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Measurement of carrier lifetime temperature dependence in 3.3kV 4H-SiC PiN diode using OCVD technique

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Introduction

The SiC bipolar rectifier is a good alternative compared to the SiC Junction Barrier Schottky diode for applications requiring very high current capability and breakdown voltage higher than 3 kV. The carrier lifetime is a very influent parameter in bipolar device characteristics. Several values (in a wide range) of this parameter can be found in the literature depending on material quality and extraction method (recovery charge, OCVD (Open Circuit Voltage Decay) or optical methods). In this paper, OCVD technique is used to investigate the influence of temperature on the electrical carrier lifetime of 3.3 kV 4H-SiC PiN diodes processed with a new generation of SiC material [1].

Diode description

The cross-section of the PiN diode is shown on Fig.1. The starting material is an N⁺/N⁻/P⁺ epitaxied 4H-SiC wafer grown at Linköping University ($t_{\text{epi}} = 45\mu\text{m}$, $N_D = 6 \times 10^{14} \text{ cm}^{-3}$). The starting SiC substrate surface was treated with a previously reported technique [1] to convert basal plane dislocations to threading dislocations. Details on the process fabrication and the first dc characterisation can be found in [2]. In Fig.2, the forward characteristics are shown in a temperature range of 25°C-150°C. The voltage drop decreases with the increase of the temperature. This is due to the increase of the carrier lifetime. This behaviour is also obtained on Fig. 3 with the increase of the recovery charge. The conditions of the switch-off are reported in [3]. Another technique based on Open Circuit Voltage Decay (OCVD) is used to evaluate accurately this evolution versus temperature.

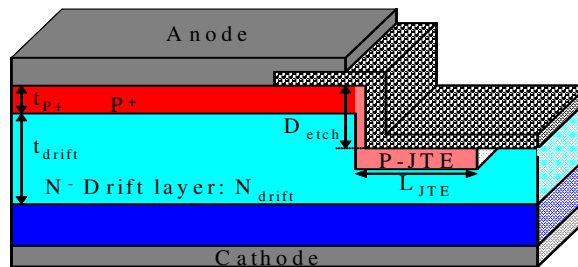


Fig.1. Schematic cross-section of the fabricated mesa/JTE PiN diodes.

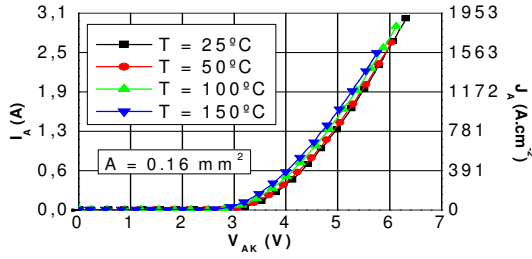


Fig.2. Forward I(V) characteristics of a 0.16 mm² diode, temperature range 25°C-150°C.

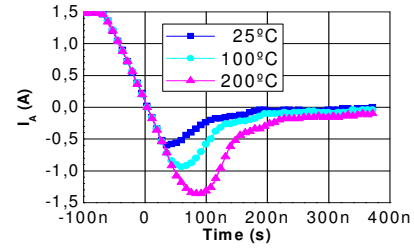


Fig.3. Reverse recovery current waveform of a 2.6 mm² sample.

Experimental set-up

To apply OCVD technique, a high injection current is required in forward bias of the diode. Thus, an experimental set-up where the basic principle is shown in Fig.4, has been developed enabling higher current cut off than the previous one [4]. The switching device (Si-MOSFET) is specially driven to switch off the forward diode current in less than 20 ns. Subsequent voltage decrease is related to the ambipolar lifetime $\tau = \tau_n + \tau_p$.

The diode is fastened to a metal block heated up with a cartridge heater and the temperature is measured using a thermocouple tightened on the alumina substrate of the diode (Fig.4). A forward current of 1.75 A is applied to the 0.16 mm² diode and the voltage drop evolution after current extinction is measured in the temperature range 30 – 150 °C.

