OBIC Measurements of 1.3kV 6H-SiC Bipolar Diodes Protected by Junction Termination Extension

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Abstract. Silicon carbide has suitable properties for high power electronic applications. We present here results on 6H-SiC bipolar diodes protected by Junction Termination Extension. We have achieved breakdown voltage of ~1200 V, which is close to the theoretical value, and forward current density of 120 A cm^{-2} at 5 V. Optical Beam Induced Current measurements and simulations have shown that JTE are very efficient and that their parameters are close to the optimum. Nevertheless, a little increase of their doping level should increase the breakdown voltage up to ~1400 V.

Introduction

Due to its good electrical properties, mainly a high critical electric field and a large bandgap, silicon carbide has demonstrated potentialities for high power devices. We have designed and realised bipolar diodes to sustain a reverse voltage of about 1.3 kV. To avoid surface premature breakdown and thus benefit the advantages of SiC, we have protected our diodes with an aluminium-implanted ring, surrounding the emitter. This ring is named Junction Termination Extension (JTE). We have investigated the performances of these diodes in terms of Current-Voltage (IV) measurements, and analysed the effect of the JTE using Optical Beam Induced Current (OBIC) measurements.

Samples details

6H-SiC n-type epitaxial layers with values of thickness of 10 µm, and of doping level N_D = 1.6×10^{16} cm^{-3}, on n$^+$-type 6H-SiC substrates, have been purchased from Cree Research for this study. The p$^+$ emitter has been realised by multiple aluminium implantations at 300°C with energies varying between 25 and 300 keV, with a total dose of 1.75×10^{15} cm^{-2}. Lateral protections have been realised by RT Al implantations with a total dose of 1.3×10^{13} cm^{-2}. This produces a p-type region doped at 3×10^{17} cm^{-3} on a depth of ~0.5 µm. Then samples are annealed in a rf-induction heating furnace at 1700°C during 30 min. [1]. Diodes have been metallized with Ni in backside and Al-Ti in the front side. Different kinds of diodes are available, with varying emitter diameters and JTE lengths. The surface is not passivated.

Current-voltage measurements

IV measurements have been performed with a Keithley 237 Source Measurement Unit. Reverse biases are delivered by a 12.5 kV-100 mA FUG supplier. In forward biases, ~50% of diodes (protected or non protected) show current densities > 150 A cm^{-2} at 5 V (Figure 1), with a best result of 220 A cm^{-2}. In reverse biases, about 40% diodes protected with JTE have been able to block up to 1100 V (Figure 2) with a best result at 1270 V, which is very closed to the theoretical value given by numerical simulations (see Table I), using the ionisation coefficients determined by Baliga [5]. The lowest significant current is 10^{-11} A. The last data points which are drawn are considered as the breakdown voltage (next point is more than 0.1 µA). The majority of non-protected diodes have shown breakdown voltages V_{br} at about 500 V. In the following, we will use the Baliga coefficients, due to their good agreement with our measurements on both protected and non-protected diodes.

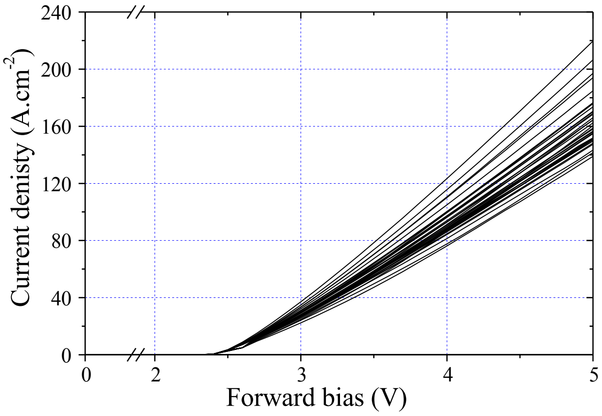

Figure 1 : IV characteristics of some diodes with JTE, in forward bias, measured with a SMU K237.

