



The luminescence emitted from the type Ib and IIa diamonds under the SiO₂ polishing process



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ABSTRACT

The luminescence of triboplasma during diamond polishing was investigated. The main luminescence in the ultraviolet range came from N₂ molecules in the air. The colors of the visible range of triboplasma were the same as those observed in the photoluminescence images, excited by the ultraviolet light. The color of the triboplasma luminescence was green for type Ib diamond, which was mainly from the H3 center. The blue luminescence for type IIa diamond was mainly from Band A. The correlation between the diamond temperature and periphery speed indicate that the mechanical abrasion component also increased linearly. However the polishing rate showed a threshold at the periphery speed of 26 km/h which corresponds well with the threshold of the triboplasma generation. These results imply that the electrical and optical energy of the triboplasma excited the defect level at the diamond surface and enhanced the chemical polishing rate of the diamond.

1. Introduction

Due to its extremely high hardness, diamond is widely used for industrial tools such as cutting tools and abrasive tools. In addition, diamond is a promising material for optical components and next-generation electronic devices because of its various excellent physical properties. Suppression of crystal defects in diamond is one of the key technologies for realizing these next-generation devices. Impurities, vacancies and interstitials are typical examples of point defects. For higher-dimensional defects, screw dislocations, edge dislocations, stacking faults and twinning are examples of linear and planar defects. To suppress impurities that severely affect optical and electrical properties [1,2], we have developed new synthetic method for high-purity type IIa single crystal diamonds under high pressure and high temperature (HPHT) [3]. The synthetic type IIa diamond is useful for a wide range of industrial and scientific applications such as in the monochromator for synchrotron X-ray beams, optical elements, semiconductor substrates, and high-sensitivity sensors (detectors). We suppressed linear and planar defects and synthesized high-quality type IIa diamonds with large dislocation-free areas of 5 × 5 mm² [4,5]. However, some dislocations and stacking faults were still observed, especially in the (111) growth sector. These linear and planar defects affect the optical and electrical properties. X-ray topography is a powerful tool for investigating dislocations and stacking faults. Dislocations in our type IIa diamonds have been observed by Kato and Masuya [6,7].

We also suppressed the density of these dislocations and stacking faults through post-annealing process under normal pressure [8].

The polishing process is the other key technology in the fabrication of high quality diamond tools, optical components and electronic devices. Diamond polishing has been performed for many centuries using fast-rotating cast iron disks (scaife) with diamond powder or metal-bonded diamond wheels [9,10]. However, polishing processes using diamond powders or grits cause significant surface and subsurface damages to the polished diamonds. Wilks proposed a microcleavage model that explained the different material removal rates for different polishing directions [11]. Such wear mechanism produces mechanical damage, degrading the performance of cutting tools, abrasive tools and electronic devices. To avoid surface and subsurface damage, chemical polishing methods of diamond were developed by many researchers. Ollison used oxidizing agents such as KNO₃ and/or KOH with alumina plate [12]. Thomas used colloidal silica with polishing pad to produce very low surface roughness [13,14]. However, higher polishing rate are necessary for industrial use.

Recently, we proposed a new high-precision polishing method using a ceramics wheel, which suggested that diamond was abraded mainly by chemical reaction, and so, less surface damage was introduced [15]. We found that among the various types of ceramics wheels, SiO₂ wheels had the highest wear rate against diamond [16].

The luminescence of triboplasma can be observed during diamond polishing using the SiO₂ wheel [17,18]. Such discharge and plasma

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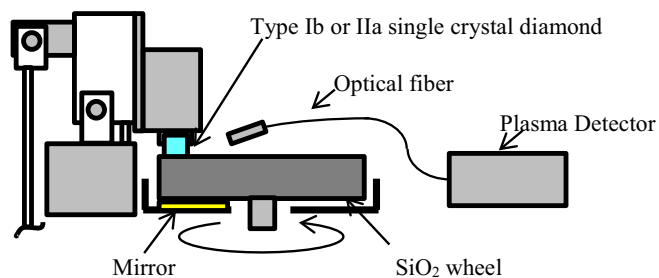


Fig. 1. Schematic drawing of a polishing machine and a plasma detector.

excitation enhances the reaction on the surface of the diamonds. However, the reports focused on the ultraviolet range, with little discussions about the luminescence in the visible range. In this paper, we discuss our observations about the visible range of the triboplasma luminescence and the polishing mechanism of diamonds.

2. Experimental

Two types of single-crystal diamonds were synthesized by the temperature gradient method under a high pressure of 5–6 GPa and a high temperature of 1300–1400 °C. We used Fe-Co-Ni alloy as the solvent metal to grow type Ib diamonds containing nitrogen impurities of around 100 ppm. For high-purity type IIa diamonds with impurities less than 0.1 ppm, we used high-purity Fe-Co alloy with Ti as the nitrogen getter and high-purity carbon source. Details of the synthetic method and quality of the type IIa diamond were described in our previous papers [3–5]. The photoluminescence (PL) images of these diamonds were taken by DiamondView™ (Diamond Trading Company) [19] under irradiation of ultraviolet light (with wavelength of less than 225 nm).

