FACTA UNIVERSITATIS (NIŠ)
SER.: ELEC. ENERG. vol. 15, No. 1, April 2002, 33-39

OCVD Carrier Lifetime Measurements on an Inhomogeneous Diode Structure

Vitezslav Benda and Zdenek Novák

Abstract: This paper investigates the problem of evaluating the lifetime of a carrier measured by the OCVD method on structures with a non-uniform carrier lifetime distribution. A simple model of two diodes connected in parallel (lumped charge approximation) has been used for evaluating the measured carrier lifetime. The theoretical analysis was experimentally verified.

Keywords: OVCD method, lifetime of carrier, lifetime distribution, lumped charge approximation.

1 Introduction

All characteristics of bipolar semiconductor devices, especially power devices such as diodes, transistors, thyristors, IGBTs, etc., depend on carrier lifetime. In the case of silicon devices, local recombination centres creating deep energy levels in the gap (created by both heavy metal impurities and point defects) mainly control the carrier lifetime. Some recombination centres are created as a result of high temperature processes during device fabrication, for example during diffusions, etc. Recombination centres are also deliberately introduced into the structures of devices either by heavy metal diffusion or high-energy particle irradiation to optimise device parameters.

Carrier lifetime measurements can provide information about defect densities in device structures, and diagnostics of recombination centres can give

Manuscript received April 6, 2002. An earlier version of this paper was presented at the 23rd International Conference on Microelectronics, MIEL 2002, May 12-15, 2002, Niš, Serbia.

The authors are with Faculty of Electrical Engineering, Department of Electrotechnology, Czech Technical University in Prague, Technicka 2, 16627 Praha 6, Czech Republic (e-mail: `benda@fel.cvut.cz`).

information about recombination centre parameters. They are often used for in-process checks on the quality of high- temperature processes, especially in the case of power devices. The OCVD method [1] has often been used for this purpose. This method supposes a constant carrier lifetime in the low-doped region of the diode structure.

On the other hand, it has been experimentally found that the carrier lifetime in the structures of power devices after high temperature processes is practically always non-uniformly distributed, and the differences over large-area structures may be considerable [2]. An example of experimentally found carrier lifetime distribution in a thyristor structure (the local carrier lifetime varies from 50 μs to 120 μs) is shown in Fig. 1. Therefore, this study was done with the aim to describe in greater detail the problem of evaluating carrier lifetime measured by the OCVD method on structures with an inhomogeneous carrier lifetime distribution.

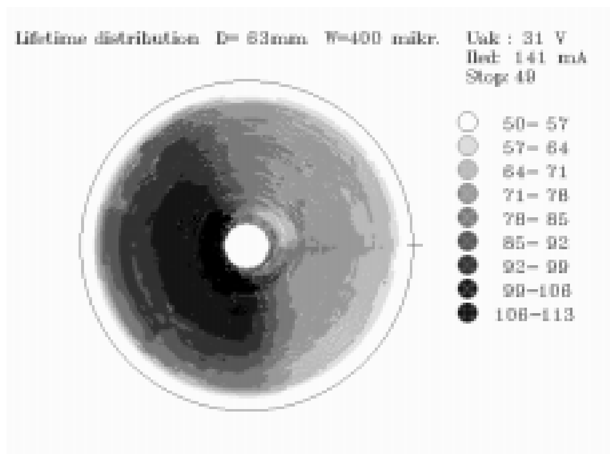

Fig. 1. An example of non-uniform carrier lifetime distribution in a thyristor structure (the central area was not measured).

2 Description of the Model

2.1 Theoretical considerations

The OCVD method [1] is one of the most widespread methods for determining carrier lifetime in the bulk of diode structures. The forward current IF flows through the diode, then the circuit is abruptly opened and the forward voltage drop decay is measured, as demonstrated in Fig. 2.

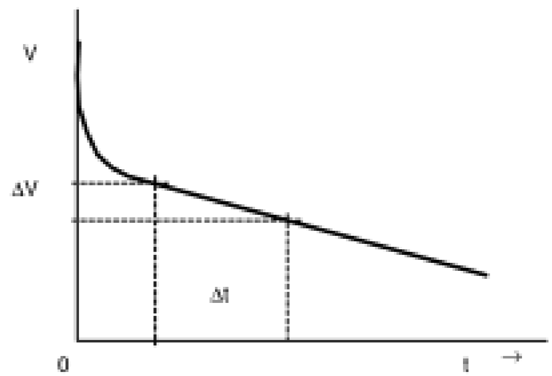

Fig. 2. Variation of voltage after opening the circuit (OCVD method).