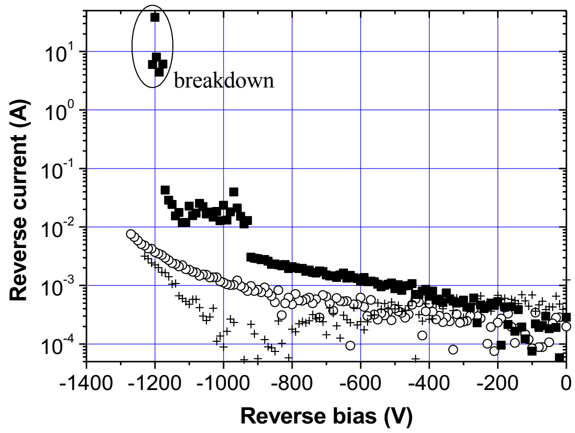

Figure 2 : IV characteristics of 3 diodes (emitter diameter ∅ = 160 µm) with JTE, in reverse bias, by step of 10 V.

	Konstantinov coef.	Ruff coef.	Baliga coef.
Theoretical 1D Vbr	1240 [V]	920 [V]	1540 [V]
2D Vbr : with JTE	950 [V]	790 [V]	1100 [V]
2D Vbr : without JTE	380 [V]	310 [V]	460 [V]

Table I : Numerical simulations of breakdown voltages of our bipolar diodes. Theses values have been calculated with Medici™ software for diodes protected or not protected by JTE, using 1-D (one Dimensional) and 2-D models, and using the ionisation coefficients published by Konstantinov [3], Ruff [4], and Baliga [5]. *NB: In the JTE, all dopants are ionised due to the presence of the electric field. So V_{br} should not depend on temperature due to the ionisation energies of acceptors levels, when JTE are fully depleted before the breakdown occurs (i.e. for low JTE doses).*

The large breakdown voltage difference between protected and non-protected diodes, obtained in experimental measurements, is significant of the beneficial role of JTE, when dopants are correctly activated (i.e. incorporation of Al in substitutional SiC lattice sites) by the post implantation annealing. Moreover, we have noticed that testing the diodes in air, in silicone oil or in SF_6 does not increase significantly V_{br}. We have therefore used Optical Beam Induced Current (OBIC) measurements in order to study the distribution of equipotential lines at the surface of the samples.

OBIC measurements

Details about this technique have been described elsewhere [2]: a UV beam produced by an Ar^{++} laser (300 nm < λ < 363,8 nm) is focused at the surface of the samples, modulated at f = 70 Hz by a mechanical chopper, and therefore generates free carrier. When they are generated in a space charge region, electrons and holes are separated by the electric field and a current is generated and detected by a lock in amplifier (SR 830). By translating the beam, we can measure the generated current along the diameters of the diodes. In this study, we have used a wavelength of 351.1 nm, which corresponds to a penetration depth of ~ 9.4 µm in 6H-SiC.

Figure 3 shows such a measurement performed on a diode without JTE. The structure has been drawn on the figure for easier comparison. It is clear that on non-protected diodes, the OBIC signal increases very fast at the edge of the emitter, which is due to the high electric field present in this corner region. This leads to a severe reduction in breakdown voltages of these diodes (~500 V).

OBIC signal obtained on a protected diode is represented in Figure 4. The difference with Figure 3 is evident: the current peak is much wider. This is relevant to the spreading out of the equipotential lines. The peak width agrees well with the JTE length (120 µm) and it means that JTE are depleted even at very low voltage. On diodes with shorter JTE (50 µm), the spreading out of the OBIC signal is also in agreement with the JTE length. We can also notice that at 600 V, a peak also appears at the emitter edge of protected diodes. This peak remains at the edge at the emitter edge even at 900V with non-equilibration by the JTE contribution. Normally an optimal doping of the JTE involves two peaks with the same range of magnitude at the edge of the emitter and the JTE. This indicates that the electric field increases much more near the emitter edge. This could mean that the doping level of JTE is close to the optimised value but a little lower. In order to confirm these assumptions on the distribution of the equipotential, OBIC signal has been simulated with Medici^{TM}.

