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DIRECT MEASUREMENT OF THE LOCAL DIFFUSION LENGTH GRAIN BOUNDARIES BY EBIC WITHOUT A SCHOTTKY CONTACT

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Abstract The EBIC signal of a grain boundary using only Ohmic contacts on the neighbouring grains is discussed in the light of electronic properties of the grain boundary and as a diffusion problem. The solution of the diffusion equation for two perpendicular planes with different recombination velocities is presented. The evaluation of the diffusion length and the recombination velocities of both the surface and the grain boundary is studied. A few examples of measurements on polycrystalline cast silicon (SILSO) show that these parameters vary significantly along a single grain boundary.

1. Introduction

There are numerous publications (e.g. /1/2/3/) concerned with the measurement of diffusion length and grain boundary (GB) recombination properties in polycrystalline silicon by EBIC. Most of them start with the standard geometry assuming a Schottky contact on or a shallow p-n junction beneath the specimen surface and a GB perpendicular to it. We present a different geometry without an additional charge collecting proposed by Mataré and Laaksoo /4/ which allows the characterisation of unprocessed material.

2. Basic Experimental Setup and Phenomenology

The experimental setup is very simple: two grains separated by a common GB perpendicular to the free surface are Ohmically connected to an current amplifier (fig.1).

fig.1 experimental setup, EBIC image and linescan

Note that no additional external bias or charge collecting field is necessary. Scanning the electron beam with its axis parallel to the surface normal : perpendicular to the GB results in a characteristic bright/dark current profil. The rise has an exponential like shape. The signalwidth which is defined here as the distance between the current peaks scales with the beam energy. The maximum amplitude of the signal shows a characteristic dependance on the beam current .

3. The electronic model

Due to the fact of an EBIC signal at the GB without an external bias or field we can start with the assumption of an electrical charge collecting field at the GB which we will describe by the double barrier model/5/. The shape of the current profil and its dependance on the beam energy lead to the conclusion that spacial dimension of the field is negligible compared to spacial resolution . Fig.2 shows the currents at the GB in a p-type semiconductor , when excess carriers Δn , Δp are generated at one side (grain 1) of the GB (i.e. $n_0 \ll \Delta n = \Delta p \ll p_0$, where n_0, p_0 are the concentrations of minority and majority carriers , respectively, at thermal equilibrium). j_{e1} is the current of electrons which are attracted by the electric field; j_{h1} and j_{h2} are the currents of holes from either side which can overcome the barrier by thermal excitation. The idea proposed for the signal formation /6/ is that the attracted electrons recombine with holes which are trapped in the GB localized states. Holes from both sides of the GB which overcome the barrier in equal rates will fill these traps again, this induces a recombination current j_r . This current will be determined by the amount of excess minorities. The hole current from grain 2 induces a carrier density difference. This is balanced partly by majority carriers from grain 1 which overcome the barrier and partly by the current through the amplifier from grain 1 to grain 2. To discuss the dependency on the beam current I_b two cases of different injection levels are considered:

1) The beam current is so low that the recombination current does not effect the GB charge and the GB potential barrier Φ_b . With j_{er} and j_{hr} being the reemission currents of electrons and holes, respectively, we can write for the steady state $j_{e1} - j_{er} = j_{h1} + j_{h2} - j_{hr}$. Using the simple case of the Shockley-Read-Hall statistics /7/ with the assumptions of a single midgap level, flat band conditions and equal capture cross sections $\sigma_n = \sigma_h$, we get with GB trap density N_T and thermal velocity v_{th} : $j_{EB} = 1/2 j_r = \Delta n(GB) / \tau = 1/2 q N_T v_{th} \sigma \Delta n \exp(q\Phi_b/kT)$, and thus $j_{EB} \sim I_b$.

2) If the injection level is higher (but still $\Delta n \ll p_0$), the recombination current will cause a decrease the grain boundary barrier. Neglecting the reemission of electrons and holes, we can write $j_{e1} = j_{h1} + j_{h2}$ with $j_{e1} = q N_T \sigma v_{th} f \Delta n \exp(q\Phi_b/kT)$ and $j_{h1} = j_{h2} = q N_T \sigma v_{th} (1-f) p_0 \exp(-q\Phi_b/kT)$ where f is the occupancy factor and q the elementary charge.

