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Investigation of Deep Levels in Diamond based Radiation Detector by Transient Charge Spectroscopy with Focused Heavy Ion Microbeam

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Abstract

A transient spectroscopy analysis of pulse signals induced by heavy ion micro probe was applied for chemical vapor deposition (CVD) diamond-based radiation detector to investigate the effects of native defects in on the degradation of charge collection efficiency (CCE). A high-purity CVD diamond with thickness of 100μm was employed for the analysis, and as a result, a defect with activation energy of 0.27 eV which is involved in the degradation of CCE was detected.

1. Introduction

Single-crystalline CVD diamond is regarded as an ideal material as a next generation radiation detector because of its excellent electrical characteristics [1,2]. Typically, high-purity diamond with high resistivity would be used as detector body to collect whole charges induced by ionized particle under the influence of high-electrical field. To evaluate detector life-time and the radiation-resistance of the detector, it is important to clarify deep levels distributed in the devices. Deep level transient spectroscopy (DLTS) is a technique that is widely used to investigate deep levels in semiconductors [3,4]; however, the conventional DLTS has some disadvantages for characterizing defects in devices with high-resistivity such as radiation detectors. On the other hand, another approach of deep level evaluation technique was proposed using the properties of radiation-induced pulse signal inside the radiation detector [5,6]. Several defect levels in 4H SiC substrate was measured from transient properties of charge induced by alpha particle with Alpha particle induced charge transient spectroscopy (APQTS) system [5]. Furthermore, similar charge transient spectroscopy using heavy ion microbeam probe (HIQTS) system had been developed on 3MV tandem accelerator system. And the analysis of 4H SiC schottky barrier diodes (SBDs) was successfully performed using focused oxygen micro-probe [7]. The results suggest that it would be also applicable to the analysis of deep levels in other wide bandgap semiconductor like diamond.

In this study, we analyzed deep levels in radiation detector based on single-crystal CVD diamond using HIQTS system with focused oxygen and other heavy ion micro probe.

2. Experimental

Sample preparation

A high-purity single-crystalline CVD diamond wafer with size of 3.0 mm × 3.0 mm and thickness of 100 μm was employed as the radiation detector. Three layered electrode of Ti/Pt/Au was prepared on both sides of the CVD diamond wafer. Current-voltage (I-V) and capacitance-voltage (C-V) characteristics were evaluated before the ion beam irradiation.

Heavy Ion Charge Transient Spectroscopy (HIQTS)

Fig. 1 shows the schematic of HIQTS system at JAEA/ Takasaki. CCE characteristics of high-purity CVD diamond-based radiation detector were measured by using 10.5 MeV oxygen ions before HIQTS measurements.

CCE obtained from the CVD diamond-based radiation detector was lower than its expectation delivered from the

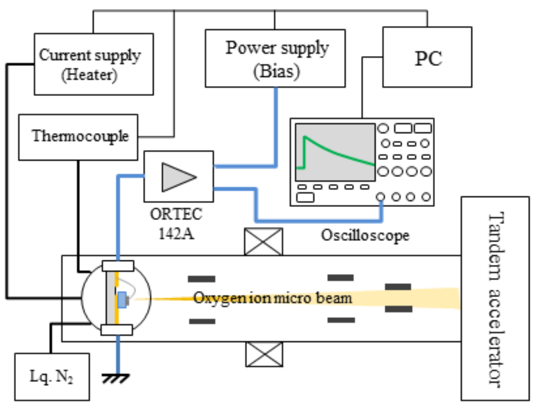

Fig. 1 Schematic diagram of HIQTS system based on 3MV tandem accelerator

comparison of CCE for Si detector. Therefore it is expected that the fabricated detector had a native defects which is electrically active to degrade charge collection performance of radiation detection. From plateau of CCE curve, typical reverse bias voltage of 50 V was determined for QTS analysis to evaluate the defect level and was applied to diamond during HIQTS measurement. The charges generated in diamond were collected using a charge sensitive preamplifier (CSP; ORTEC, 142A) and the output signals were recorded using a digital storage oscilloscope (DSO; Agilent, DSO2024A). In-house software based on LabVIEW handled the pulse signal measurements and controlled the temperature with a flow of liquid nitrogen and embedded heater unit outputs. HIQTS signals induced by 10.5 MeV-O ions were consecutively measured in temperature ranges from 180K to 280K. The HIQTS signals were analyzed using rate window method in a similar manner to DLTS analysis.