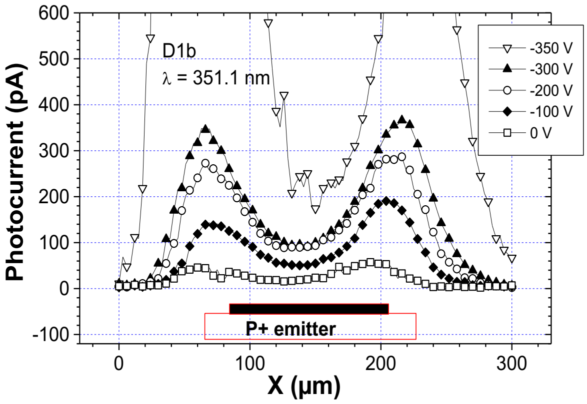

Figure 3 : OBIC measurements performed on a p$^+$n diode without JTE, for increasing reverse voltage (emitter diameter ∅ = 160 µm).

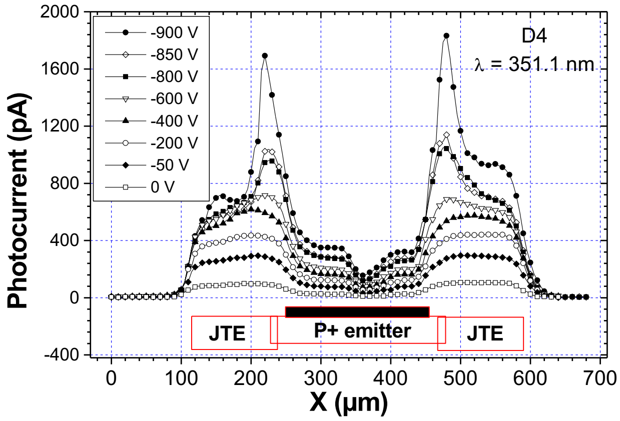

Figure 4 : OBIC measurements performed on a p+n diode protected by JTE, for increasing reverse voltage (emitter diameter ∅ = 250 µm).

OBIC simulations

Figure 5 shows both theoretical (computed using Baliga coefficients for the ionisation rate) and experimental OBIC signal obtained on a diode without JTE, when 0 V is applied on the anode. From the slope in the semi-logarithmic scale, we have deduced the value of the minority carrier lifetime τ of 450 ns. In the following, the theoretical curves have been calculated using this value.

The simulated behaviour of the OBIC signal is in agreement with experimental results. For diodes without JTE, the OBIC peak which arises close to the emitter edge increases strongly at low voltage (~ 400 V in Figure 6). For JTE-protected diodes, a peak close to the emitter occurs at much higher voltage (~800 V), due to the lateral extension of the space charge region, as shown

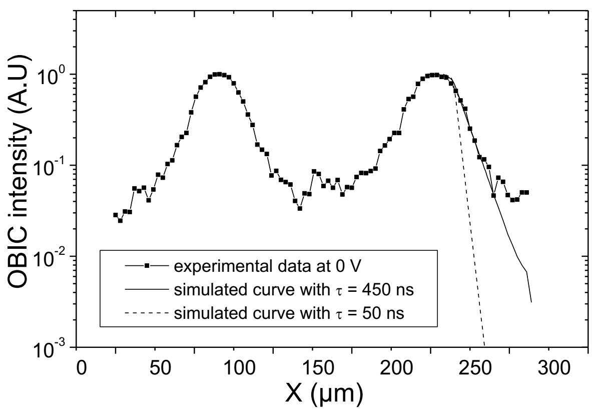

Figure 5 : Comparison of theoretical curves with experimental data obtained at 0 V on the diode without JTE (cf. Figure 3), using minority carrier lifetime values of 50 ns and 450 ns. The theoretical curves have been plotted only at the edge of the emitter.

on Figure 7. The OBIC signal is rather constant on the whole length of the JTE. The lack of a peak on the OBIC signal at the edge of the JTE even for a polarisation of 1100 V in reverse bias confirms an insufficient protection from the JTE. As a result, to reach the theoretical one

Dimensional Vbr value (Table 1) a little increase of the JTE doping level is necessary. This deduction confirms also a good activation of the dopants implanted to create the JTE and the significant role of the post-implantation annealing in the performance of these devices in reverse bias.

