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ADVANTAGES OF ac-EBIC IN DETERMINING THE SEMICONDUCTOR PARAMETERS

A. ROMANOWSKI

Institute of Electron Technology, Janiszewskiego 11/17, PL-50-372 Wrocław, Poland

Abstract - The influence of trapping centres on the phase shift of the short circuit current generated by point source is analyzed. It is shown that maximum value of the phase corresponds to emission coefficient. Minority trapping centres of the Cu implanted n^+p shallow junction are measured by ac-LBIC and ac-EBIC.

1.- Introduction.

Electron beam induced current (EBIC) technique was first used thirty years ago but it is still very attractive because it allows to determine some of the semiconductor parameters such as: diffusion length, lifetime, recombination at the defects, dislocations, grain boundaries. The recent work on EBIC has been concerned with the scanning analysis of the deep levels (SDLTS) /1,2,3/. Among the others ac-EBIC technique seems to be promising in the SDLTS. Therefore we look briefly on influence of the deep levels on the short circuit current generated by electron or light beam. In theoretical analysis we take pattern upon von Roos works /4,5/. Next we describe the method of determining the capture cross section and activation energy. The verification of the method we carry on with p-Si semiconductor implanted by Cu.

2.- Deep levels. Theory.

The rate equation for a single trap is given by /6/:

$$\frac{\partial \delta p_T}{\partial t} = c_p p n_T - e_p p_T - c_n n p_T + e_n n_T \quad (1a)$$

where $n_T + p_T = N_T$ and N_T is the concentration of the trapping centres and from the neutrality condition $\delta n = \delta p_T + \delta p$. Thus in the linear approximation (low injection) the rate equation has a form:

$$\frac{\partial \delta p_T}{\partial t} = \frac{\delta p}{\tau_t} - e_p^* \delta p_T \quad (1b)$$

τ_t is a lifetime of free carriers captured by traps and e_p^* total emission of the trapped carriers :

$$e_p^* = e_p (1+K), \quad K = \frac{p_0}{p_1} + k_p \quad (2)$$

where $e_p (= \tau_T^{-1})$ is emission of the trapped carriers while $k_p = \frac{c_n n_0}{c_p p_1}$ and if $k_p \ll 1$ then the centre behaviours like a trapping centre and for $k_p \gg 1$ the recombination process dominates /6/, and $e_p = c_p p_1$.

Neutral region:

The transport diffusion equation for the first Fourier harmonic δp with uniform distribution of the traps has a form /7/:

$$\Delta \delta p - \lambda^{*2} \delta p = -G/D \quad (3)$$

where $\Omega_T = \omega \tau_T$, $\Omega = \omega \tau$, $L^2 = D\tau$. If $\Omega \ll \tau/\tau_t \ll 1$ then:

$$\text{Im } \lambda^* \approx \frac{1}{2L} \frac{\tau}{\tau_t} \frac{\Omega_T}{(1+K)^2 + \Omega_T^2} \quad (4)$$

For shallow junction /8/ $I_{sc} \propto \exp(-\lambda^* h)$ and short circuit current is equal to:

$$I_{sc} = A e^{-i\phi} \quad (5)$$

where h is the distance between the point generation source and the edge of the depletion layer. From (4) the phase shift is given by:

$$\phi = \frac{\tau}{2\tau_t} \frac{h}{L} \frac{\Omega_T}{(1+K)^2 + \Omega_T^2} \quad (6a)$$

and the phase reaches maximum value for $\Omega_T = 1+K$. Thus knowing chopping frequency ω_0 when a phase takes the maximum value we can find the

emission coefficient:

$$e_p = \frac{\omega_0}{1+K} = \frac{\omega_0}{f^{-1}(E_T) + k_p} \quad (7)$$

where $f(E)$ is Fermi distribution function.

Depletion layer:

The continuity equation for excess carriers for the first Fourier component is equal to [7]:

$$\frac{\partial \delta p}{\partial x} + \gamma \delta p = G/v_s \quad (8)$$

where v_s is drift velocity and $\text{Im } \gamma = \frac{1}{\tau_t v_s} \frac{\Omega_T}{1+\Omega_T^2} + \frac{\omega}{v_s}$.

Thus the short circuit current generated by the point source placed at the depleted region is equal to:

$$I_{sc} = q G_t e^{-\gamma h} \quad (9)$$

where h is distance between the edge of the depleted region and the point source ($h \leq w$, w is depletion layer width). From (9) the short circuit current may be expressed by (5) with the phase shift:

$$\phi = \frac{h}{\tau_t v_s} \frac{\Omega_T}{1+\Omega_T^2} \quad (6b)$$

where $\tau/\tau_t \gg \Omega$ was assumed. This time the phase reaches the maximum value for $\Omega_T = 1$ or $e_p = \omega_0$.

