DEPTH DISTRIBUTION OF DEFECTS IN ELECTRON IRRADIATED DIAMOND

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Annotation. Detailed measurements of photoluminescence of diamond irradiated in 1 MeV electrons have been performed. It has been found that the depth distribution of radiation defects can be described by contributions of strong defect production by primary electrons and weak secondary irradiation by gamma rays. The depth of the strong defect production is almost two times less that the theoretically predicted propagation of 1 MeV electrons (1.2 mm). The secondary gamma irradiation penetrates through the whole diamond sample of a few millimeter thick. Several new optical centers has been found in irradiated CVD diamond and analyzed.

INTRODUCTION

Effects of radiation damage of diamond by fast electrons have been studied since many years [1-6]. Although we have a solid understanding of the processes of defect production and interaction between defects in electron irradiated diamond, the information on the distribution of the radiation defects in electron-irradiated diamond is still missing. In this communication we present a detailed study of radiation defects produced in CVD diamond subjected to 1 MeV electron irradiation with the emphasis on their depth distribution.

EXPERIMENTAL

A 3.4 mm thick low nitrogen CVD diamond was used in this research. Prior to irradiation, the sample was annealed at a temperature of 1900°C for a few minutes in vacuum and then irradiated with 1 MeV electrons at a dose of 1.5×10^{18} cm^{-2}. After irradiation, the sample was cross-sectioned along the direction of irradiation. The distribution of defects through the sample depth was studied using photoluminescence (PL) spectroscopy and fluorescence imaging.

RESULTS AND DISCUSSION

A three layer structure of the sample is seen in the image (Fig.1): a substrate layer used for CVD growth and two thicker layers of the grown CVD diamond. The spots, where PL measurements were performed, are shown with red dots. The blue area is the color change caused by irradiation. This primary irradiated layer is about 0.7 mm deep.

The spectra taken at a depth of 1.5 mm (nominally non-irradiated area) reveal strong luminescence due to two centers with zero phonon lines (ZPLs) at 462.5 and 498.8 nm and rather developed NV^0 and SiV centers. The primary radiation GR1 center is detected too.

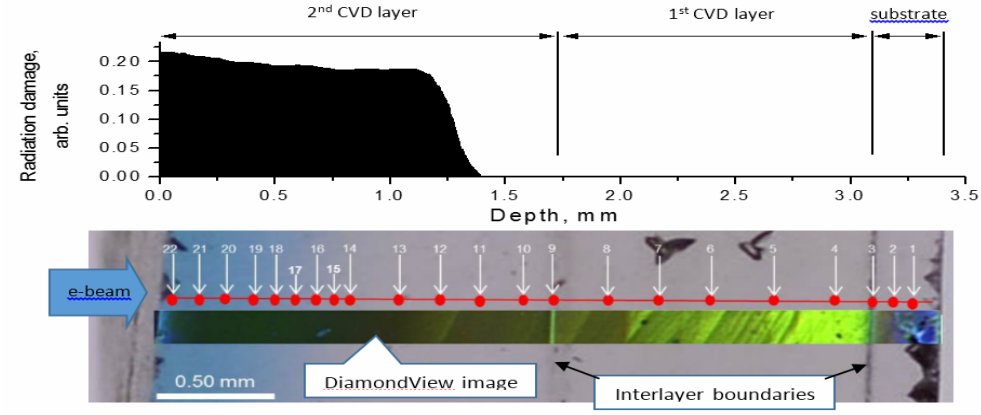
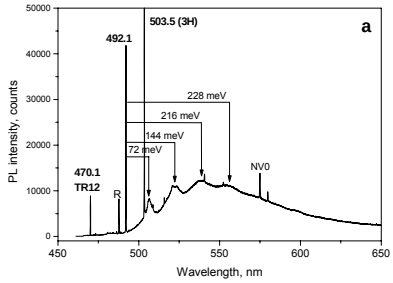
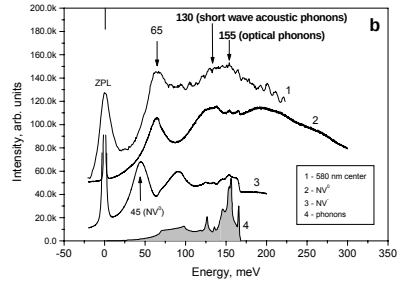


Figure 1. – Cross-sectional view of the irradiated diamond is compared with theoretical distribution of vacancies. Interfaces between the layers (points 3 and 9) are seen as two gray narrow stripes in the photograph and as dark and bright green stripes in DiamondView fluorescence image. Red points show where PL measurements were performed

The spectra taken from the blue irradiated area show dominating GR1 center and other major radiation centers with ZPLs at 492.1, 580, 503.2 (3H center), 389, 584, 849.2 and 470.1 (TR12 center). We analyze in detail the 492.1 and 580 nm centers as well as the 3H center.

Vibronic structure of the 492.1 nm center (Fig. 2a) is similar to that of the 3H center, what allows us to assume that the 492.1 nm center could be a manifestation of 3H defects trapped by some other defects, e.g by dislocations.





