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Characterization of Electrical Field Enhancement at the Edge of Schottky Electrode on Diamond

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Abstract

Electrical field enhancement at the edge of the Schottky electrode on diamond under reverse bias condition was characterized by electron beam induced current (EBIC) measurement. The increase of the EBIC signal was clearly observed at the edge of the electrode when the electrical field was increased more than 0.9 MV/cm. We also confirmed that the EBIC signal was not uniformly distributed at the edge of the electrode but very bright spots existed. The leakage current of the diodes corresponded to the bright spots at the edge of the electrode.

1. Introduction

Diamond is the promising material for future electronics devices because of its superior properties such as high breakdown field (>10MV/cm), highest thermal conductivity (2200W/mK) in materials, high mobility (>2000 cm^2/Vs) and low dielectric constant [1,2]. Unipolar diodes such as Schottky barrier diodes (SBDs) and Schottky pn diodes with very high breakdown voltages > 10kV [2] or extremely high current density > 40kA/cm^2 [3] have been reported. However, the breakdown voltages of the devices are much lower than those expected from the theoretical value. One of the reasons is the enhanced electrical field at the edge of the Schottky electrode under the reverse bias condition. The estimated electrical field at the edge of the electrode is more than 3 times higher than that at the center of the electrode [4]. In this study, field enhancement at the edge of the Schottky electrode has been characterized by electron-beam induced (EBIC) measurement.

2. Experimental

For the EBIC characterization, pseudo-vertical structured SBD (pVSBD) was fabricated on p-/p+ stacked diamond film. Firstly, the surface of the high-pressure and high temperature (HPHT) synthesized semi-insulating single crystal Ib-type diamond substrate (001) was polished with 2.5 degrees of off angle along with [110] direction to enhance the step-flow growth. Heavily boron doped p+ layer with 8 μm thickness was grown by microwave plasma assisted chemical vapor deposition (MWCVD). A drift layer with lightly boron doped p- layer with 0.9 μm thickness was grown on the p+ layer. The polish and the growth condition were described in a paper published elsewhere [5]. The boron concentrations of p- and p+ layer were confirmed by secondary ion mass spectroscopy (SIMS) as 2x10^{16} and 2x10^{20} /cm^2, respectively. The surface of the film was cleaned and oxidized by mixed acid treatment (HNO_3 and H_2SO_4) at 250°C. Ti/Au Ohmic contacts were formed at the corners of the substrate on the p+ layer after making via holes in the p- drift layer. Schottky electrodes of Mo with 8 nm thickness were deposited by electron-beam assisted evaporation. No edge-termination structures such as field-plate or junction-terminated extensions are adopted in this study. The diameter of the Schottky electrode was 100 μm. The cross sectional structure of the diamond pVSBD is shown in fig. 1.

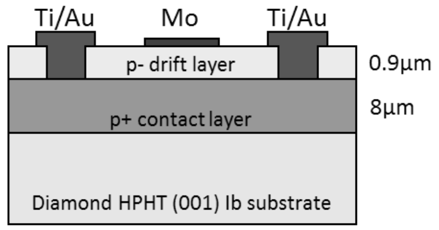

Fig.1 Cross sectional structure of diamond pVSBD.

EBIC measurement was carried out using a Schottky field emission scanning electron microscopy (FE-SEM), FEI Inspect F50 and a homemade probe system. pVSBD was biased using Keithley 2611 source-measure unit. Current-voltage characteristics of pVSBD were also measured using the same setup in the FE-SEM. In this study, two devices named device A and B were characterized.

3. Results and discussion

EBIC signal maps on the device A are shown in fig. 2. The reverse biases up to Vr=100V were applied on the device. As shown in the figures, EBIC signals at the edge of the Schottky electrode are almost constant to the reverse bias up to 40V (0.74 MV/cm), since the bright area is observed at the outer peripheral fringe of the electrode when the bias is increased more than 60V (0.9 MV/cm). The EBIC signals at the peripheral fringe of the electrode as functions of reverse bias are plotted in fig. 3. The intensity of EBIC signal is increased with increase of the reverse bias and the high intensity area is also widened.

