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Study of defects in diamond Schottky barrier diode by photocurrent and photoluminescence spectroscopy

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Abstract

Defects are essential for applications in semiconductor devices, such as Schottky barrier diode, transistor. In order to control the defects, we must first understand them. However, methods to characterize the defects in diamond are limited by its wide band gap 5.5 eV. We report photocurrent spectroscopy measurement on a vertical diamond Schottky barrier diode to detected defects based on the detection of charge carriers promoted via optical emission by two-step process. The photoluminescence with different applied bias to identify the charge state of nitrogen related defects observed in the photocurrent spectrum.

1. Introduction

Diamond has a great potential for semiconductor applications as an advanced material; however, defects induced during diamond epitaxial layers growth limit the electrical and optical performance of diamond devices in many applications. For this reason, defects spectroscopy in diamond is today one of the main serious concerns.

In this work, photocurrent and photoluminescence (PL) spectroscopy were used to study defects in p-type diamond. Photocurrent is a sensitive method for investigation of defects in diamond compared to other ones such as admittance spectroscopy, because optical emission is easier to cover wide band gap than thermal emission [1][2]. Here, the first attempt to study the defects in vertical diamond Schottky barrier diode by photocurrent spectroscopy is discussed. Three thresholds are observed and PL was used to further identification of charge state.

2. Sample preparation

IIb type diamond was used as substrate to fabricate a vertical Schottky barrier diode. Boron doped diamond homoepitaxy of p- layer was grown with a thickness of 1um by microwave plasma chemical vapor deposition (MPCVD) technique (with an off angle of 3.536°) and the boron concentration is controlled by diborane and methane gas concentration. After that we evaporated sandwich contacts with Mo as the Schottky contact and Ti/Pt/Au for Ohmic contact. The Ti (30nm)/Pt (30nm)/Au (100nm) contacts were annealed at 420 °C for 30 min to form titanium carbide which gives rise to Ohmic properties. As a Schottky electrode, Mo electrodes (10 nm in thickness and 300μm in diameter) were fabricated by using photolithography after ozone treatment.

3. Results and discussion

Photocurrent spectroscopy in the diamond Schottky barrier diode was measured in the photon energy range from 1.24 to 3.1 eV at room temperature using super continuum light. The result is shown in figure 1. The thresholds absorbed in photocurrent curve is probably caused by the presence of individual excited impurity energy levels. The spectrum was fitted using the convolution of Inkson's formula with a Gaussian phonon-broadening: [2]

$$\delta(E) = A \int_{-\infty}^{+\infty} \frac{(E-E_i)^{3/2}}{E(E-B)^2} \frac{[-(\varepsilon-E_i)^2/2w^2]}{(2\pi w^2)^{1/2}} d\varepsilon \quad (1)$$

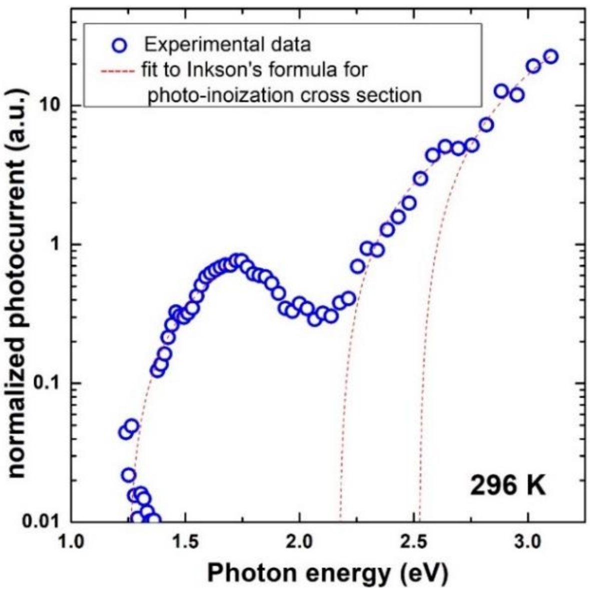

Fig. 1 Photocurrent spectra of diamond Schottky diode at room temperature. The photocurrent spectra are normalized to the light intensity. The dashed lines represent the numerical fit of the spectra by Eq. (1).

The increase of photocurrent signal with photon energy may be attributed to a hole or electron emission process from hole trap states in the depletion layer of the Schottky diode. So that the result indicated the presence of defects around 1.3 eV, 2.2 eV and 2.5 eV in the band gap of diamond. The most likely candidates are nitrogen related defects.