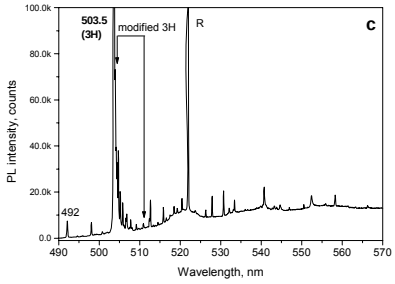


Figure 2. – (a) Spectrum of 492.1 nm center and 3H center. Energies of the vibronic features of the 492.1 nm center are exact multiples of 72 meV. (b) Comparison of PL spectra of centers NV^0, NV^- and 580 nm in energy scale with the ZPL energy set to zero. One-phonon density of states of diamond lattice is shown by curve 4. Spectrum of 580 nm center was measured at room temperature in ultra-low nitrogen diamond irradiated with carbon ions. (c) Spectrum of 3H center excited with 488 nm laser

A center with ZPL at 580 nm is one of the strongest in the blue irradiated layer (Fig. 2b). Its vibronic spectrum is very close to that of the NV^- center with the major contributions of 65 meV and 153 meV vibrations. We assume that 580 nm center, like NV^- center, may contain negatively charged vacancy. ZPL of the 3H center is accompanied by many weak satellite lines on the long wavelength slope (Fig. 2c).

Analysis of the spectral position of these lines and their intensity allows us to assume that these emissions originate from 3H defects interacting with some other point defects located in the vicinity (3H-X pairs). Similar explanation of the multiple ZPL structure was originally proposed for the luminescence of donor-acceptor pairs in diamond [7].

Distribution of the centers formed preferentially (centers GR1, 3H, 389 nm and 735.8 nm) and exclusively (centers TR12 and 580, 530.6, 527.8, 492.1 nm) in the primary irradiated area are shown in Fig. 3a and Fig. 3b respectively. All these centers originate from primary radiation defects formed directly during irradiation. The distribution of 3H and TR12 centers is more confined as compared with that of GR1 center what suggests that 3H and TR12 defects have complex atomic structure and they require higher density of radiation damage to form. Quite unexpected feature in the depth distribution of GR1 center is its presence all over the sample. So we have to assume that besides the primary electron irradiation the sample has experienced also gamma irradiation, which is deeply penetrating, but less efficient.

In Fig. 3a, the distribution of intensity of GR1 center is compared with the efficiency of production of vacancies in diamond by 1 MeV electrons calculated in [8]. The theory predicts almost uniform formation of vacancies in a 1.2 mm thick layer. Instead, we have found that the intense formation of GR1 center occurs only to a depth of 0.7 mm. The reason of this discrepancy is probably due to vacancy-interstitial recombination. Since more energetic electrons create more distant and thus more stable vacancy-interstitial (V-I) pairs, the I-V recombination is less at the irradiated surface and becomes stronger with depth.

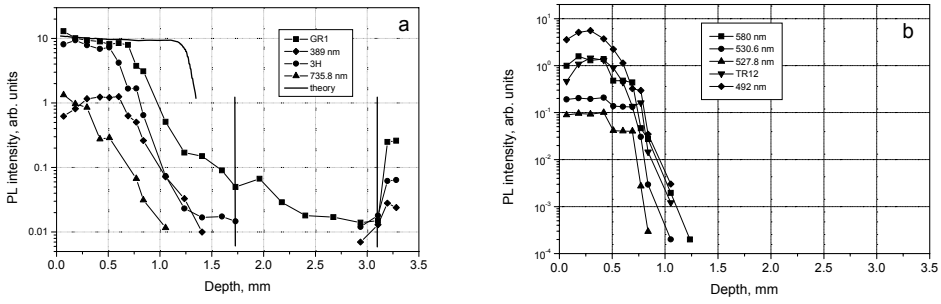


Figure 3. – (a) Depth distribution of radiation defects showing contribution of secondary gamma irradiation. (b) Distribution of primary radiation defects formed in direct interaction with fast electrons

The available data allows us to deduce that in diamond the V-I pairs, to be stable at room temperature, must be separated by a distance of at least 0.5 nm. The energy of electrons capable to produce such pairs must be over 0.5 MeV.

CONCLUSION

In diamond during electron irradiation the radiation defects are produced by primary electrons and by secondary gamma irradiation. The depth of the strong primary electron damage is lesser than the theoretically predicted one due to vacancy-interstitial recombination. The gamma-induced damage is much weaker, but it penetrates through the whole diamond volume.

Narrow ZPLs adjacent to ZPL of 3H center have been found and ascribed to weakly interacting complexes of 3H defects with some impurity atoms (3H-X complexes). The radiation center with ZPL at 580 nm has been ascribed to a negatively charged intrinsic vacancy-type defect. The radiation center with ZPL 492.1 nm has been explained as a modified H3 center.

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DI-INTERSTITIAL-OXYGEN CENTER IN SILICON: STRUCTURE, ELECTRONIC PROPERTIES AND ANNEALING BEHAVIOR

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Annotation. The experimental and theoretical data on the structure, electronic and dynamic properties of the I_2O complex are presented.

Self-interstitial clusters (I_n) in silicon impact the fabrication of electronic devices and have been extensively studied recently [1–3]. Theoretical calculations have predicted that I_2 is highly mobile in Si [4–6], so it is thought that di-interstitials play an important role in self-interstitial clustering and can interact with other lattice defects. The silicon di-