Determination of 4H-SiC ionization rates using OBIC based on two-photon absorption

Hassan Hamad, Christophe Raynaud, Pascal Bevilacqua, S Sharnholz, Bertrand Vergne, Dominique Planson

Determination of 4H-SiC ionization rates using OBIC based on two-photon absorption

H. Hamad[1)], C. Raynaud[1)], P. Bevilacqua[1)], S. Sharnholz[2)], B. Vergne[2)], D. Planson[1)]
[1)] INSA de Lyon, Laboratoire Ampère, 21 Avenue Jean Capelle, 69621 Villeurbanne Cedex, France.
[2)] French-German Research Institute of Saint Louis (ISL), 5 Rue du Général Cassagnou, 68301 Saint-Louis Cedex, France.
hassan.hamad@insa-lyon.fr

Ionization rates are requested to predict the breakdown voltage of electronic devices. They are used in numerical simulators like SENTAURUS TCAD [1] in order to model the leakage current and the breakdown of the devices. They are rarely studied and the results already published are, more or less, scattered [2-4]. Many methods like OBIC or EBIC (Optical/Electron Beam Induced Current) are used to determine the ionization rates. In this paper, OBIC method is used in 4H-SiC. An optical beam illuminates perpendicularly a reverse biased PN junction. Photon absorption process leads to generate electron-hole pairs (EHPs). EHPs created in the space charge region (SCR) will be accelerated by the electric field and thus an induced current is measured, hence the naming of the method: Optical Beam Induced Current OBIC (Fig. 1). For voltages close to the breakdown voltage, the electric field becomes high, the EHPs gain a kinetic energy and collide with the atoms in the crystalline structure leading to the generation of a new EHPs, which in turns may lead to the creation of new EHPs; this is manifested by an increase of the OBIC signal. The multiplication coefficient is defined as the ratio between the induced current at a given voltage V and at V_0 (for which there is no multiplication). The ionization coefficient curves are derived from the multiplication curves.

According to the wave length (respectively the photon energy E_Φ), the absorption of one photon can lead to generate an EHP if E_Φ is high enough compared to the semi-conductor bandgap E_G ($E_\Phi > E_G$). If E_Φ is smaller than E_G ($E_\Phi < E_G$), one-photon absorption process becomes impossible and then two or more photons must interact at the same time with an atom to be absorbed and to generate an EHP. This is the multi-photon absorption process that has been theoretically predicted in 1931 [5]. Since the two-photon absorption probability is weak compared to single photon absorption process, high beam power densities are necessary to generate EHPs. Two-photon absorption process was recently demonstrated on 4H-SiC by using a green laser beam (532 nm) [6].

In this paper, OBIC measurements based on two-photon absorption process are realized using a pulsed green laser at 532 nm (Fig. 2). The device under test is a circular avalanche diode with a breakdown voltage of 59 V. It presents a thin and highly doped active layer, which means high electric field devices (> 3 $MV.cm^{-1}$). The diodes are elaborated on a 10×10 mm^2 sample produced by the French-German Institute of Research of Saint-Louis ISL. An optical window was performed using SIMS technique on some diodes (Fig. 3) allowing the optical beam to penetrate towards the drift region of the diode [7]. To extract the ionization rates, Chynoweth model is adopted and the equation 1 shows the expressions of obtained ionizations rates of 4H-SiC. The results are in good agreement with other results obtained on the same diodes using OBIC technique based on one-photon absorption process (Fig. 4) [8]. The comparison with published results in the literature (Fig. 5) shows that the hole's ionization rates α_p are greater than electron's ionization rates α_n (as the other authors) but the ratio α_p/α_n is about twice (much smaller than the published results).

$$\alpha_p = 1.71 \times 10^6 \exp\left(-{}^{11.8}/_{E}\right)$$
$$\alpha_n = 1.11 \times 10^6 \exp\left(-{}^{12.2}/_{E}\right) \qquad \text{Equation 1}$$

where α_p and α_n are expressed in cm^{-1} and the electric field E in $MV.cm^{-1}$.

[1] "Sentaurus Device User Guide Version F-2011, http://www.synopsys.com/home.aspx.
[2] A-O. Konstantinov, Q. Wahab, et al., Materials Science Forum, vols. 264-268, 513 (1998).
[3] W. S. Loh, B. K. Ng, et al., Electron Devices, IEEE Transactions on, vol. 55, n°. 8, p. 1984 (2008).
[4] D-M. Nguyen, C. Raynaud, et al., Materials Science Forum, vols. 717-720, 545 (2012).
[5] M. Goeppert-Mayer, Ann. Phys, vol. 9 p.273 (1931).
[6] Hassan Hamad, Christophe Raynaud, et al., Applied Physics Letter, vol. 104, p. 082102, 2014.
[7] M. Lazar, F. Jomard, D-M. Nguyen, C. Raynaud, G. Pâques, S. Scharnholz, D. Tournier, D. Planson, Materials Science Forum, vols. 717-720, 885 (2012).
[8] H. Hamad, C. Raynaud, et al., Materials Science Forum, vols. 821-823, 223 (2015).

