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Characterization of defects in diamond PiN diodes by electron beam induced current

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Abstract

Defects on two different types of diamond PiN diodes have been characterized by electron-beam induced current (EBIC). EBIC intensity maps under zero and reverse biased PiN diodes indicate that PiN diode with low leakage current has no hot spots under reversed biased condition since dark spots exist under zero and biased conditions, however, that with high leakage current has hotspots as well as high density of dark spots under biased condition. It indicates that the recombination/generation center and carrier multiplication effect formed at crystallographic defects is one of the reasons of high leakage and low breakdown voltage of diamond PiN diodes.

1. Introduction

Diamond is one of the promising materials for future semiconductor devices such as power electronics devices, high-frequency power devices, radiation detectors and integrated circuits survived under harsh environmental conditions. Thanks to the improvement of the crystal quality and doping controllability of the epitaxial p and n-type films by chemical vapor deposition (CVD) technique, both the unipolar and bipolar devices with high blocking voltage have been fabricated [1]. However, the leakage current of the devices, especially bipolar diode, is always higher than the theoretical value estimated by generation [2]. In this study, two different types of PiN diodes, high and low leakage current, have been characterized by electron-beam induced current (EBIC) to understand the reason of high leakage current.

2. Experimental

Diamond PiN diodes were fabricated on n+/i/p+ stacked films. The schematic cross section of the devices is shown in fig.1. The stacked n+/i/p+ films were deposited on semi-insulating diamond {111} substrates by CVD. In order to reduce the current path and surface leakage current, mesa structure was formed by a plasma etching process using oxygen gas. Ohmic contacts were deposited on n+ and p+ layers. The thickness of each n+, i and p+ layer is 0.2, 1-1.2 and 2 μm, respectively.

The current-voltage and capacitance-voltage characteristics of the devices were measured using Keithley 2612 and Keysight 4284A, respectively. EBIC was measured in secondary electron microscopy (SEM) equipped with automatically controlled measurement probes as shown in fig.2. EBIC images were obtained by the collection of carriers generated by the electron beam. The current signal was amplified by Stanford Research SR570. Bias probe in on the p+ not to make any electrical damage on pre-amplifier. The acceleration voltage and electron-beam current were 20 kV and 1.4 nA, respectively.

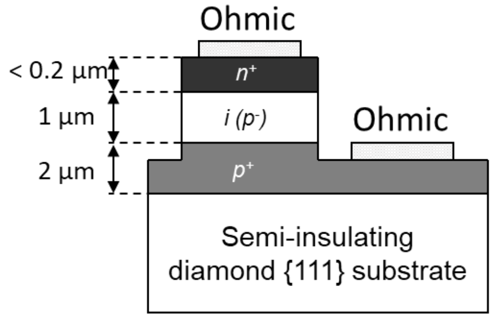

Fig. 1. Schematic cross-section of diamond PiN diode.

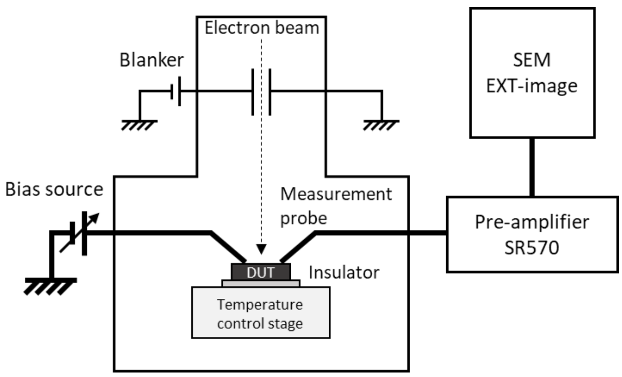

Fig. 2. Electron beam induced current system.

3. Results and discussion

From current-voltage characteristics, two different types of diodes, such as high and low leakage current, have been obtained. Hereinafter, high and low leakage devices are called as device A and B, respectively. Device A blocks reverse bias Vr > 200V, which corresponds to > 1.8MV/cm of the average electrical field at the junction. The leakage current of the device A is less than 100μA/cm^2 at 200V. On the other hand, the leakage current of device B reaches to 20mA/cm^2 at Vr < 50V.

