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Irradiation effects in semiconducting diamonds

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Abstract

Effects of X-ray, β and UV irradiation on semiconducting diamonds (type IIb) were studied and compared with those induced at the same conditions in natural (type Ia) and in synthetic diamonds. Methods of optical absorption, of X-ray and light induced luminescence, of thermoluminescence (TL) as well as of optically stimulated luminescence and optically stimulated thermoluminescence (OSL and OSTL) were used for the investigations. The IIb diamonds showed in the UV a weak absorption band at 260 nm and a sharp increase of absorption below 230 nm, while in the Ia samples the absorption increased sharply below 300 nm and absorption bands appeared near 310, 385 and 415 nm. In the X-ray induced luminescence of all samples an emission band appeared near 440 nm; in the Ia samples, additional band was recorded near 500 nm and a very weak one at about 360 nm. In all samples TL could be excited by X-ray, β as well as by 360-nm UV radiation; and in the IIb diamond also by 225 and 470 nm. In the TL of IIb diamonds main emission bands appeared at 475 and 665 nm, and in the OSTL of the Ia samples at 650 nm. The thermal activation energies were evaluated and found to be of about 0.36, 0.52 and 0.67 eV at the 360, 420 and 520 K peaks, respectively. The main TL peaks appeared in all samples above RT at the same temperatures and with the same thermal activation energies. The results indicate that these TL peaks are due to the same radiation induced trapping levels in all investigated types of diamonds, while in the emission of the various samples different luminescence centers are involved. The TL reached in all investigated samples saturation for relatively low radiation doses.

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Keywords: Diamond; Irradiation effects; Radiation defects

1. Introduction

Irradiation effects and formation of radiation induced defects in diamonds have been studied for several decades. Most of these studies concentrated on natural—type Ia diamonds; in some studies also semiconducting—type IIb diamonds were investigated (e.g.: [1–4]). More recently also synthetic diamonds [5] as well as diamond films grown by chemical vapor deposition technique (CVD) [6] were applied for these studies. Some of the CVD diamonds were also found to be highly suitable for application in radiation dosimetry [7].

In the present work, effects of X-ray, β and UV irradiation were studied in semiconducting diamonds (type IIb) and compared with those induced at the same conditions in natural (type Ia) and in synthetic-boron containing diamonds. Methods of optical absorption, of X-ray and light induced luminescence (XL and PL) of thermoluminescence (TL) as well as of optically stimulated luminescence and optically stimulated thermoluminescence (OSL and OSTL) were applied for the studies.

2. Experimental techniques

The X-ray irradiations were performed with a W-tube (40 kV, 15 mA) and the β irradiations with a ^{90}Sr source of a 1.5 Gy/min dose rate. The UV irradiations were

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carried out with a Xe lamp (150 W) and a grating monochromator. The β irradiations were carried out at room temperature (RT) and the X and UV irradiations at various temperatures between 80 and 300 K. The TL measurements above RT were carried out in a TL compartment, flushed by N_2 gas; the heating rate above RT was 5 K/s. For the low temperature absorption, luminescence and thermoluminescence measurements the samples were kept in liquid nitrogen vacuum cryostat and for the TL measurements they were heated at a rate of 20 K/min. The OSTL and OSL were stimulated at various temperatures between 80 and 400 K by monochromatic light in samples which had previously been exposed to X or β radiation. The optical absorption was measured with a Cary 17 spectrophotometer. The PL, OSL, TL and OSTL measurements were taken with Aminco-Bowman/2 luminescence-spectrometer.

3. Results and discussion

3.1. Optical absorption

The IIb diamonds showed in the UV a weak absorption band near 260 nm and a sharp increase of absorption below 230 nm. In the Ia samples the absorption increased sharply below 300 nm and an additional absorption band appeared on the absorption tail at 310 nm and weaker bands at 385 and 415 nm.

3.2. XL, PL and OSL

During X-ray irradiation at RT, a luminescence band was recorded in the IIb samples at 450 nm. At liquid nitrogen temperature (LNT) an XL emission band appeared in these samples at 435 nm and was narrower and by an order of magnitude stronger than at RT. In the Ia type diamonds a main XL band was recorded at RT at 445 nm with a shoulder at 500 nm and a weaker band at 360 nm. By cooling to LNT the main 445 nm band intensity increased by a factor of three. In Fig. 1, XL emission spectra of the various types of diamonds are given. No photoluminescence could be detected by UV excitation in the IIb and in the synthetic diamonds neither before nor after prolonged exposure to ionizing radiation. In Ia samples, which had previously been exposed to ionizing radiation, a luminescence emission could be excited by UV light. This luminescence disappeared after heating to about 800 K and is therefore attributed to an OSL emission, where carriers are trapped by ionizing X-ray or β irradiation at certain defect levels and then optically stimulated by UV or even visible light. These results also indicate that the defects, induced by ionizing radiation, become unstable at about 800 K. The main OSL emission band was at