Using lumped charge approximation, changes of charge of excess carriers in the volume of the diode can be described by

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = I(t) - \frac{Q}{\tau}, \tag{1}$$

where τ is an effective carrier lifetime. After opening the circuit in $t = 0$, the charge stored in the base of the diode decreases for $t > 0$

$$Q(t) = Q(0)e^{-\frac{t}{\tau}}. \tag{2}$$

With excess carrier concentration in the base of the diode a post-injection voltage at the PN junction is connected. For the particular case of a thick diode structure with a homogeneous base and abrupt PN junction, the carrier lifetime can be determined from the slope of voltage decay [1] by

$$\tau = \alpha\frac{kT}{q}\left(\frac{\mathrm{d}V}{\mathrm{d}t}\right)^{-1}, \tag{3}$$

where $1 \leq \alpha \leq 2$ ($\alpha = 1$ describes low injection conditions, $\alpha = 2$ should be used under high injection conditions). This approximation expresses the so-called "OCVD carrier lifetime". Generally, the exact solution can be obtained by solving the continuity equation (it may be non-linear), and the voltage decay may also depend on other parameters, e.g., diode base width, junction capacitance and parallel resistance [3].

For our study, we tried to model the non-uniform structure as a parallel combination of two diodes with different carrier lifetimes in low doped regions, as shown in Fig. 3. Diode D_1 represents a part of the structure with carrier lifetime τ_1, D_2 represents a part of the structure with carrier lifetime τ_2; let us consider $\tau_1 > \tau_2$.

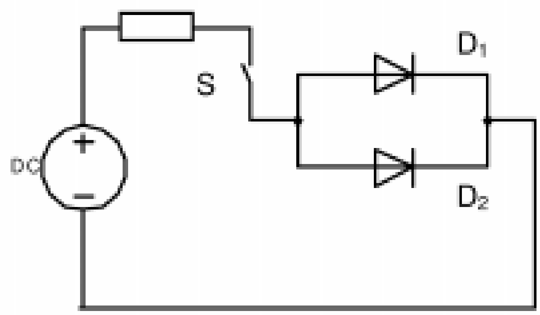

Fig. 3. Two-diode approximation of an inhomogeneous diode structure.

The voltage at the contacts of both diodes must be the same during the transient process after opening the outer circuit with switch S. Differences in the voltage across the PN junction during the transient process result in extraction of carriers in the high carrier lifetime region and carrier injection in the low carrier lifetime region. Therefore, the measured effective carrier lifetime depends on the carrier lifetime in the individual diodes and it can also depend on the starting conditions (on-state current before opening the circuit).

Using the lumped charge approximation, the excess carrier charge changes in individual parts of the structure (individual diodes) can be described by

$$\frac{\mathrm{d}Q_1}{\mathrm{d}t} = I_1(t) - \frac{Q_1}{\tau_1} \tag{4}$$

$$\frac{\mathrm{d}Q_2}{\mathrm{d}t} = I_2(t) - \frac{Q_2}{\tau_2}, \tag{5}$$

where Q_1 is the excess carrier charge in the diode D_1 and Q_2 is the excess carrier charge in the diode D_2.

When switch S is opened, $I_1 + I_2 = 0$ and the voltage drop across the two diodes must be the same throughout the transient process. Therefore,

$$\frac{\mathrm{d}(Q_1 + Q_2)}{\mathrm{d}t} = -\frac{Q_1}{\tau_1} - \frac{Q_2}{\tau_2} = \frac{Q_1 + Q_2}{\tau^*}, \tag{6}$$

where τ^* is the time constant of parallel combination of the two diodes, which can be assumed as an effective carrier lifetime measured by the OCVD method on an inhomogeneous diode structure.

From Eq. (6) a relation can be found between carrier lifetime τ_1, carrier lifetime τ_2 and effective carrier lifetime τ^*

$$Q_1\left(\frac{1}{\tau^*}-\frac{1}{\tau_1}\right)=Q_2\left(\frac{1}{\tau_2}-\frac{1}{\tau^*}\right). \tag{7}$$

The effective carrier lifetime should be in the interval $\tau_2 < \tau^* < \tau_1$. The exact relations between τ_1, τ_2 and τ^* depend on the area of the partial diodes and excess carrier concentration at the beginning of the transient process. In a simple approximation it is possible rewrite (7) in the form

$$A_1\Delta n_1\left(\frac{1}{\tau^*}-\frac{1}{\tau_1}\right)=A_2\Delta n_2\left(\frac{1}{\tau_2}-\frac{1}{\tau^*}\right), \tag{8}$$

where A_1 is the area of the high lifetime region and Δn_1 is the excess carrier concentration in this region, A_2 is the area of the low carrier lifetime region and Δn_2 is the excess carrier concentration in this region. From (8) can be found

$$\tau^*=\frac{\tau_1\tau_2(A_1\Delta n_1+A_2\Delta n_2)}{\tau_2 A_1\Delta n_1+\tau_1 A_2\Delta n_2}. \tag{9}$$

It may be used for qualitative evaluation of experimental data. The quantitative analysis is much more complicated because the forward current distribution (and, consequently, excess carrier concentration) in both high lifetime and low lifetime regions must be in correlation with the forward V-A characteristics of these regions (partial diodes).

