



Spectroscopic studies of triboluminescence from a sliding contact between diamond, SiO₂, MgO, NaCl, and Al₂O₃ (0001)

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ABSTRACT

We have measured spectra of the light emission from the frictional contact between the pin of natural diamond, synthetic fused silica, MgO, or NaCl and the disk of quartz or synthetic sapphire in a vacuum in the wavelength range between 380 and 1000 nm. Each spectrum shows the relaxation of electronic excited vacancies, which are thought to be produced at the solid surface by mechanical abrasion.

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1. Introduction

Light emission caused by mechanical force applied to solid is called triboluminescence and is usually observed during friction or fracture of solid materials. Spectroscopic investigation of the triboluminescence has proposed the possible origins of the light emission, i.e., electric discharges of surrounding gas, electronic excitations of lattice defect in the solid [1], and a thermal radiation [2]. Spatially resolved spectroscopic measurement of the triboluminescence between a diamond pin and a quartz disk around the contact in $\sim 10\ \mu\text{m}$ diameter during sliding friction revealed two-dimensional structure of the triboluminescence; the light emission from the gas discharge in a gap space around the contact and the light emission at the contact area which is observed regardless of gas species and pressures and even in a vacuum [3]. We have found a luminescence from solid which appeared only under the region of gas discharge in a certain gas pressure between 1 and 1000 Pa. This solid luminescence was thought to be stimulated by ion or electron from gas discharge [4]. However there are few studies on the light emission from the contact area itself, which should be rather regarded as triboluminescence in a sense that the light is directly induced by mechanical damage.

Our previous investigation [5] of the light emission during friction between the diamond pin and the quartz or MgO disk

showed that the contact emission contained infra-red radiation and that the light was observed even in a vacuum. We suggested a possibility that the light emission from the contact was caused by frictional heat [5]. Recently, Hird et al. analyzed the spectrum of triboluminescence from diamond in terms of the Planck's equation for black-body radiation in the range of visible radiation [6]. In order to clear whether the light emission from the sliding contact of diamond is thermal radiation or not, it is necessary to measure the spectrum as wider as possible, especially into the infra-red region.

Another possible origin for the light emission from the sliding contact is fracture of solid, i.e., fractoluminescence. It was found that the spectrum of the light emission related to lattice defects of the solid in fractoluminescence of SiO₂ [7,8] and MgO [9]. The studies of photoluminescence and cathodoluminescence of natural and synthetic diamond [10–13] revealed the color centers related to lattice defect. However it was not clarified if the light emission from the sliding contact is identical to the typical fractoluminescence accompanied by the macroscopic fracture of solid, since it is likely that charged particles emitted from the cleaved surface [14] possibly induce the solid luminescence on the defect-rich cleaved surface.

Spectroscopic measurement of the light emission only from a real contact area during friction in a vacuum will reveal the origin of the triboluminescence of the solid: thermal radiation due to frictional heat, solid luminescence related to lattice defects, or other unknown processes. We have developed an equipment for the spectrum measurement of the light from the sliding contact in the wavelength range between 380 and 1000 nm. In the present

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study, firstly, we show the spectrum of the infra-red radiation emitted from the sliding contact between a diamond pin and a quartz disk. Secondly, we show the spectrum of light from the sliding contact of diamond, fused silica, NaCl, or MgO pins with a sapphire (0001) disk under the condition that the specimens can be abraded.

2. Experimental equipment

The sliding friction experiments were performed by a pin-on-disk type apparatus settled in a vacuum chamber with a base pressure of about 10^{-3} Pa. The pin-on-disk apparatus is illustrated in Fig. 1 and the detail has been reported in our previous paper [5]. The specimen fixed at the end of the pin was contacted to the disk with a normal force (F_N) in the range between 10 and 1000 mN. A quartz disk and a sapphire one were used in the present experiments. They have a high transmittance from near ultra-violet to infra-red radiations. The disk thickness was 1 mm and the diameter was about 50 mm. The disk was rotated by a motor that gives a sliding speed (V_S) in the range between 1 and 150 mm/s to the contact. A spectrometer was placed opposite side of the pin. Our spectrometer consists of a microscope, a CCD camera, and the transparent grating which can be inserted between the microscope and the camera for spectrum analysis: the grating makes dispersion of the light from the contact point on the CCD plane. The shorter limit of wavelength range is 350 nm due to the transmittance of the optical microscope and the longer limit is 1200 nm because of the sensitivity of the CCD.