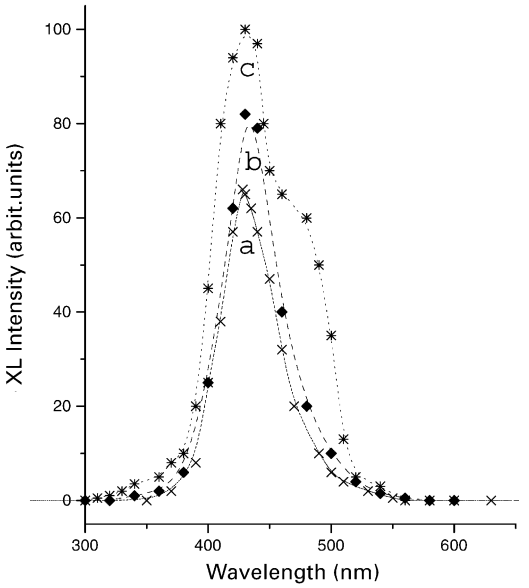

Fig. 1. X-ray induced emission spectra of various samples measured at LNT: (a) a synthetic diamond, (b) a semiconducting IIb and (c) a natural Ia diamond.

340 nm and had a stimulation maximum at the absorption peak at 310 nm. An additional broad band was recorded in the Ia samples between 420 and 480 nm; this broad band is apparently composed of two spectral components at 435 and 475 nm. The 340 nm emission band could also be excited by longer wavelengths up to about 550 nm. This finding supports the conclusion that this emission is due to a process of optical stimulation. The intensity of all these OSL emission bands increased markedly by cooling from RT to LNT.

3.3. TL and OSTL

In all samples, TL could be excited by X, β as well as by UV radiation. TL peaks above RT appeared in the various samples at 360, 420 and 520 K. The relative intensities of the various peaks differed and in some samples additional peaks were recorded at about 480 and 550 K The thermal activation energies at the main TL peaks were evaluated by the "initial rise" and "different heating rate" method (Booth formula) [8]. The values of the thermal energies were found to be in all samples about 0.36, 0.52 and 0.67 eV at the 360, 420 and 520 K peaks respectively.

After irradiation at LNT, different TL peaks appeared in the various samples. After X irradiation, the main peak appeared in the IIb samples at 265 K, and a weaker one at 145 K. In the Ia samples TL peaks appeared after

LNT irradiation at 180, 225, 260 and 300 K. In the synthetic samples, TL peaks were recorded at 145, 240, 300 and 355 K. The 355 K peak is probably the same as the 360 K peak, which appears after RT irradiation. This 360 K peak decays very fast at RT (about 75% of its initial intensity in 1 min); this is apparently due to thermal fading.

In all examined diamonds, TL could also be excited by UV light and the dependence of the excitation efficiency on the wavelength of the exciting light was measured. TL excitation spectra of the main 360 K peak had in all samples a maximum at 365 nm. In the IIb samples the UV excitation spectrum had an additional main maximum at 225 nm and at LNT also at 470 nm. In the IIb diamonds, the main peak appeared by 225 nm excitation at 265 K and by 365 nm excitation at 285 K. TL excitation spectra are shown in Fig. 2. In Ia diamonds that had previously been X-ray or β irradiated at RT and subsequently illuminated at LNT with light of 310 nm glow peaks were recorded during heating from LNT to RT at 116 and 285 K. These glow peaks could not be excited by 310 nm UV light in un-irradiated Ia diamond samples and not in X or β irradiated samples that were heated to 800 K before exposure to the 310 nm illumination. These 116 and 285 K glow peaks excited by the 310 nm illumination are therefore attributed to a process of OSTL. In this process, carriers which were trapped by the ionizing radiation in deep traps at RT, are subsequently stimulated by the illuminating light and transferred to shallower traps; the OSTL is emitted during their thermal release and radiative recombination. It may be noted that the wavelength of 310 nm was also optimal for the stimulation of OSL in pre-irradiated Ia samples. In the pre-irradiated synthetic diamonds, illumination with 500 nm caused the optical bleaching of the 520 K TL peak and the rise of the 420 K peak; this is also attributed to a photo-transfer from a deep trap to a shallower one. No OSTL was recorded in the IIb samples.

The spectral composition of the TL emission was measured at the main glow peaks. In the TL emission of type IIb diamonds, the main bands appeared at 475 and 665 nm. The emission of the main OSTL peak in the Ia diamonds was at 650 nm. Emission spectra measured at the main glow peaks are shown in Fig. 3. The fact that different emission bands appeared in the various examined diamonds indicate that different luminescence centers are involved in the emission of these samples. The finding that the main TL peaks appeared in the various samples at the same temperatures and with the same thermal activation energies indicate that these TL peaks are due to the same radiation induced trapping levels.