To investigate the optical emission mechanism observed in the photocurrent measurement, the photocurrent spectrum was taken as a function of the 500nm green light power and displayed in figure 2. In this approach, a quadratic fit to the experimental data indicated that the measured photocurrent is resulted from two-step optical emission processes. The defect is excited and then an electron is promoted from the valence band to defect level generating free hole. As well as, free electron generation may exist. We consider the reason of an additional increase of the conductivity with illumination, which is due to increase of the number of free carriers. We also measured the capacitance-voltage characteristics (not shown). The result suggested that the negative charges in depletion region increases, the positive charges generated, contribute to photocurrent signal.

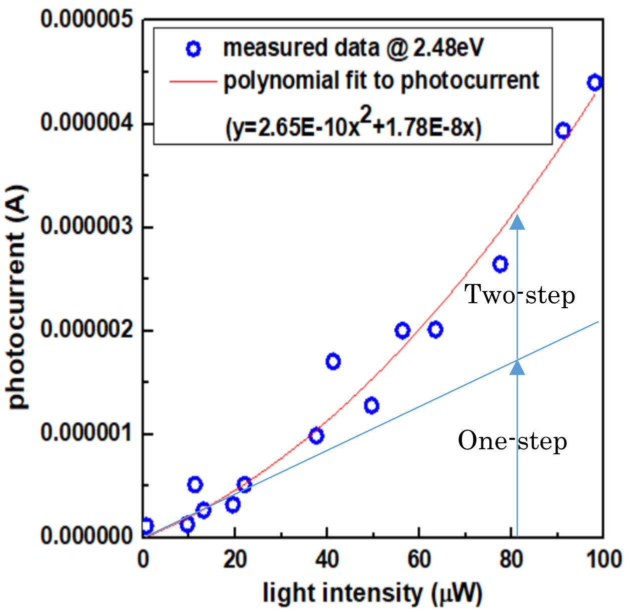

Fig. 2 The photocurrent as a function of the 500nm green light power

Because the two-step excitation of photocurrent is similar to the modulation of nitrogen-vacancy (NV) center excitation, and the value of energy level is close to the known position of NV center [3], we consider that the defect probably is nitrogen related defect, e.g., NV center. We measured the PL and compared the results under different bias voltages to identify further defects. The variation of PL spectra as a function of the applied bias voltage to the Schottky diode suggested that the charge state of carriers can be controlled by bias voltages since the effect on Fermi level. To discuss these variations, we plot the difference of PL spectrum between 1 V and -35 V as shown in figure 3. It is clear that the charge state of carriers is changed with bias voltages. For forward bias, the holes flow from diamond to metal. These injected holes are trapped in negatively charged carriers giving rise to a transition to natural state. when applied 0 bias or reverse bias, natural state return to negatively charge [4].

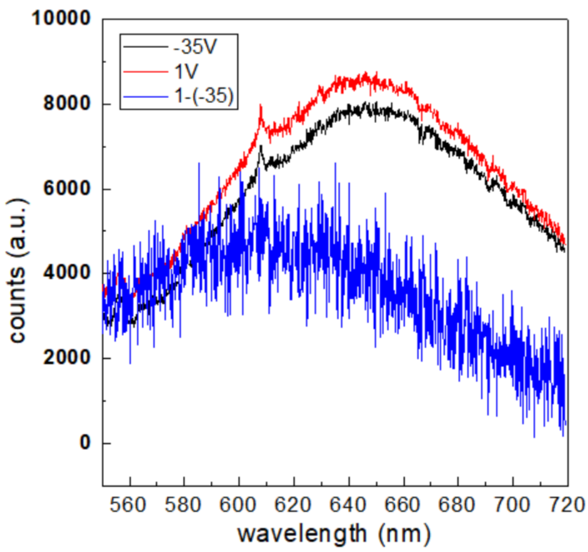

Fig. 3 PL with different applied voltages using 532 nm green laser at room temperature. The blue line is the normalized difference between 1 V and -35 V.

4. Conclusions

In this work, we presented the identification of defects and charge states in a vertical diamond Schottky barrier diode. From photocurrent spectroscopy, the defect levels at 1.3eV, 2.2eV and 2.5eV were detected. Also, it was observed two-step optical emission process. By applying bias on the Schottky contact and simultaneous illumination (532 nm laser light), carriers can be actively transported between the negative state and natural state. It is due to the field-induced band bending in depletion region of the Schottky barrier diode, in such way that the Fermi level shifts around defects levels, which varied the charge state of carrier and its electrical and optical properties.

References

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