APPLICATION NOTE

EBIC measurement of the minority carriers' diffusion length in a GaAs solar cell p-n junction

INTRODUCTION

Electron beam current collection techniques (EBIC/EBAC/EBIRCH) are widely used in electrical failure analysis to localize defects [1]. These techniques either produce a spot highlighting the defect's location in the electrical current image or serve for a comparison of a reference and a failing sample. Some defects, damages or process variations require quantitative analysis of current values measured at each pixel. It is especially true for the electron beam induced current (EBIC). From EBIC signals, one can quantify carrier mobility, diffusion lengths, recombination processes, and defect distribution within the material. This information is crucial for understanding the performance and quality of semiconductor devices, which, in turn, leads to improved design and fabrication processes.

In order to obtain specific parameters describing the charge carrier dynamics, one needs to associate accurate current values with each pixel of the EBIC image. In this application note, we show how calibrated EBIC signal acquisition can be used to measure the minority charge carrier diffusion length at the p-n junction of a GaAs solar cell. Minority charge carriers are either electrons or holes depending on the semiconductor doping. Their diffusion length, or lifetime, is related to defects or dislocation density in a semiconductor.

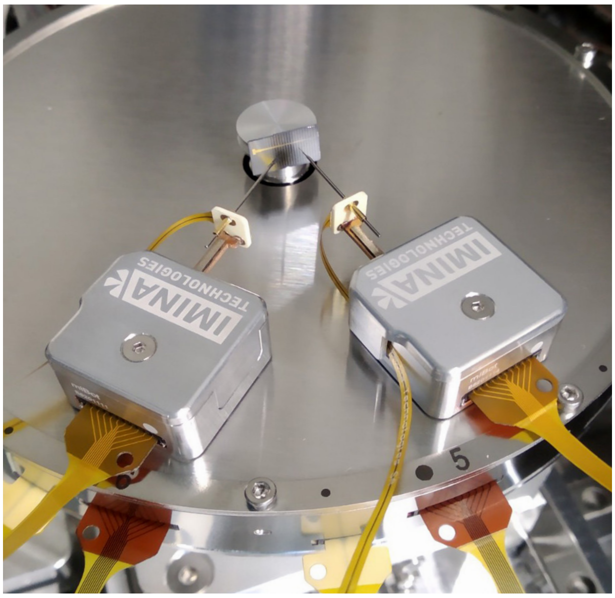

Figure 1. Sample mounted on the SEM stub and miBot nanoprobers used in the experiment. Only one probe is needed for this experiment, the second one is a backup.

SETUP

A GaAs solar cell with the top-down architecture is cleaved to access its cross-section and p-n junction. It is mounted on the side of an SEM stub with the cross-section facing up and is placed at the center of the Imina Technologies Nanoprobing platform equipped with two miBots. See Figures 1 and 2 for a picture and a schematic of the experimental setup. The platform is installed in a Tescan CLARA SEM. IBSS GV10x plasma cleaner is used to avoid carbon contamination while imaging. An EFA module from Point Electronic is used to acquire the EBIC signal.

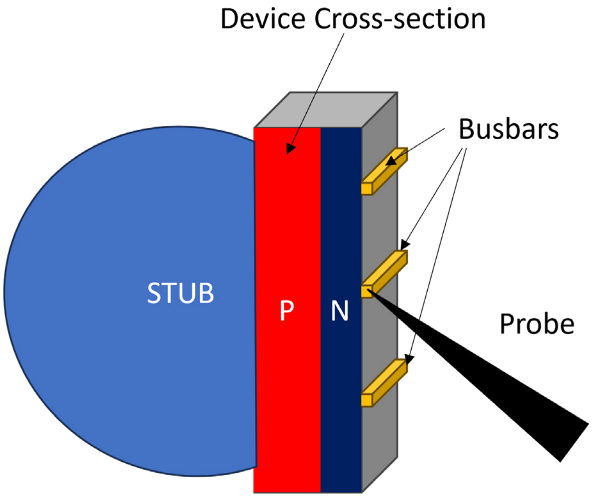

Figure 2. Sketch of the sample geometry as viewed from the top, with the device glued onto the SEM stub with the p-n junction facing the electron beam, and the busbars located on the vertical surface of the sample, easily reachable by the probes.

EXPERIMENT

The top surface of the sample has busbars leading to the emitter of the solar cell. We contact it with a probe tip connected to the HIGH input of the current amplifier. The base of the solar cell is connected to the backside of the sample and to the stub. The nanoprobing platform features an Active Sample Holder which electrically connects the stub to the LOW input of the current amplifier.