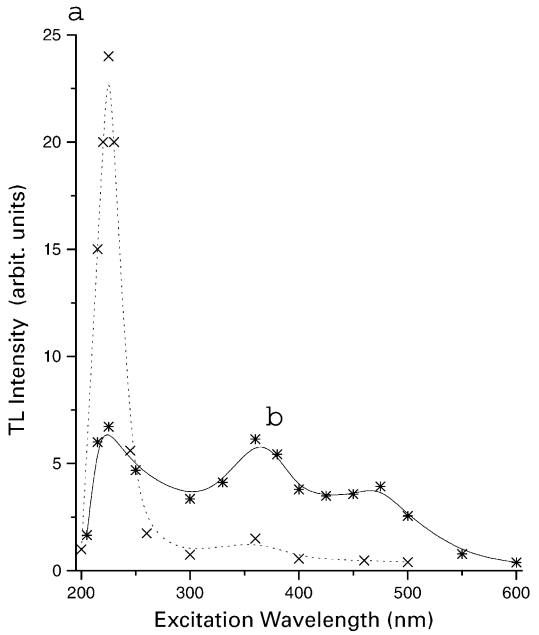

Fig. 2. TL excitation spectra of: IIb diamond at (a) RT, (b) LNT.

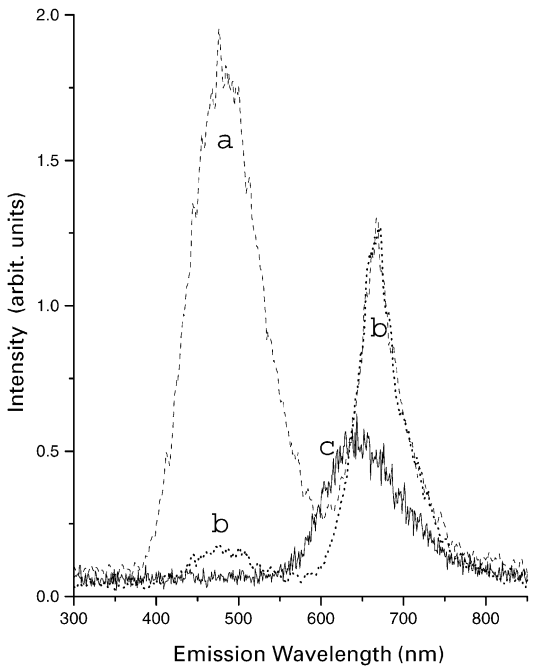

Fig. 3. TL Emission spectra of IIb diamond recorded after UV irradiation at LNT with: (a) 225 nm, (b) 360 nm UV light and (c) emission spectrum of Ia diamond, recorded at the 116 K OSTL peak after X irradiation at RT and 310 nm, illumination at LNT.

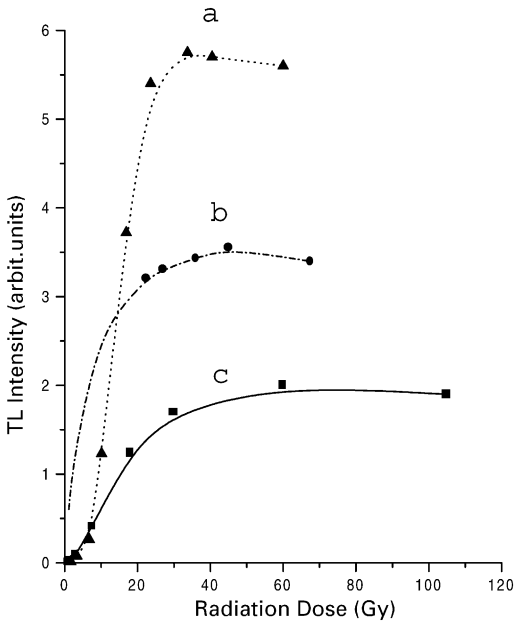

Fig. 4. Dependence of the TL intensity on beta dose of: (a) Ia diamond (enlarged $\times 10$), (b) IIb diamond and (c) synthetic diamond.

The dependence of the TL intensity on the dose of the exciting radiation were also measured. The dependence of the TL intensity on the dose of the exciting β radiation is shown in Fig. 4 for the various investigated types of diamonds. It can be seen that the TL intensity reaches in these samples saturation for relatively low doses. A similar behavior of dose dependence was also recorded for UV excited TL. This behavior is not favorable for application in TL dosimetry, but may be different for other types of synthetic diamonds.

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