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Optical Detected Magnetic Resonance of Nitrogen-Vacancy Centers in Vertical Diamond Schottky Diode

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Abstract
In this work, we reported an active electrical control of nitrogen-vacancy (NV) centers charge and spin state by a vertical diamond Schottky diodes (VDSD). The photoluminescence (PL) and Optical Detected Magnetic Resonance (ODMR) of NV centers generated by ion-implantation in the VDSDs are discussed. By applying reverse voltage across VDSDs, the NV^0 are converted into NV^- charge state because of the band bending in the depletion layer. Thus, the voltage dependence of the PL exhibits an increase intensity of NV^- zero phonon line (ZPL) with the applied voltage whereas the intensity of NV^0 ZPL decreases. Moreover, the NV^- phonon sideband increases with the applied voltage. On the other hand, the resonance dip of the NV^- ODMR spectrum splits for applied reverse voltage higher than 10 V. The dips splitting width increases with the applied voltage, and so, with the electric field magnitude within the VDSDs. Such dips splitting results from the Stark effect.

1. Introduction

NV centers in diamond are intensively investigated for quantum applications owing to their outstanding properties such as a long spin coherence time even at room temperature [1] [2]. Negatively charge NV centers spin state can be optically and electrically manipulated and read-out [3]. The electrical spin state control and readout opens the way for the implementation of advanced diamond devices based on NV centers for quantum applications. Nowadays, nitrogen ion-implantation is one of the best methods for generating NV centers in diamond devices [4]. However, ion-implantation induces crystal defects in addition to NV centers [5]. Recently, we reported the existence of nitrogen-related deep defects levels in diamond Schottky diodes with nitrogen ion-implanted layer by transient photocapacitance spectroscopy (1.2 and 2.2 eV below conduction band edge) [5] .Thus far, the effect of such defects on NV centers features are still unclear.

In this paper, NV centers generated by ion-implantation in VDSD are investigated by PL and ODMR. The effect of applied voltage across VDSD on the NV centers charge state, PL, and ODMR are reported. The effect of additional nitrogen related defects induced by ion-implantation and electrical control of negatively charged NV centers (NV^-) spin state are discussed.

2. Method

VDSDs with nitrogen-ion implanted layer have been fabricated. The detailed fabrication process is reported in [5]. 1-µm-thick lightly boron doped diamond layer (acceptors density: 3×10^6 cm^{-3}) was first grown on highly conductive IIb diamond substrate (acceptors density: 10^{20} cm^{-3}). Nitrogen ion was then implanted in the epitaxial layer with an energy of 80 keV (dose of 10^{12} ions cm^{-2}, implantation depth: 100 nm). Finally, the sample was annealed at 600°C. Ti (30 nm)/Pt (30 nm)/Au (100 nm) metallic stack was deposited at the bottom of sample and annealed at 420°C to form ohmic contact (see Fig.1(b)). 10-nm-thick Mo electrodes (300 µm in diameter) were fabricated at the top side of the sample to form Schottky contact. PL and OMDR were performed by using a homemade confocal microscope system as shown on Fig.1(a). A 532 nm laser was used as excitation source. A 0.50 NA objective was used to focus the laser onto the device. The red luminescence from the NV centers was measured using a CCD camera.

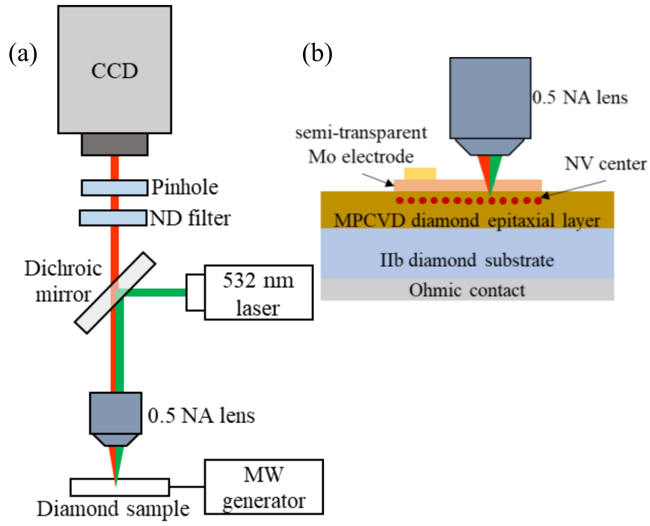

Fig. 1: Schematic of (a) the measurement setup and (b) diamond Schottky diode cross-section.