3. Results

Fig. 2 shows the example of HIQTS signals obtained at temperatures of 190K, 210K, and 230K. The results suggested that trapped charges would be largely released from the defects by changing substrate temperatures.

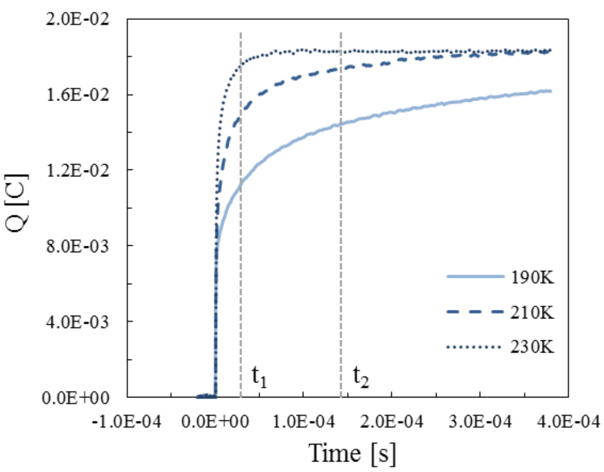

Fig. 2 HIQTS signals obtained at temperature of 190K, 210K, and 230K

HIQTS spectra were then extracted from charge transient signal by applying rate window method as shown in Fig. 3. Different time constant of t_1 and t_2 were used to obtain the differences in release of ΔQ from defect levels.

$$\Delta Q = Q(t_2) - Q(t_1) \qquad (1)$$

Then Arrhenius plot of a peak appeared in HIQTS spectra was obtained as shown in Fig.4. The plot showed the activation energy of the defect, which is electrically-active to the charge pulse signal detection in the CVD diamond, was estimated to be around 0.27 eV. This defect is involved in the degradation of CCE. Further investigations are necessary to investigate the origin of these defects which should be determined with dopant analysis and additional procedures of QTS including annealing properties. However this experimental result suggests that these defect levels would exist in the crystal as grown and commonly degrade electrical properties of radiation detectors based on CVD diamond.

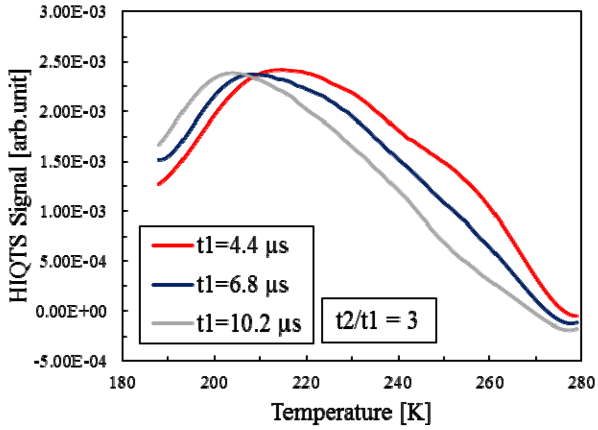

Fig. 3 HIQTS spectra extracted from charge transient signal by applying rate window method

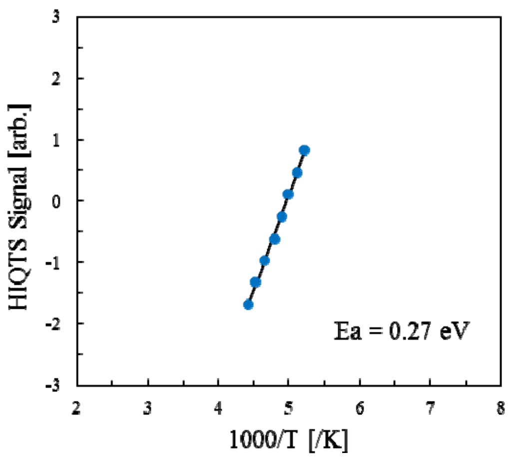

Fig. 4 Arrhenius plot of HIQTS signal

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