Characterization of hole trapping in ß-Ga_2O_3 Schottky diode by electron beam induced current

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The different properties of ß-Ga_2O_3 make it a very attractive semiconductor for high voltage electronic devices and solar-blind ultraviolet photodetectors. [1] However, technological advances of Ga_2O_3 are limited by the lack of control over defects and impurities that determine the electronic properties and performance of devices. Another drawback is the large hole effective mass and thus low hole mobility. By using electron beam induced current (EBIC), we can analyze the defects within the bulk and understand the role of hole traps and charge carrier recombination mechanism. The collection coefficient efficiency (CCE) and the diffusion length (L) are the important parameters that need to be extracted to understand these phenomena.
The material used in this study is an epitaxial ß-Ga_2O_3 layer grown on Sn-doped ß-Ga_2O_3 substrate ($7x10^{18}$ cm^{-3}) with a surface orientation (001) (Tamura corporation, Japan). The epitaxial layer is ~11.5µm thick and doped with silicon around ~$2.1x10^{16}$ cm^{-3}. Ohmic and Schottky contacts were deposited to obtain vertical Schottky diodes. Theoretically, the EBIC current collected in a vertical Schottky diode results mainly from the creation of electron/hole (e/h) pairs inside the depletion region. When e/h pairs are well generated inside the semiconductor, within the space charge region (SCR) (see Fig.1), the normalized EBIC signal $I_c/(V_{acc} \times I_b)$ (I_c: EBIC current, V_{acc}: acceleration voltage, I_b: electron beam current) is supposed to be independent of the applied voltage. In this case, if there are no hole traps, the CCE is assumed to be 1. Using the following equation: $I_c = \frac{I_b * V_{acc} * \eta * CCE}{E_{e/h}}$, we can determine the e/h pair creation energy ($E_{e/h}$). But for our Ga_2O_3 Schottky diode, the normalized EBIC signal as function of the applied voltage did not reach a plateau for $V_{acc} = 7keV$(Fig. 2) (EBIC measurements at room temperature). By increasing polarization, we increase the collected current. Additionally, since the CCE is much lower than 1, there are significant losses in charge collection which may be due to the hole trapping by deep acceptors [2]. We also discuss two methods for determining the diffusion length. Since diffusion length of Ga_2O_3 is small, we need to use the more reliable method. First, we use the dependence of I_c on the distance to the edge of the Schottky diode (see Fig.3), then we can extract L by fitting with the following equation: $I_c(x) = \exp(-\frac{x}{L}) \times x^n$. The other method is to fit the dependence of the collected current on the acceleration voltage (see Fig. 4) using the generation rate of e/h pairs $G = \frac{I_b V_{acc} \eta}{E_{e/h}}$ and the depth-dose dependence $h(z) = \frac{2.175}{R} \exp\left[-A\left(\frac{z}{R} - 0.16\right)^2\right]$ [3].

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[2] E. B. Yakimov, A. Y. Polyakov, N. B. Smirnov, I. V. Shchemerov, P. S. Vergeles, E. E. Yakimov, A. V. Chernykh, M. Xian, F. Ren, and S. J. Pearton, *Role of Hole Trapping by Deep Acceptors in Electron-Beam-Induced Current Measurements in β-Ga2O3 Vertical Rectifiers*, J. Phys. Appl. Phys. **53**, 495108 (2020).
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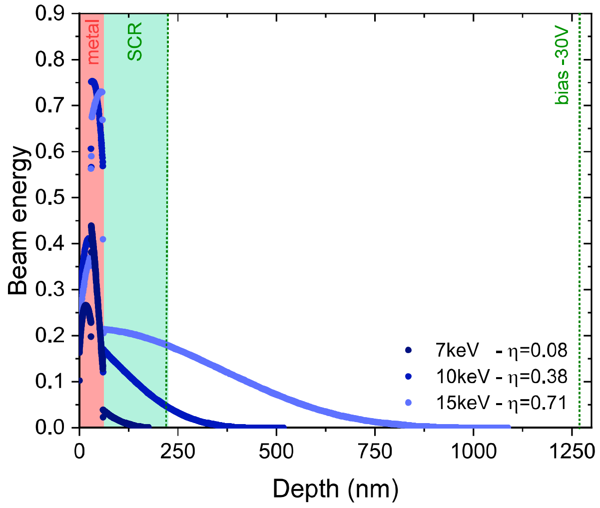