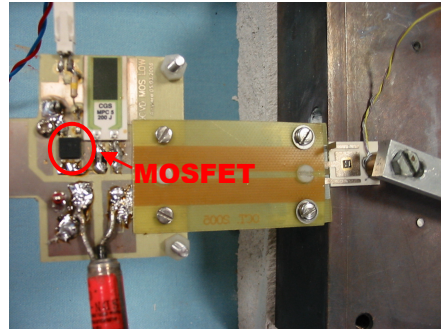
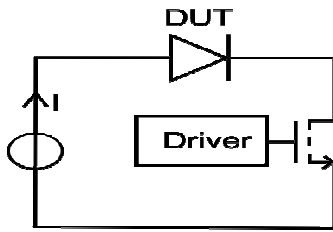


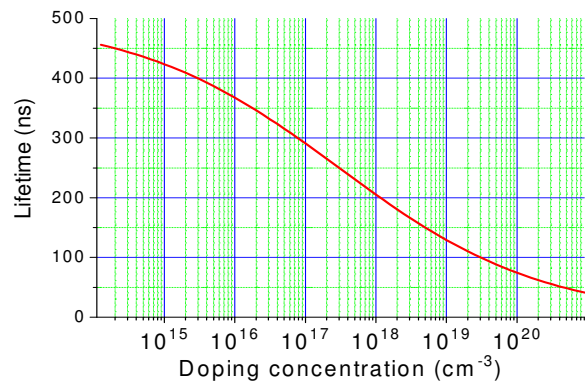
Fig.4. Schematic and picture at the right of the experimental set up.

Simulation and Analysis

Fitting experimental diode voltage curves with finite element simulations is the best way to obtain an accurate value of the ambipolar lifetime in the base region. Sentaurus™ device software is used to simulate the OCVD circuit.

$$\tau_{n,p} = \frac{\tau_{\max}}{1 + \left(\frac{N_{\text{tot}}}{3 \cdot 10^{17}} \right)^{0.3}}$$

Fig.5. Model for lifetime doping dependence (The curve corresponds to a τ_{\max} value of 500 ns).



Lifetime dependence versus doping.

Due to the lack of information about the doping dependence of the SRH (Shockley-Read-Hall) lifetime in SiC, a silicon model (Fig.5) taken from [5] is used. For the same reason, lifetimes of electrons and holes are supposed to be equal.

The fitting process starts with the forward current (before circuit opening) adjustment. It determines the initial injection level. Then the τ_{\max} parameter and bandgap value are modified to fit respectively the voltage slope and level after the initial voltage step (which corresponds to ohmic voltage drop). Fig.6 shows good fits of 30 °C and 150 °C experimental curves with the device simulations. From measurements and fitting simulations, ambipolar lifetime ($= 2 \times \tau_{\max}$) is found to be 600 ns and 3.5 μ s respectively.

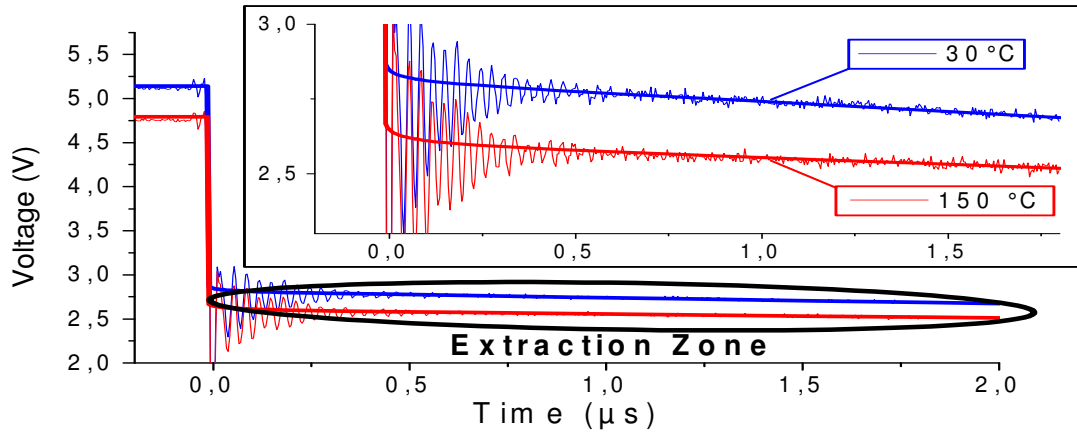


Fig.6. OCVD Voltage measurement at 30 and 150 °C (thin line) and fitting simulations (thick line). Insert is a zoom of the decay.

