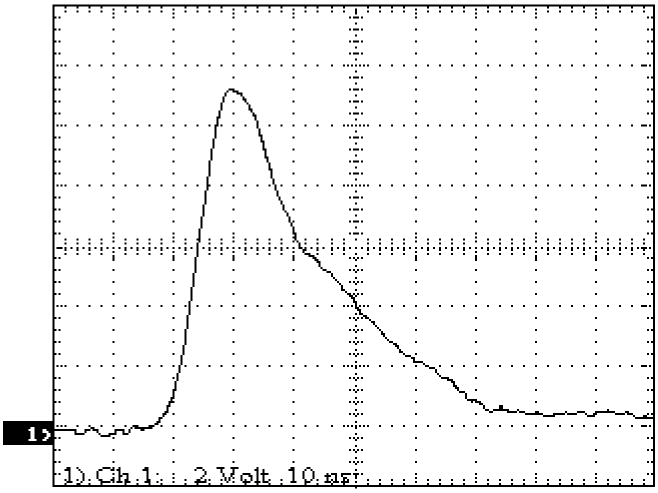
Figure 5: Numerical (line) and experimentally determined (dots) p-i-n diode ionizing current amplitude vs laser intensity

One can see that the experimental results confirm the non-linear behaviour of p-i-n diode at dose rates above 10^7 rad(Si)/s.

As for the distortion of pulse waveform at high dose rates it was confirmed also. The experimental p-i-n diode current pulse waveforms are represented in Fig. 6. At dose rate $1{,}6 \cdot 10^6$ rad(Si)/s the current pulse waveform repeats the radiation one. At dose rate $3{,}4 \cdot 10^7$ rad(Si)/s we can see prolonged behavior.



a)



b)

Figure 6: P-i-n diode ionizing current waveforms under laser pulses with 1.6 10^6 (a) and 3,4 10^7 (b) rad(Si)/s equivalent dose rates

IV. CONCLUSION

The simulation and experiments under p-i-n diode structure have shown that linear dependence between dose rate and ionizing current pulse amplitude is valid only at relatively low dose rates up to 10^7 rad(Si)/s. In the field of high dose rates this dependence becomes non-linear and ionizing current increases more slowly than dose rate. The ionizing current pulse form becomes more prolonged and dose not repeats the dose rate waveform.

The non-linear character of behavior and prolonged reaction must be taken into account when p-i-n diode is used as dose rate dosimeter.

IV. REFERENCES

[1]. The "DIODE-2D" Software Simulator Manual Guide, SPELS, 1995.