Solving this equation for Φ and substituting it in $j_{EB} = j_{e1} - j_{h1} + j_{h2} = j_{e1}$

fig. 2 currents in the GB double barrier mode with electron beam excitation in grain 1

leads to $j_{EB} = 1/2 q N_T \sigma \sqrt{f(1-f)p_0} \sqrt{\Delta n}$, and thus $j_{EB} \sim \sqrt{I_b}$

Fig.3 shows that for beam currents ≤ 50 nA (30 keV) case 1 is a good description and for higher beam currents the squareroot function of case 2 fits the measured data well. The first case, proportionality between recombination current and Δn , will be an important assumption in the next section for the diffusion model.

fig.3 EBIC vs beam current: a) case 1, linear b) case 2 square root dependency.

4. The Diffusion Model

4.1 Boundary Conditions

In order to evaluate the diffusion length from the measured current profiles it is necessary to solve the diffusion problem for this special geometry. Both the GB /8/ and the surface /9/ will be characterised as planes with finite recombination velocity which is defined as the ratio of current through and carrier density at the GB. With the geometry of fig.6 the boundary conditions for our diffusion problem can be written as:

$$\frac{\partial \Delta n}{\partial x} \Big|_{x=0} = v_{GB} \Delta n \quad \frac{\partial \Delta n}{\partial z} \Big|_{z=0} = v_S \Delta n$$

Now we have to solve the diffusion equation

$$D \nabla^2 n(\mathbf{r}) - \frac{1}{\tau} n(\mathbf{r}) = -g(\mathbf{r})$$

with D diffusion constant, τ lifetime, $g(\mathbf{r})$ generation function and $L = \sqrt{D\tau}$ diffusion length.

Fig.4 geometry of the diffusion problem

4.2 The Green's Function

The Green's function has to obey the boundary conditions and the diffusion equation for $g(\mathbf{r}) = \delta(\mathbf{r})$ (Deltadistribution).

For the case of one plane $z=0$ with a finite recombination velocity Berz and Kuiken /10/ found with the method of images $G(\mathbf{r}, (x_0, 0, z_0)) = PS(\mathbf{r}, (x_0, z_0)) + PS(\mathbf{r}, (x_0, -z_0)) + LS_z^-(\mathbf{r}, (x_0, -z_0))$ where $PS(\mathbf{r}, (x_0, z_0))$ is a point source at $(x_0, 0, z_0)$ $PS(\mathbf{r}, (x_0, -z_0))$ is an image source at $(x_0, 0, -z_0)$ and $LS_z^-(\mathbf{r}, (x_0, -z_0))$ is a line sink at $(x_0, 0, -z_0)$, which is a one dimensional

continuous charge distribution; with $S_z = v_s / (D/L)$:

$$LS_z^-(r, (x_0, -z_0)) = - \frac{2 S_z}{L} \int_0^\infty \exp(-S_z \rho / L) \frac{\exp(-\sqrt{(x-x_0)^2 + y^2 + (z-z_0+\rho)^2} / L)}{\sqrt{(x-x_0)^2 + y^2 + (z-z_0+\rho)^2}} d\rho$$

For our case of two perpendicular planes we extended this method and found the following Greensfunction (fig 5):

$$G(r, (x_0, 0, z_0)) = PS(r, (x_0, z_0)) + PS(r, (x_0, -z_0)) + PS(r, (-x_0, z_0)) + PS(r, (-x_0, -z_0)) \\ + LS_z^-(r, (x_0, -z_0)) + LS_z^-(r, (-x_0, -z_0)) + LS_x^-(r, (-x_0, z_0)) + LS_x^-(r, (-x_0, -z_0)) \\ + F(r, (-x_0, -z_0))$$

where $F(r, (-x_0, -z_0))$ is a two dimensional continuous charge distribution defined by

$$F(r, (-x_0, -z_0)) = \frac{4 S_x S_z}{L^2} \int_0^\infty \int_0^\infty d\mu d\nu \exp(-S_x \mu - S_z \nu) \frac{\exp(-\sqrt{(x+x_0+\mu)^2 + y^2 + (z+z_0+\nu)^2} / L)}{\sqrt{(x+x_0+\mu)^2 + y^2 + (z+z_0+\nu)^2}}$$

4.3 The Current

Because of our geometry the EBIC current is now defined as the integral current through the grain boundary plane:

$$I_x = D \frac{\partial}{\partial x} \int_{x=0} \int dy dz G(x, y, z, x_0, 0, z_0)$$