The cathodoluminescence (CL) spectra were measured by using a field-emission scanning electron microscope (JSM-7000F, JEOL) at an incident energy of 15 keV. All PL and CL images and spectra were taken at room temperature.

The (100) surfaces of the diamond plates were polished using silica (SiO₂) glass wheels (SW), as shown in Fig. 1. The diameters of the wheels was 200 mm. The rotation speed of the wheel ranged from 400 to 2500 rpm, corresponding to the periphery speed ranging from 13 to 85 km/h. Sample loading was varied from 0.5 to 3.0 kg, corresponding to the load pressure ranging from 0.2 to 1.2 N/mm². Process time of 1–4 h was required in order to be able to measure the polishing rate with a height gauge. The removed volume was calculated from the difference of the height multiplied by the sample size of 7 × 6.5 mm. The triboplasma luminescence was observed by high-resolution spectrometer (HR4000, Ocean Optics).

3. Results and discussion

Photographs of the diamonds during the polishing process are shown in Fig. 2(a)(b). The upper luminescence is the diamond sample and the lower luminescence is a mirror image of the sample. The colors of the luminescence were green for type Ib diamond and blue for type IIa diamond. The spectra of the triboplasma are shown in Fig. 2(c)(d). The spectra mainly consist of sharp peaks in the ultraviolet range and a weak broad band in the visible wavelength. The sharp peaks are attributed to N₂ molecules. In the visible wavelength, the wavelength of the broad band is different for the two types of diamonds. The band for the type Ib diamond is in the green range from 500 to 650 nm with the peak at 560 nm, while the band for the type IIa diamond is in the blue range from 400 to 580 nm with the peak at 460 nm (Fig. 2(e)(f)). Such triboplasma during the wear process between the diamond and the insulators (ceramics) was studied by Nakayama and Miura [20,21].

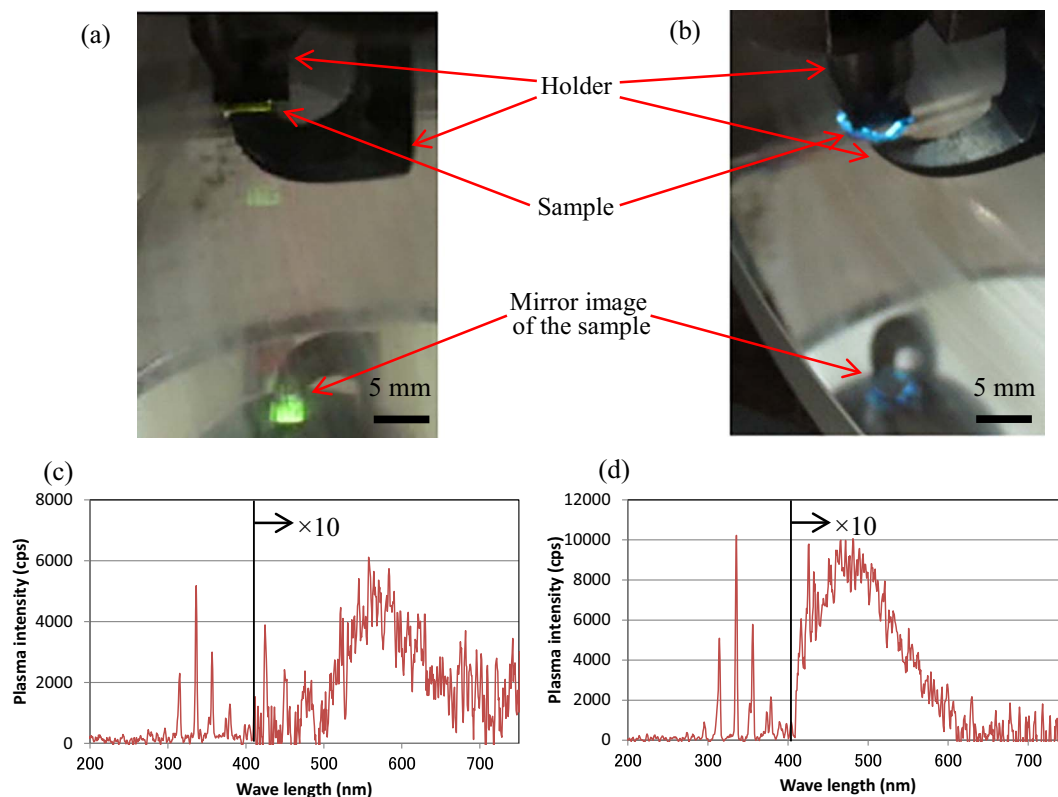


Fig. 2. Photographs and spectra of tribological plasma luminescence during polishing. (a) and (c) are those of the type Ib single crystal diamonds, and (b) and (d) are those of the type IIa single crystal diamond. In the photographs (a) and (b), the upper luminescence is the side view of the diamond sample and the lower luminescence is the mirror image of the sample. (c) and (d) are the spectra of the tribological plasma in the range from ultraviolet to visible wavelength. The intensities of the spectra with the wavelength of more than 410 nm are multiplied by 10.

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