Diffraction images taken by the CCD camera through the transparent grating (before correction of the sensitivity of the system) during friction between the diamond pin and the sapphire disk were shown in Fig. 2. The spectrum of the triboluminescence was measured separately for two regions. The diffraction image in Fig. 2 (a) was taken without an optical filter; the distribution of the

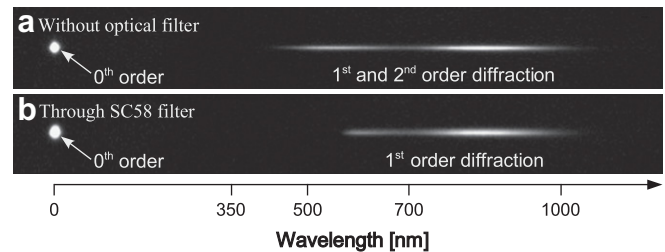


Fig. 2. Diffraction image of triboluminescence from the sliding contact between a natural diamond pin and a sapphire disk. Image (a) was taken without an optical filter and responsible for spectrum in the wavelength range between 350 and 700 nm. Image (b) indicates spectrum between 580 and 1000 nm by using a SC58 filter.

diffraction light between 350 and 700 nm is the first order diffraction of the light source. The optical long-path filter with a cut off wavelength of 580 nm (SC58) was used to remove the second order diffraction in the longer wavelength range (>700 nm) of a spectrum, which is shown in Fig. 2 (b).

The wavelength and the spectral sensitivity of the spectrometer in the range between 380 and 1000 nm were calibrated by a He–Ne laser and the thermal radiation from a tungsten hot filament at the color temperature of 2700 K. Resolution of the spectrum depends on the width of the contact area along the diffraction axis; it was typically between 12 and 40 nm in the present experiments.

3. Results and discussions

3.1. Friction between a diamond pin and a quartz disk

The spectra of light from the contact between a pin made of natural diamond with a radius of curvature of 0.3 mm and a synthetic quartz disk are shown in Fig. 3 (a). Two broad bands appear in the spectrum; a strong broad band at 900 nm and a weak broad band between 400 and 600 nm (see $\times 20$ spectrum in Fig. 3 (a)). The broad band at 900 nm may be regarded as thermal radiation suggested in our previous studies [3,5]. The measured distribution, however, is quite different from the Planck's formula. Moreover the shape of the spectrum was independent of the sliding velocity and the normal force as shown in Fig. 3 (a). The deviation from the Planck's formula and the independence of the sliding conditions implies that the thermal radiation is not a dominant component in the spectrum observed here. The broad band at 900 nm in the spectrum is likely solid luminescence caused by fracture.

The luminescence spectra during abrasive friction were measured using a sharper diamond pin (curvature of 0.01 mm) and a quartz disk. Fig. 3 (b) shows the developments of the spectrum in progress of sliding. The spectrum taken at the beginning of sliding (filled circles) shows a broad band at 900 nm, which is identical to the spectrum in Fig. 3 (a). A new band developed at 630 nm, while the broad band at 900 nm decreased. There was a visible scratch on the sliding track after this measurement. The fracture of the quartz surface due to scratch with the sharp diamond tip is the origin of the light emission at 630 nm, which likely relates to the non-bridging oxygen hole center (NBOHC) [15]. The fact that the broad band at 900 nm decreased after appearance of the peak at 630 nm suggests that wear of the diamond tip was reduced. This suggests that the light emission at 900 nm is caused by abrasion or fracture of the diamond.

3.2. Natural diamond

Triboluminescence of natural diamond was investigated in comparison with synthetic sapphire. Fig. 4 shows the spectra of the

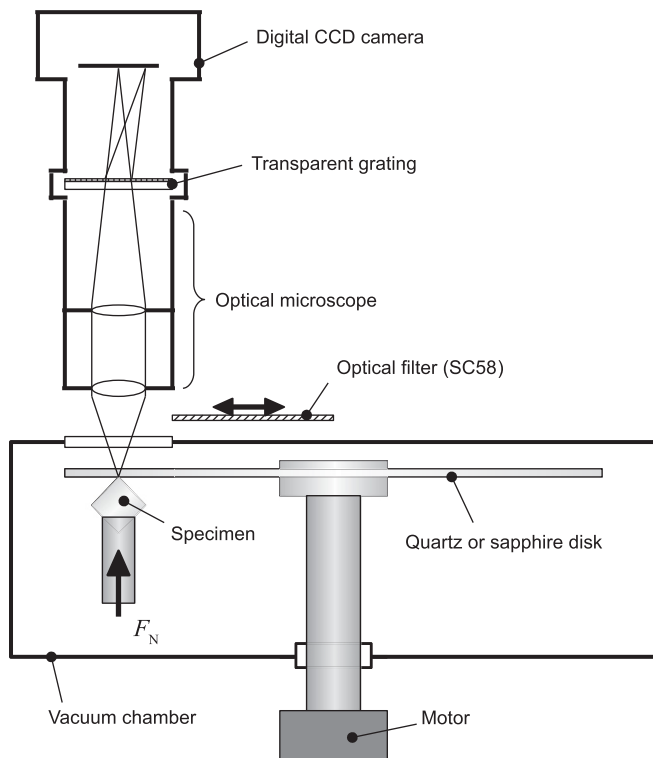


Fig. 1. Experimental equipment for triboluminescence spectroscopy.

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