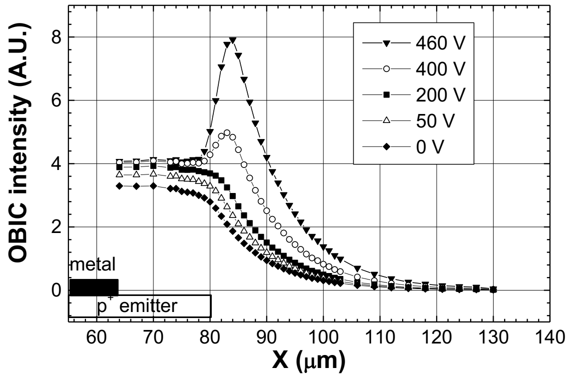

Figure 6 : Theoretical OBIC intensity computed for the diode without JTE, using a lifetime of 450 ns.

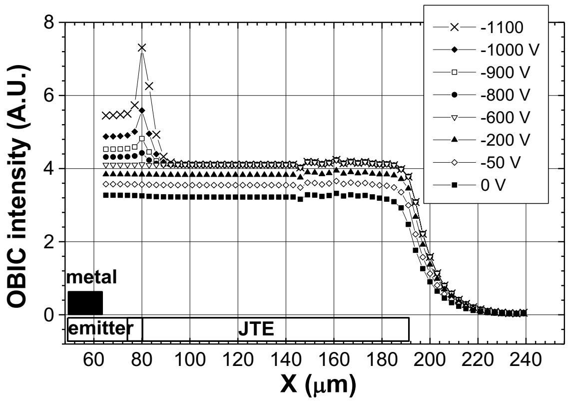

Figure 7 : Theoretical OBIC intensity computed for the protected diode, using a lifetime of 450 ns.

Conclusions

We have fabricated bipolar diodes with effective protection against premature breakdown. The observed breakdown voltage is in good agreement with the calculated one. This is due to the beneficial role of Junction Termination Extension, which are close to the optimum. OBIC measurements and simulations have shown that JTE are depleted and come into effect even at low voltages, and that for voltages near V_{br}, the electric field increases at the periphery of the emitter. This is a proof that nevertheless the JTE doping level is a little too low. As V_{br} is close to the desired value (for which the diodes have been designed), we can also conclude that during the post-implantation annealing, almost all the dopants have been activated in the JTE.

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References

[1] M. Lazar, C. Raynaud, D. Planson, M.L. Locatelli, K. Isoird, L. Ottaviani, J.P. Chante, R. Nipoti, A.Poggi, G. Cardinali: Mater. Sci. Forum, Vols. 389-393 (2002) p. 827.

[2] K. Isoird, M. Lazar, L. Ottaviani, M.L. Locatelli, C. Raynaud, D. Planson, J.P.Chante: Appl. Surf. Sci. Vol.184 (2001) p. 477.

[3] A. O. Konstantinov, Q. Wahab, N. Nordell, U. Lindfelt: J. Electronic Mater. Vol. 27 (1998) p. 335.

[4] M. Ruff, H. Mitlehner, R. Helbig: IEEE Transaction Electron Devices, Vol. 41 (1994) p. 1040.

[5] R. Raghunathan, B.J. Baliga: IEEE Int. Symp. On Power Semiconducor and Devices and IC‘s, Weimar, Germany (1997) p. 173.