Figure 1 Casino simulation of the distribution of electron beam energy inside the metal (red area) and the semiconductor. At an acceleration voltage of 7keV, all e/h pairs are created inside the space charge region (SCR, green area) (η is the beam energy absorption coefficient inside the SC)

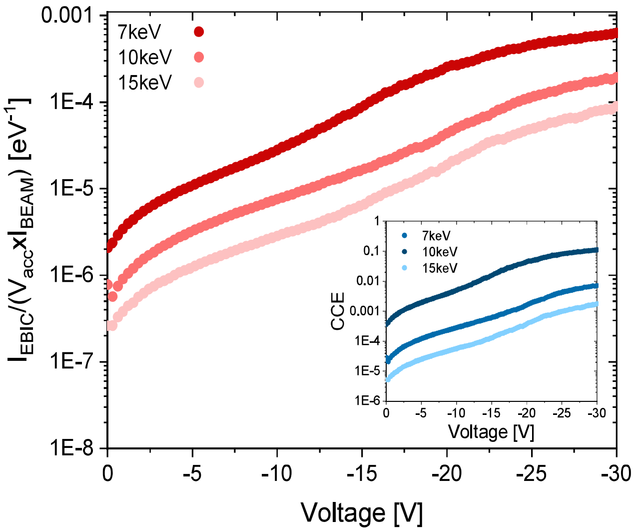

Figure 2 Normalized EBIC current depending on the applied voltage for different acceleration voltage: 7keV, 10keV and 15keV. Inset: Coefficient collection efficiency estimated considering the e/h pair creation energy equal to 14.2eV (according to the equation $E_{e/h} = 2.8E_{gap} + 0.6eV$)

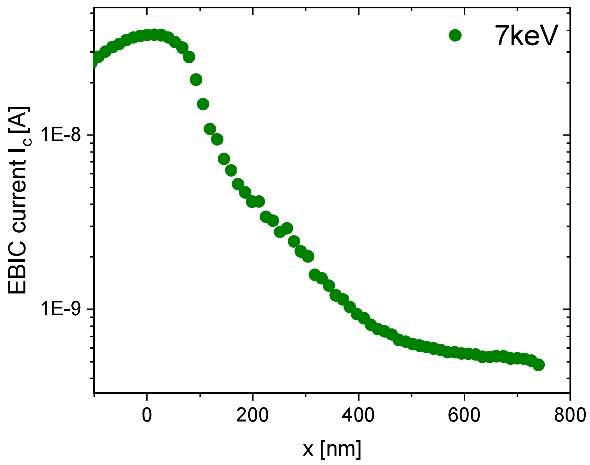

Figure 3 EBIC current as a function of distance x from the edge of the Schottky diode.

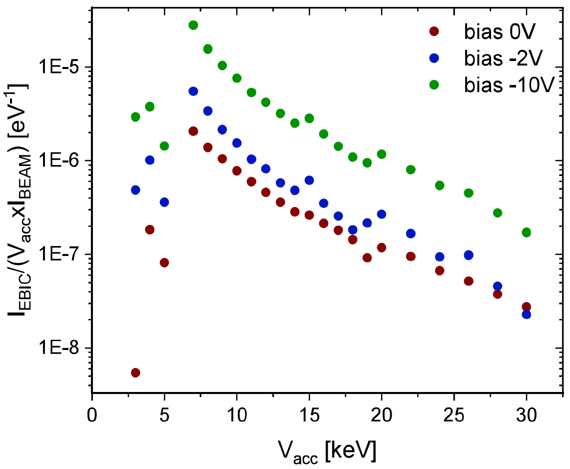

Figure 4 Normalized EBIC signal as a function of acceleration voltage measured with 0, -2 and -10V applied voltage.