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MINORITY CARRIER LIFETIME MEASUREMENTS IN SEMICONDUCTOR DEVICES MONITORED BY A MICROPROCESSOR IN E.B.I.C. MODE

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Abstract. Electron Beam Induced Conductivities (E.B. I.C.) transient measurements monitored by a microprocessor can be a very flexible technique for the measurement of minority carriers lifetime in semiconductors. This technique adapted in our case for silicon and germanium becomes a very powerful tool in conjunction with continuous E.B.I.C. measurements, especially in the case of silicon solar cells.

Fundamentals of E.B.I.C. mode - Diffusion length and lifetime measurements

When an electron beam impinges on a semiconductor material, this gives rise to the creation of an excess of minority carriers, for example in N-type semiconductor

$$\Delta p = \Delta n = q^{-1} \frac{6 G_t I_B \tau_p}{\pi R^3} \text{ with } G_t = \frac{E_0}{E_p} (1 - k_n)$$

$q$ electron charge, $E_0$ beam energy, $I_B$ beam intensity, $R$ electron range, $E_p$ hole-electron pair energy creation, $k_n$ correction factor for backscattered electrons, $\tau_p$ hole lifetime.

In low injection conditions ($\Delta n \ll n$ electron concentration), theoretical modeling of the penetration of electrons, generation of minority carriers and the collection of the carriers giving rise to the Electron Beam Induced Current (E.B.I.C.) by a junction perpendicular to the surface or parallel to the surface have been well supported in the past ten years (1) (2) (3) and more recently for the transient analysis (4) (5). The continuous E.B.I.C. measurement permits to directly achieve the value of the diffusion length of the minority carriers which represents the average value reached by the excess of created minority carriers before to be recombined and corresponds to a global value on the volume covered by the scanned area. The same measurement can also give the surface recombination velocity (6).

Transient E.B.I.C. can give using the slope of the curve measured in logarithmic scale, the minority carrier lifetime, after a correction factor which takes into account of the surface recombination and the distance-spot junction. (The beam is fixed in this experiment). The lifetime value corresponds to a more punctual volume which takes into account of the presence of punctual defects which act as traps for the carriers. Following SHOCKLEY-HALL-READ(7) the lifetime can be expressed as:

$$\tau_p = (\sigma_p N_t V_{th})^{-1}$$

$\sigma_p$ capture cross section of traps, $N_t$ number of traps, $V_{th}$ thermal velocity of electrons.

Diffusion length and lifetime are related by $L_p^2 = D_p \tau_p$ ($D_p$ diffusion constant of holes).

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The presence of electrically active defects (point-line or line-shaped defects) can be interpreted as a perturbation with a lifetime equal to \( \tau_D = (N_D \sigma_D V_{th})^{-1} \) where \( N_D \) is the density of recombination centres inside the defect and \( \tau_D \) the defect capture cross-section. The measured lifetime is in this case a combination of two lifetimes so \( \tau^{-1} = \tau_D^{-1} + \tau_p^{-1} \).

In indirect bandgap semiconductors like silicon and germanium the diffusion length value can reach several tens or hundreds of microns and in that case the electron penetration volume can be approximate by a sphere or a point-source. The limitations and accuracy on the determination of the parameters lifetime and diffusion length are actually clearly defined taking into account of the value of the surface recombination (8).

Minority carrier lifetime measurement by EBIC monitored by a microprocessor

For a range of lifetime varying from 100 nsec to several \( \mu \)sec a system where a microprocessor pilots the obtaining of the transient decay of the EBIC for a beam fixed at a certain distance from the junction and gives the data processing has been especially designed for this purpose (9).

![Fig. 1: System using a microprocessor for the lifetime measurement.](image)

Figure 1 shows the principle of the system. The clock of the microprocessor generates the pulses for the beam blanking where the off period can be varied from 10 \( \mu \)sec to 1 msec. The rise time of the voltage pulses applied to the electro-static plates is limited by the risetime of the power amplifier which transmits the voltage to the plates.