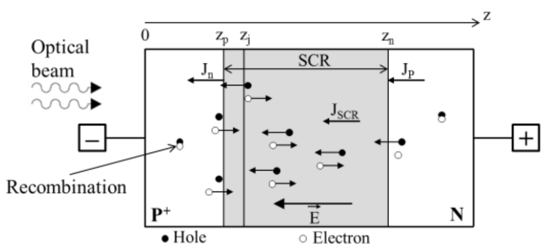

Fig. 1: Cross-sectional view of a PN junction to illustrate the OBIC principle.

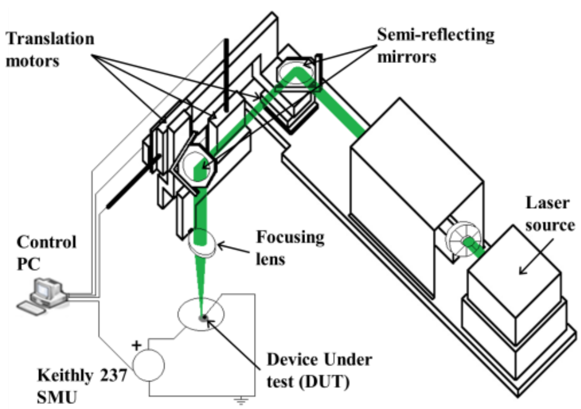

Fig. 2: Schematic view of OBIC bench.

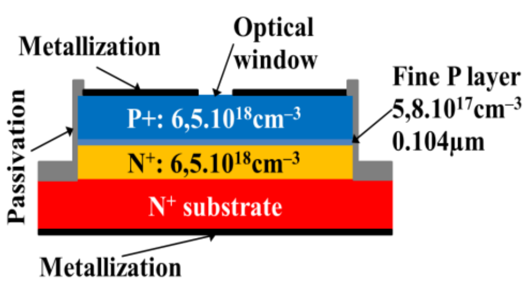

Fig. 3: Cross-sectional view of avalanche diode.

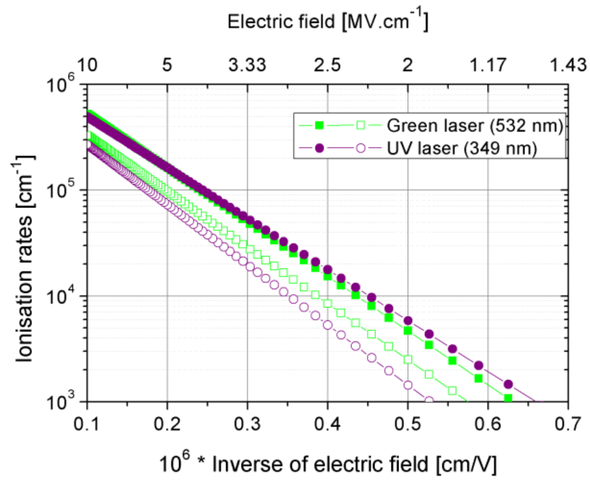

Fig. 4: Ionization rates vs. electric field with green and UV lasers.

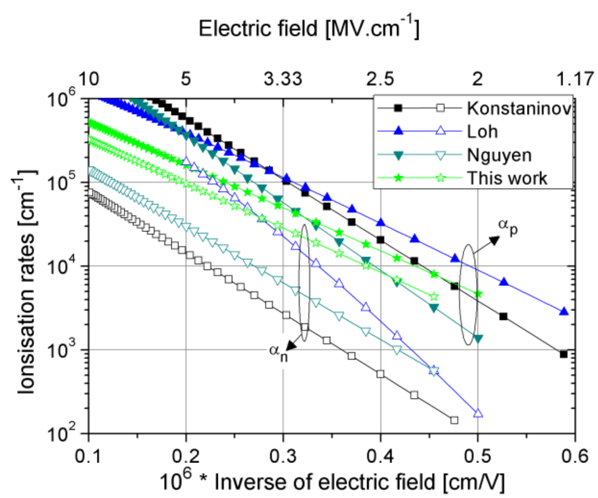

Fig. 5: Ionization rates vs. electric field compared with other authors.