First, to help locate the busbars and to land a probe on one of them, we tilt the microscope stage by about 10 degrees. In this position, the busbars are clearly visible, and the probe can be gently landed on one of them, close to the cross-section as shown in Figure 4.

Once the probe is landed, we bring the microscope stage back in the flat position to have a perpendicular view of the cross-section. miBots are very stable mechanically, so they maintain electrical contact with the sample even as the microscope stage is moving.

SEM acceleration voltage is set to 2 kV. This acceleration voltage is a good tradeoff to to obtain a high surface resolution of the p-n junction profile without suffering from deeper penetrating electrons and their scattering that would blur the p-n junction profile. The beam current is set to the relatively high current of 3 nA, to get higher EBIC signal.

RESULTS AND ANALYSIS

Figure 5 shows the EBIC signal generated by the p-n junction in the sample. The brightest part of the red line corresponds to the center of the p-n junction. We calculate the minority carriers' diffusion length from the line-profile perpendicular to the junction. Fifty line-profiles were averaged over the depletion zone to smooth the signal as shown in Figure 6.

We determine the minority carriers' diffusion length using the method from Chan et al. [2]. This method fits the current as a function of distance from the p-n junction as:

$$\ln\left(\frac{I}{x^{\alpha}}\right) = -\frac{x}{L} + \ln\left(k\right)$$

Where:

I is the EBIC current

x is the distance from the junction

α is the linearization coefficient

L is the bulk minority carrier's diffusion length

k is a constant

Here, α depends on the surface recombination velocity of the free surface (Vs). If Vs = 0, then α = -0.5. If Vs = ∞, then α = -1.5. So α must lay somewhere between -0.5 and -1.5.

The surface recombination velocity determines the recombination rate of electrons and holes at the surface of a semiconductor. The more defects semiconductor has, the greater the surface recombination velocity is. It can therefore be seen as an indicator of defect density.

The right side of the equation 1 is a linear function of x. To satisfy the equation, there must be a value of α for which the left side of the equation is a linear function of x as well.

We tested different values of α and fitted results into a straight

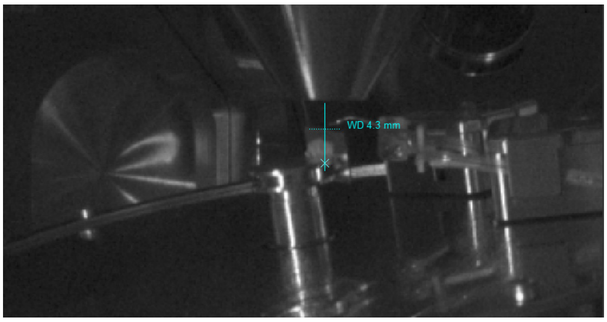

Figure 3. View of the sample inside the SEM chamber. The arrow marks the working distance of 4.3 mm.

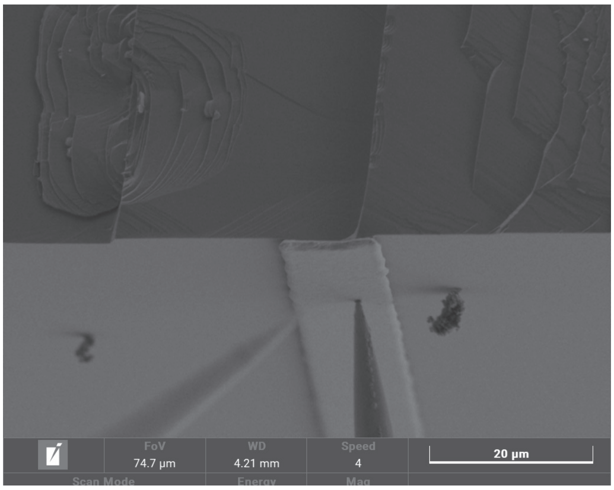

Figure 4. miBot probes landed on the busbars to collect the electron beam induced current across the p-n junction.

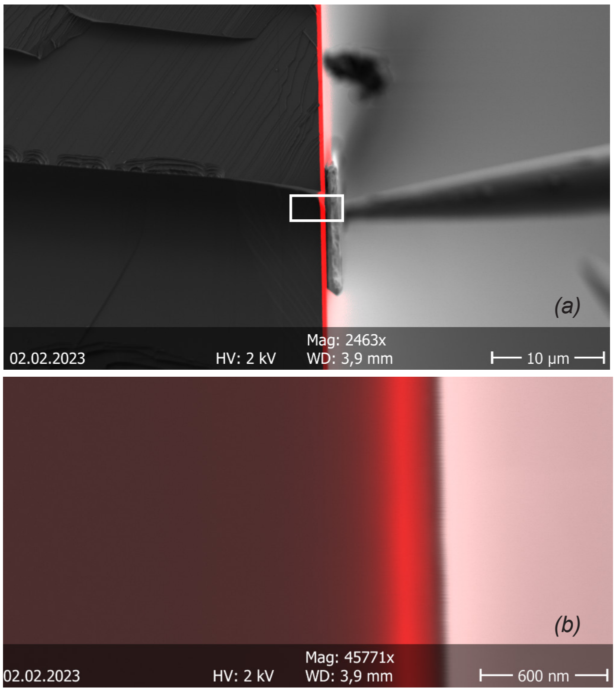

Figure 5. (a) EBIC image of the cross-section and (b) a zoom-in of the area marked with the white frame in (a).