Integrating analytically as far as possible leads to:

$$I_x = 2 G S_x / \pi \left[\int_0^{z_0} K_0(\sqrt{X_0^2 + Z^2}) dZ + \int_0^{z_0} \exp(-S_z N) K_0(\sqrt{X_0^2 + (Z_0 + N)^2}) dN \right. \\ \left. - S_x \left(\int_0^\infty dM \exp(-S_x M) \int_0^{z_0} K_0(\sqrt{(X_0 + M)^2 + Z^2}) + \right. \right. \\ \left. \left. \int_0^\infty dM \int_0^\infty dN \exp(-S_x M - S_z N) K_0(\sqrt{(X_0 + M)^2 + (Z_0 + N)^2}) \right) \right]$$

fig.5 Green's function for two perpendicular planes with different recombination velocities obtained by the method of images

Fig.6 shows the calculated currents for a selection of parameters S_x , S_z and as a function of the dimensionless coordinate $X=x/L$: we can see that the highest GB recombination velocity gives the highest amplitude and that an infinit surface velocity renders the smallest signal. The curve for zero surface velocity is purely exponential and the slope of the semilogarithmical plot is unity, so that the reciprocal slope with unscaled coordinates is equal to the real bulk Diffusion length. As expected, a high surface recombination velocity results in a reduction of the apparent diffusion length (1/derivative in the semilog. plot) : close to the boundary at $X=0.5$ it is reduced to 50% ($S_z = \infty$, $S_x = 1$) . Fig.7 shows the variation of the penetration depth which is represented here as

the coordinate Z_N . A small penetration depth leads to high reduction of the apparent diffusion length and the amplitude.

fig.6 $\log I_x$ for different recomb. velocities

fig.7 $\log I_x$ for different penetration depths

To evaluate the parameters from the measured linescans we developed the following procedure: the slope of the calculated semilog. profile evaluated in a small but finite interval has been tabulated for number of points X in the dimensionless parameters. Fitting the slope of the semi-log. plots of the measured profil at the corresponding distances to many values of test diffusion lengths will lead to the best set of parameters S_x , S_z and L .

4.4 Finite size effects:

Because of the complex integrals we had to assume a point source excitation. We still have to test the consequences of this approximation to our model. Considering the electrical model it is clear, however, that the model must fail when the edge of the generation volume touches the GB. Here the signal must decrease strongly because a generation of electron hole pairs at both sides results in the decrease of the charge deficiency which is the origin of the EBIC. The evaluation of the distance between the peaks will therefore directly give the generation volume diameter. This is shown in fig.9. It is a plot of signal width vs. beam energy raised to the power of 1.75 which shows that the well known dependency of generation volume diameter $/11/12/$ on beam energy E_b can be confirmed.

Fig.9 signalwidth vs $E_b^{1.75}$

5. Local variation of the parameters in Solar cell Silicon.

The evaluation of the parameters for GB in p-type SILSO (fig.10) shows that the diffusion length varies significantly along a single GB. The comparison with etch pit images of the same places indicate that reduction of diffusion length is mostly due to dislocations. Fig11 shows that also the

fig. 10 etch pits images, EBIC images and line scans on three different places at the same GB amplitude of the signal which is dominated by the GB recombination velocities changes significantly along a single GB. The comparison with bulk diffusion lengths and conventionally EBIC images is still in progress. We hope that by applying this EBIC mode we will be able to make some interesting contributions to the solutions of still outstanding questions concerning recombination or segregation at GB in solar cell silicon.

References

- /1/ Donolato, C., J. Appl. Phys. 54 (1983) 1314
- /2/ Marek, J., J. Appl. Phys. 53 (1982) 1454
- /3/ Zook, J.D., Appl. Phys. Lett. 42 (1983) 602
- /4/ Mataré, Laakso, C.W., Appl. Phys. Lett. 13 (1968) 216
- /5/ Taylor, W.E., Odell, N.H., Fan, H.Y., Phys. Rev. 88 (1952) 867
- /6/ Russel G.J., Robertson, M.J., Vincent, B., Woods, J., J. Mat. Sci. 15 (1980) 939
- /7/ Shockley, W., Read, W.T., Phys. Rev. 87 (1952) 835
- /8/ Martínez, J., Criado, A., Piqueras, J., J. Appl. Phys. 52 (1981) 1301
- /9/ van Roosbroek, W., J. Appl. Phys. 26 (1955) 380
- /10/ Berz, F., Kuiken, H.K., Solid-St. Electron. 19 (1976) 436
- /11/ Gruen, A.E., Z. Naturforsch. 12A (1957) 89
- /12/ Everhard, T.E., Hoff, P.H., J. Appl. Phys. 42 (1971) 5837