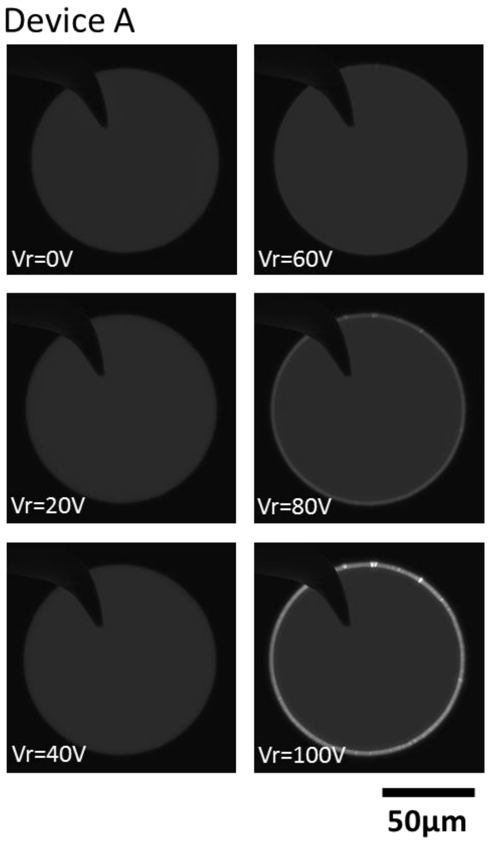

Fig. 2 EBIC signal maps of device A as functions of the reverse biases up to 100V.

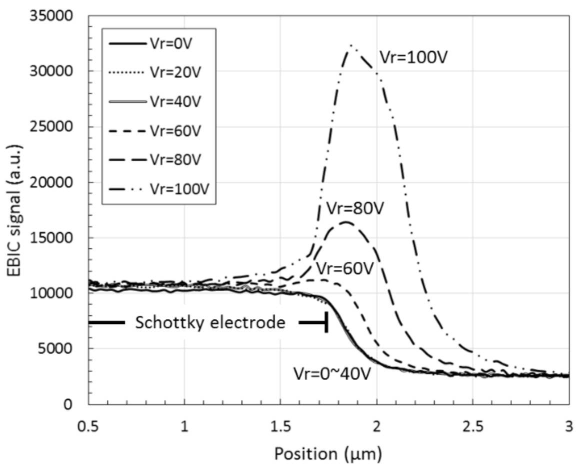

Fig. 3 EBIC signal intensity at the peripheral fringe of the Schottky electrode as functions of reverse biases.

This corresponds to the increase of electrical field at the peripheral fringe of the Schottky electrode and the expansion of the depletion layer area, however, the depletion layer width is narrower than the expected length calculated by the theoretical equation using the doping concentration characterized by SIMS. The best fit is obtained with a doping concentration of 6×10^{16} /cm^3, which is 3 times higher than that obtained from SIMS.

The EBIC intensity is not uniform in the depletion layer but high intensity spots exist as shown in fig.2. Figure 4 shows EBIC maps at Vr=100V (1.16 MV/cm) and leakage current characteristics of device A and B.

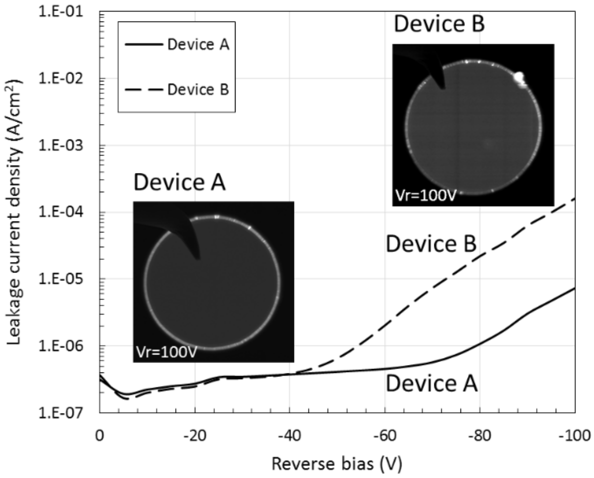

Fig. 4 EBIC maps and the leakage characteristics of device A and B.

As shown in the figure, higher leakage current is confirmed on device B which has a high intensity EBIC spot at the periphery fringe. No any special structure is confirmed by SEM at the point. Further crystallographic analysis is needed to clarify the origin of the high intensity EBIC spot.

4. Conclusions

Electrical field enhancement at the edge of the diamond Schottky barrier diode was characterized by electron-beam induced current (EBIC) method. EBIC signal and depletion layer length increase with increase of reverse bias, however, the depletion layer length is narrower than the expected value from the doping concentration in the drift layer. High EBIC intensity spots are confirmed in the depletion layer. These spots correspond to the leakage current of SBD, however, no special structure is confirmed on the spots. Further crystallographic characterization is needed to clarify the origin of the spots.

Acknowledgements

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