In our system the risetime is about 50 nsec, lower than the range of lifetime measured. The amplification of the signal is made by a wideband amplifier and the beam current is adjusted to reach 5 volts peak to peak for the output of the amplifier (usually in low injection condition). A sampler-holder gives the decay curve as function of time point by point using a sampling interval of 50 nsec during a time of 5 \( \mu \)sec. Data acquisition and averaging (up to 16 times) is made by a microprocessor which can plot the decay curve on a screen or on a X-Y plotter or print the...
numerical data.
Examples of use of the system on silicon and germanium devices

a) Silicon solar cells (polycrystalline N-type large grains)

The continuous EBIC measurement gives a diffusion length value of about 24 μm and a surface recombination velocity on the sections of 10^4 cm/s. The values obtained at different distance spot-junction are reported in the Table I giving the lifetime τp and the calculated corresponding Lp value (with Dp = 12.5 cm².s⁻¹) in good agreement with the measured value in continuous mode.

<table>
<thead>
<tr>
<th>Distance (μm) spot-junction</th>
<th>20</th>
<th>30</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (μsec)</td>
<td>0.29</td>
<td>0.34</td>
<td>0.53</td>
</tr>
<tr>
<td>τp (μsec)</td>
<td>0.61</td>
<td>0.63</td>
<td>0.65</td>
</tr>
<tr>
<td>Lp (μm)</td>
<td>26.5</td>
<td>27</td>
<td>27.4</td>
</tr>
</tbody>
</table>

The different values confirm the good homogeneity of the doping in the polycrystalline material.

b) Silicon Solar cells (polycrystalline P-type small grains)

Continuous EBIC measurements give diffusion length values varying from 4.8 μm to 10.4 μm depending on the position the beam along the junction plane and a very high surface recombination velocity.

EBIC transient measurements taken at different distances spot-junction give using a self consistent approach taking into account of the important of the correction factor gives lifetime values of 0.45 μsec which does not shows great variations with the position of the spot. The equivalent diffusion length is about 40 μm (with Dn = 36 cm²/s). The low doping of the material does not indicate a variation of the diffusion constant but the great discrepancy of the diffusion length values can only be explained by the presence of the columnar structure of the grains which can limit the collection of carriers in the case of the continuous EBIC measurement as shown in Fig. 2.

Fig. 2: Colomnar structure of a silicon solar cell and position of the beam for the EBIC measurements (continuous and transient)
Nevertheless when the beam is fixed, in the transient case, the collection of carriers can be made by a path in the columnar structure and the structure has practically no influence on the EBIC decay. As previously shown in other materials, like GaAs, the diffusion length of the minority carriers can be limited to the average spacing of the dislocations (10).

c) Silicon power mesa transistor

The measurements show great variations of the lifetime for measurements made at 100 μm from the junction (see table II)

<table>
<thead>
<tr>
<th>Slope (μsec)</th>
<th>0.83</th>
<th>1</th>
<th>2</th>
<th>3.28</th>
<th>9.52</th>
</tr>
</thead>
<tbody>
<tr>
<td>τp (μsec)</td>
<td>1.2</td>
<td>1.45</td>
<td>2.9</td>
<td>4.7</td>
<td>13.8</td>
</tr>
<tr>
<td>Lp (μm)</td>
<td>39</td>
<td>42</td>
<td>60</td>
<td>77</td>
<td>131</td>
</tr>
</tbody>
</table>

Table II: Lifetime measurements in silicon power mesa transistor.

Continuous EBIC measurements give diffusion length values varying from 34 μm to 60 μm. In that case the amplitude of variations for Lp is greater for the EBIC transient which gives a more punctual estimations of the carriers recombination.

Conclusion: EBIC transient measurement are very important to test and eventually to map the electronic quality of the semiconductor material. The use of a microprocessor has permit to obtain this results in a more flexible way in the case of silicon and germanium devices.

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