3.- Measurement.

The discussion above shows that we can determine the deep level parameters either by changing a frequency or a temperature. In our measurement we scanned temperature, however in SDLTS application the frequency variation is more valuable. The measurement set up is shown in fig.1, the capacitor had a value $10\mu\text{F}$ and temperature ranged from 77K to 310K. Selective input amplifier of the lock-in was tuned to the chopping frequency f .

The applied sample was n^+p junction diode with diameter $320\mu\text{m}$ and p -Si substrate material ab. $10\Omega\text{cm}$. Before junction formation the Cu was implanted with dose of 10^{13} cm^{-2} at 175kV, next the sample was annealed

Fig.1.- Apparatus for ac-LBIC and ac-EBIC

for 30min at 620°C in dry nitrogen. The junction was formed by implantation P on the face and B on the back. The TiW-Au was used for the top contact ring and Al for back ohmic contact. Shallow doping concentration and deep levels were detected by DLTS type DLS82E in C-DLTS mode as well as in photo C-DLTS mode. The DLTS characteristic showed two visible maxima well documented in literature /9/ with $E_V + 0.266\text{eV}$ and $E_V + 0.430\text{eV}$. Minority carrier trap was observed only for low temperature and signal had no extremum. However the photo C-DLTS with 890nm GaAlAs LED revealed another two traps: $E_V + 0.1\text{eV}$ (probably the hole trap in n^+ layer formed by V^- vacancy) and $E_C - 0.499\text{eV}$ (Au level in p region).

Fig.2.- LBIC Arrhenius diagrams for U_R : $\square$ - 0V, Δ - 3V, $\diamond$ - 4V, $*$ - 5V; (a) first trap, (b) second trap

Knowing the deep centres of the sample we measured the activation energy using the ac-LBIC with 890nm LED and next we used ac-EBIC. In fig.2a the Arrhenius plots for the first trap are shown ($U_R = 0, 3$, and $5V$) while in fig.2b for the second ($U_R = 3, 4$ and $5V$). Calculated activation energy were equal: - first trap $E_V + 0.075eV$ ($U_R = 0, 3V$) and $E_V + 0.068eV$ for $U_R = 5V$; - second trap $E_C - 0.323eV$ ($U_R = 3V$), $E_C - 0.261eV$ ($U_R = 4, 5V$). We hope that discrepancy between the data (LBIC and DLTS) is caused by recombination process. For the first trap $f(E) \approx 1$ and for the second one $f(E) \approx 0$ therefore from (2):

$$e_p^*/e_p = 1 + k_p \quad \text{and} \quad e_n^*/e_n = 1 + k_n$$

thus comparing Arrhenius plots for LBIC and DLTS we have $k_p \approx 3$, $k_n \approx 14.6$. It means that in both cases the demarcation level lay between free carrier band and trapping level.

Fig.3.- EBIC-phase vs temperature, $U_0=10kV$, $U_R=7V$ and frequencies: $\square$ - 408Hz, Δ - 603Hz, $*$ - 999Hz

Fig.4.- EBIC-phase vs position of scanning beam, $U_0=10kV$, $U_R=7V$, $T=100K$, $\square$ - 401Hz, Δ - 601Hz, $*$ 1008Hz
(2 units on X axis corresponds to 20 μm)

The great advantage of EBIC over LBIC is the possibility of changing the penetration depth h . But because of small generation volume the phase shift in the EBIC is much smaller then in the LBIC. For instance in fig.3 the phase vs temperature is shown for accelerating voltage $U_0 = 10kV$. From the Arrhenius plot the trapping level is equal to $E_C - 0.08eV$ what agrees well with the LBIC measurement. We did not find the second trap. The same was with $U_0 = 20kV$. Figure 4 shows the phase vs

position of the scanning electron beam along sample diameter.

4.- Conclusions.

We described a simple method of determining of the minority carriers traps (activation energy and capture cross section) by ac-EBIC or ac-LBIC. The method was verified on implanted n^+p junction with two minority carriers traps. The two traps were confirmed by ac-LBIC method and only one by ac-EBIC. We suspect that the second trap will also be found by EBIC but with high accelerating voltage and we think that discrepancy between DLTS and L/EBIC data are caused by recombination process.

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