line. It appears that the curve is the most linear when α = -0.5, which means a surface recombination velocity of 0. It is unlikely that Vs is actually zero, but it suggests that it is closer to 0 than it is to ∞, meaning the semiconductor is quite defect-free.

The slope of the straight line obtained when α = -0.5 corresponds exactly to 1/L, where L is bulk minority carrier's diffusion length. This allows us to extract L and obtain a value of 570 nm. This value is within the range of what we would expect from such a device.

CONCLUSIONS

Comparing images with different gain configurations can produce small offsets of the zero-current references, which in turn will affect further calculations. Getting the precise gain and offset values right is hard, as EBIC electronics involve different stages of amplification with variable gains. EBIC signal acquisition electronics must be calibrated for all possible gain values to ensure that all images will display accurate current values, regardless of the amplifier settings.

In this Application note, we used Imina Technholegies' Nanoprobing system equipped with Point Electronic's EFA module to measure the diffusion length of minority carriers in a solar cell. We collected EBIC signal from the solar cell cross-section containing a p-n junction. miBot nanoprobers are so mechanically stable that the microscope stage could be tilted back and forth without losing electrical contact, which tremendously helped to streamline the experiment workflow and get results quickly and efficiently. Thanks to the well-calibrated Point Electronic's EBIC signal acquisition module, we obtained accurate pixel current values for all amplification configurations and could quantify the device characteristics.

We collected 50 line-profiles of the EBIC signal and used them to calculate the diffusion length of minority charge carriers, which amounted to 570 nm, which is within the expected range for such devices. We also estimated that the surface recombination velocity is close to zero, which suggests a low density of defects in the semiconductor layer of the solar cell.

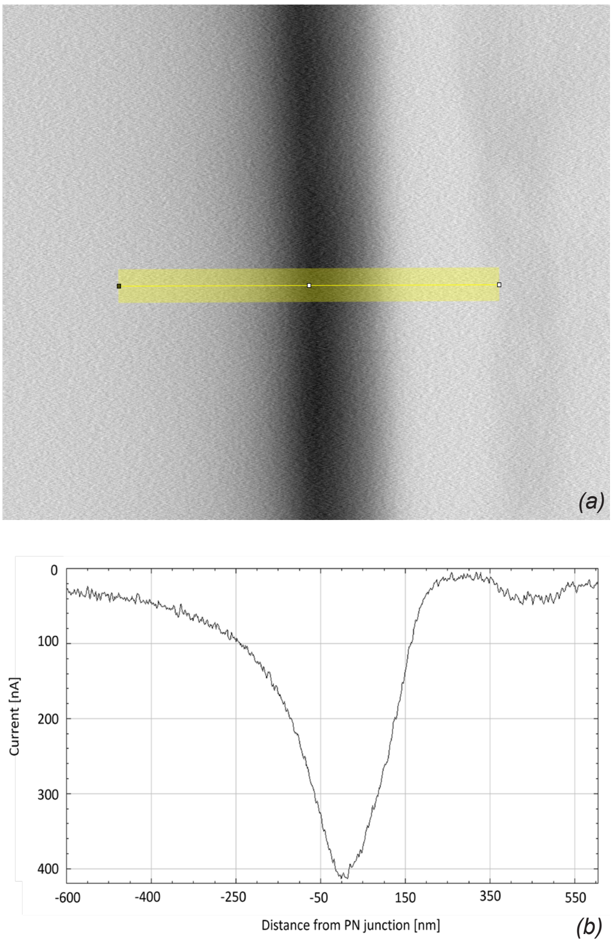

Figure 6.
(a) Line-profile perpendicular to the junction.
(b) Average of 50 line-profiles of electron beam induced current across the p-n juction, as shown in (a).

REFERENCES

[1] G. Moldovan, The emergence of electrical analysis in electron microscopy, Microscopy and Analysis, 2020.

[2] D. Chan, V. Ong, A direct method for the extraction of diffusion length and surface recombination velocity from an EBIC line scan, IEEE transactions on electron devices, 1995.

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