Ambipolar lifetime was extracted for six temperatures in the 30 – 150 °C range. The values are plotted in Fig.7. These results seem to fit a second order polynomial law in this temperature range. This lifetime evolution against temperature is in agreement with the work reported in [6] based on reverse recovery measurements. However lifetime values obtained here with the OCVD technique are approximately twenty times higher than the ones in [6].

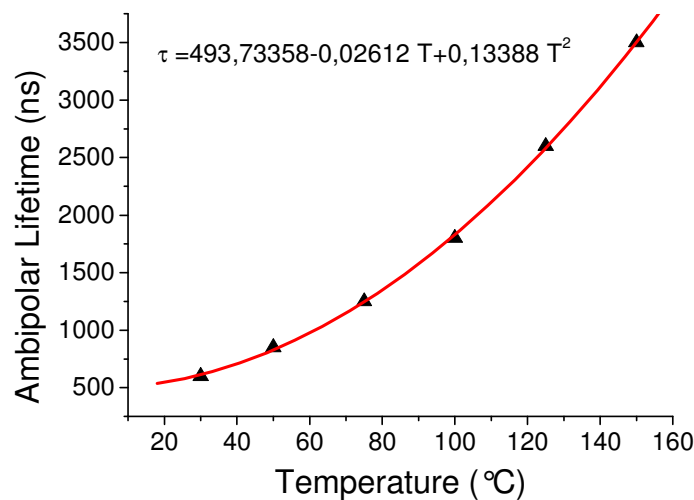


Fig.7. Ambipolar lifetime evolution against temperature (Extracted values (triangles) and second order polynomial fit).

Discussion on parasitic oscillations

In this paper, lifetime is extracted supposing that the parasitic oscillations on measurements have no influence on the voltage slope which is sensitive to the ambipolar lifetime. To defend this point, the OCVD circuit is simulated with a rough estimation of parasitic inductances and capacitances (Fig.8). The simulated voltage slope used to extract the lifetime is the same with and without these parasitic elements. However the fit between experiment and simulated oscillations is not very good. An accurate model of the MOSFET and probes should be used to get it better.

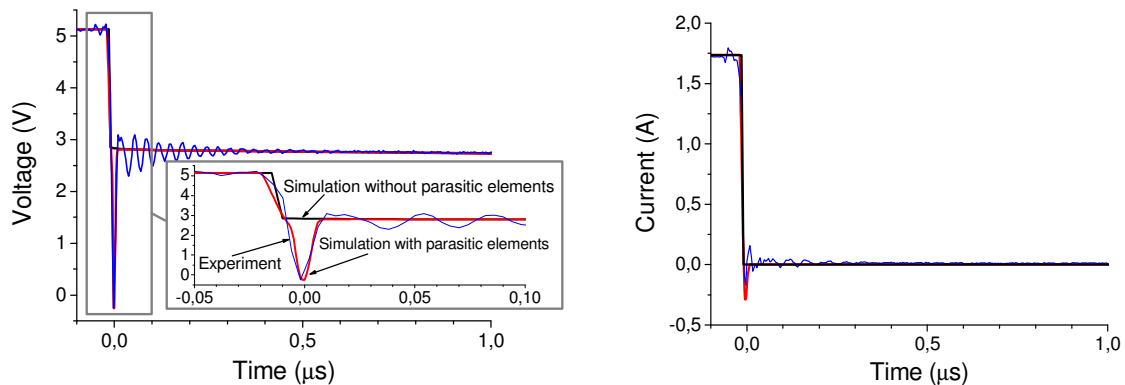


Fig.8. Measurement (blue curve) and simulated curves (red and black curves respectively with and without parasitic elements) of diode current and voltage in the OCVD circuit.

Conclusion

The carrier lifetime is a fundamental parameter for bipolar power devices. Lifetime increase with the temperature in a 4H-SiC PiN diode, processed with a new generation of SiC material, has been investigated using the OCVD technique. The ambipolar lifetime follows a second order polynomial law in the 30 – 150 °C temperature range, rising from 600 ns up to 3.5 μ s in the base region. The impact of the parasitic oscillations of the experiment on lifetime extraction is also discussed.

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