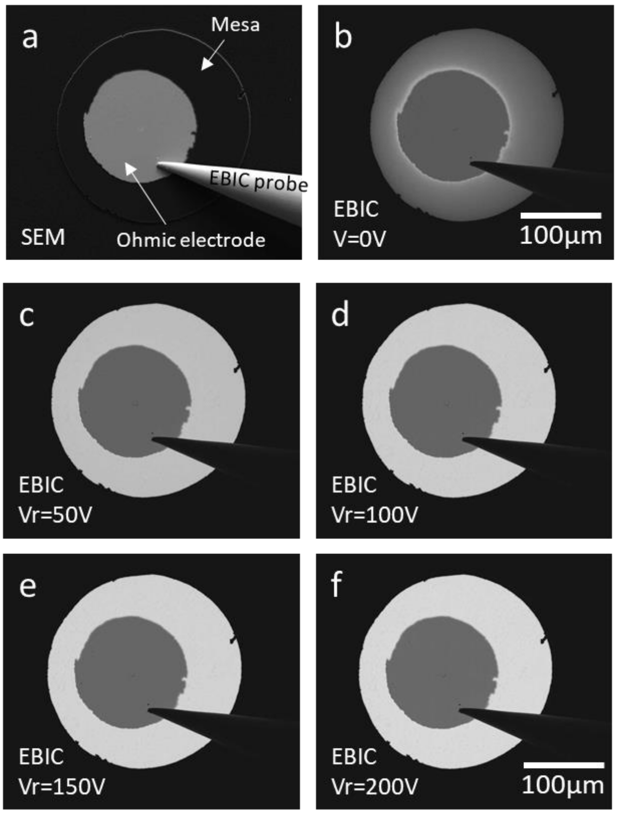

Fig. 3. An SEM image and EBIC maps of device A under zero and reverse biased conditions.

Figures 3 show topographic SEM and EBIC images of device A under zero and reverse biased conditions. Vr of 50, 100, 150 and 200V corresponds to 0.55, 0.97, 1.38 and 1.8 MV/cm of electrical field at the junction interface estimated from the device structure. Contrary to diamond Schottky barrier diode, no electrical field crowding at the periphery of the electrode or mesa edge has been confirmed even at high reverse biased conditions [3]. However, small dark spots with density > 1.5x10^5 /cm^2 have been observed under zero and biased conditions.

Figures 4 show topographic SEM and EBIC images of device B under zero and reverse biased conditions. Device B also doesn't show any electrical field crowding at the periphery of the electrode or the mesa edge. The density of the dark spots is 2.3x10^5 /cm^2 which is almost similar to that in device A. However, the size of the dark spots are much larger. These large dark sports are located at the corner of triangle morphology on the surface as shown in fig. 3b, indicating the large dark spots and corresponds to the crystallographic defects. When the reverse bias of Vr = 30 V is applied on device B, some of the dark spots turn to bright as hot spots, which indicates more the carriers are collected at hot spots. This phenomenon cannot be explained only by carrier generation/recombination center as well as band-gap narrowing because charge collection efficiency is larger than unity. The mechanisms of this effect can be explained by the larger carrier multiplication under reverse biased condition at this spot.

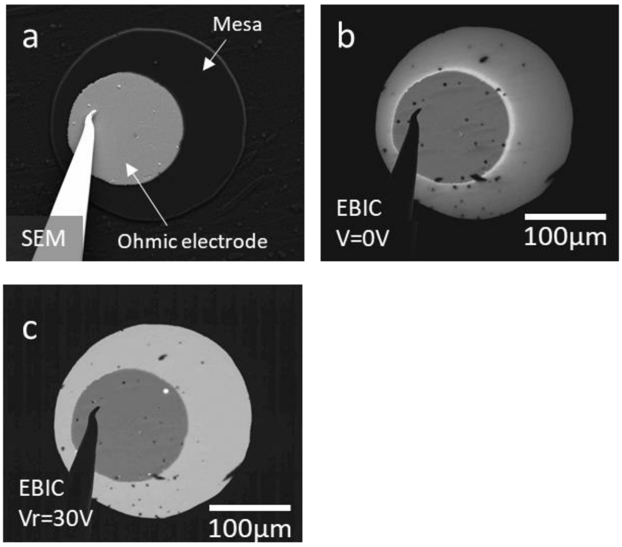

Fig. 4. An SEM image and EBIC maps of device B under zero and reverse biased conditions.

4. Conclusions

Diamond PiN diodes with high and low leakage current have been characterized by EBIC. No electrical field crowding at the periphery of the mesa has been observed, however, dark spots with density > 5x10^4 /cm^2 have been confirmed on both the devices. The dark spots are located at a corner of the triangle surface morphology, especially for high leakage device, indicating the spot is at the crystallographic defect. And some of the dark spots of high leakage device turn to bright, so-called "hot spots", under reverse biased condition. This phenomenon can be explained by carrier recombination and carrier multiplication. Larger carrier multiplication which induces high leakage current and premature breakdown at hot spots are assumed.

Acknowledgments

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