3. Results and Discussion

The PL and ODMR measurements were carried on NV centers located below the semi-transparent Mo electrode (see Fig. 1(b)). Indeed, the Mo electrode was thin enough to let both excitation laser and NV centers luminescence to pass through. PL and ODMR measurements were taken at different applied reverse voltage (Vr) across VDSDs. Figure 2 shows the achieved PL spectrums. At 0 V, both NV^0 and NV^- ZPL (at 575 nm and 637 nm respectively) were observed in the PL spectrum. The intensity of NV^0 ZPL was higher than that of NV^-. For applied reverse voltage (Vr) > 0 V, the intensity of NV^- ZPL and phonon sideband increased with Vr whereas the intensity of NV^0 ZPL decreased (see Fig.2). The decreased in the intensity of NV^0 ZPL was ascribed to the ionization of NV^0 into NV^- under high Vr due to the band bending in the space charge region [6]. The changes of PL spectrum can be explained using Fig. 3. At 0 V (Fig. 3(a)) the Fermi level is around the NV^0 and NV^- transition level and both NV centers charge states in observed (see Fig. 2). When Vr is applied, the Fermi level move towards NV^- charge transition level and causing more NV centers ionized into NV^-.

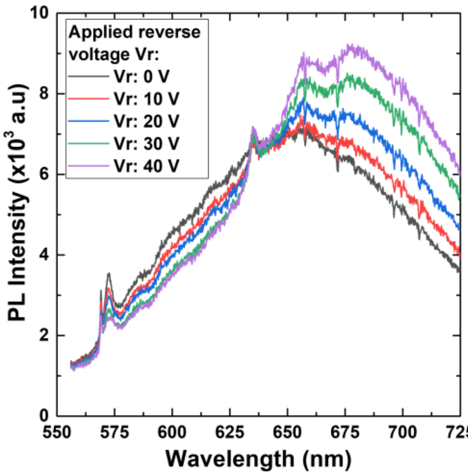

Fig. 2 NV center spectrum at different applied bias.

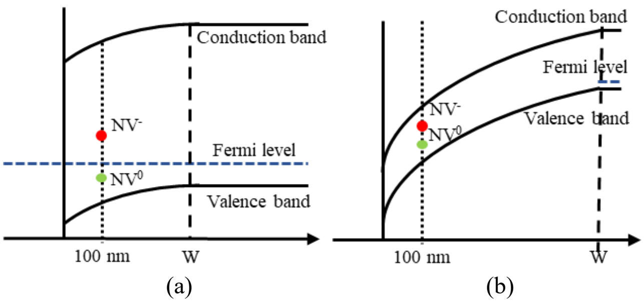

Fig. 3 Band diagram of NV center (a) at zero bias and (b) at reverse bias

Fig. 4 shows the ODMR spectrums measured for Vr ranging from 0 – 40 V. The achieved ODMR spectrums exhibited resonance dips. It has been found that the resonance dip split for Vr ≥ 10 V. Such dips splitting induced by increasing Vr was ascribed to the Stark effect [7]. The dips splitting was related to an increase in electric field within the Schottky diode. Indeed, the relationship between the splitting width and electric field is given by following equation [2]:

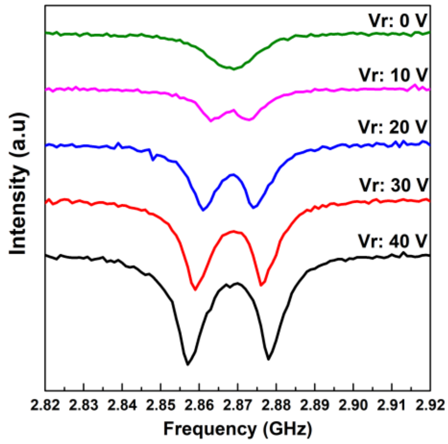

Fig. 4 ODMR spectrum at different applied bias.

$$Split\ width = \frac{2d_{gs}\Pi}{h} \qquad (1)$$

where $\Pi = E + \sigma$ is the total electric field, E is the applied electric field, σ is strain in the lattice, d_{gs} is the electric dipole moment parallel to the N-V axis and h is Planck constant. On the ODMR spectrums (Fig. 4), the dips splitting width increased with Vr, which was in good agreement with eq (1). Indeed, the depletion layer and electric field within VDSD increases with Vr. On the other hand, the contrast of ODMR spectrum was higher at larger Vr. The origin of the change in the ODRM contrast was still unclear.

4. Conclusions

In summary, we performed ODMR on nitrogen ion implanted Schottky diode and we observed ODMR splitting due to effect of electric field produces inside SCR. Ion implantation can introduce defects in diamond due to high energy ion bombardment into diamond lattice, we can use OMDR technic to measure the disturbance cause by these defects and determining the electric field strength.

References

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