2.2 Experimental verification

In our experiments, we studied the influence of non- uniform distribution of carrier lifetime in the device structure on the effective carrier lifetime in P^+NN^+ diode structures measured by the OCVD method. The non-uniformity was simulated by the parallel combination of two diode samples of the same construction with different carrier lifetimes (in one diode the carrier lifetime was reduced by iridium diffusion). The carrier lifetime was measured over the current range (10^{-3} A, 1 A) for both individual samples (τ_1 and τ_2) and their parallel combination (τ^*).

An example of the experimental results for a low current range is shown in Fig. 4, and results for a higher current range are shown in Fig. 5. The dependence of τ on I_F is due to the dependence of carrier lifetime on excess carrier concentration [4], which, in the case of iridium recombination centres, is relatively strong [5]. The experimental results are in agreement with the theoretical analyses.

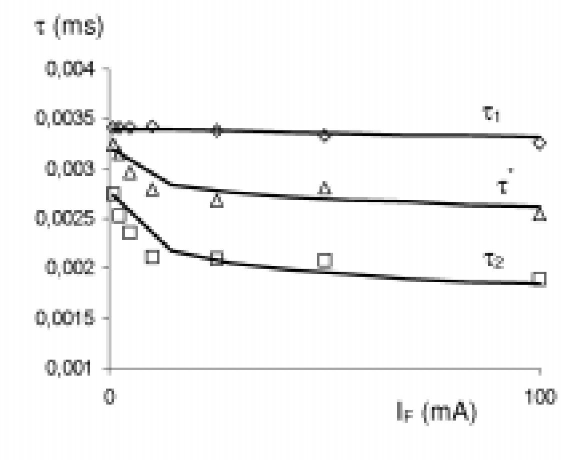

Fig. 4. Measured relation between carrier lifetime at individual diodes (τ_1 and τ_2 and their parallel conection (τ^*) in the current range 1-100 mA.

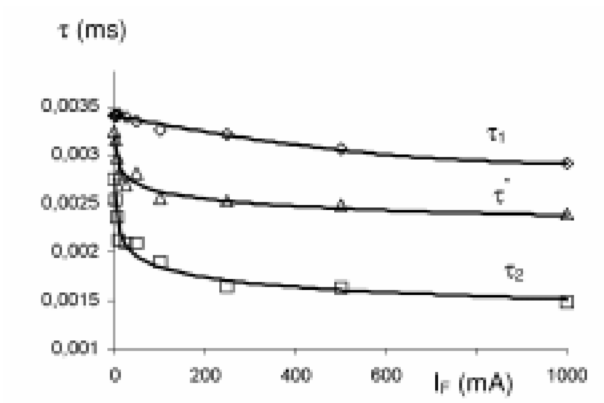

Fig. 5. Measured relation between carrier lifetime at individual diodes (τ_1 and τ_2 and their parallel conection (τ^*) in the current range 1-1000 mA.

3 Conclusion

For lower current densities, the effective carrier lifetime measured for parallel combination was close to the average value of carrier lifetime measured on individual samples. With increasing current the effective carrier lifetime is shifted to the carrier lifetime value in a diode with a longer lifetime, nevertheless still not too far from the average value. This is in good agreement with the theoretical analysis. Therefore, for low current OCVD measurements, the measured effective carrier lifetime in non-uniform samples is close to the average value of carrier lifetime in the contacted area. When using relatively low-area contacts, the measured effective carrier lifetime can depend on the position of the contacts with respect to a high (or low) carrier lifetime region.

References

[1] S. R. Lederhandler and L. J. Giacoletto: *Measurement of minority carrier lifetime and surface effects in junction devices*, Proc. of the IRE, vol. 43, 1955, pp. 477-483.

[2] V. Benda and J. Kozisek: *In-Process Monitoring of Carrier Lifetime Distribution in Technology of Large-Area Power Semiconductor Devices.* In: Proc. of the 8th International Power Electronics & Motion Control Conference PEMC'98, Prague, 1998, vol.1. , 1998, pp. I-26-I-30.

[3] M. Skaloud, A. Franek: *Contribution to OCVD method of determining the Carrier Lifetime.* In: Proc. of the 17th Yugoslav Conference on Microelectronics MIEL'89, Niš, 1989, vol. 1, 1989, pp. 290-294.

[4] V. Benda: *Using Carrier Lifetime Dependencies on Temperature and Current Density in Diagnostics of Silicon Structures.* In: Symposium on Materials and Devices for Power Electronics - MADEP, Florence, 1991, 1991, pp. 0/065-0/068

[5] V. Benda, M. Cernik and Z. Novak: *A Note on Trap Recombination in Power Semiconductor Devices.* In: Proc. of the 4th International Seminar on Power Semiconductors ISPS'98, Prague 1998, 1998, pp. 59-64.