

Plasma Spectroscopy of Sucrose Triboluminescence in Air and Hydrogen gas

空気や水素ガス中でのショ糖結晶の破壊に伴う発光のプラズマ分光計測

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We have observed emission spectra of triboluminescence caused by fracturing a sucrose crystal in air or a hydrogen gas. For the air experiment, we measure and analyze band spectra of the nitrogen molecule second positive systems to estimate rotational and vibrational temperatures of nitrogen molecules. For the hydrogen gas experiment, we measure and analyze line widths of hydrogen H α and H β emissions to estimate atom and electron densities.

1. Introduction

Luminescence produced by crystal fracture is called triboluminescence. Triboluminescence of a sucrose crystal is well known and has been observed for hundreds of years. Triboluminescence is thought to be caused by a gas discharge between a crystal crack. The mechanism of the discharge generation is, however, not fully clarified [1].

In an air discharge, it is known that an emission band of the nitrogen molecule second positive systems is observed [2]. From the shape analysis of the band spectra, rotational and vibrational temperatures of nitrogen molecules have been estimated [3]. The rotational temperature is known to be close to the air temperature [4]. On the other hand, in a hydrogen discharge, atom and electron densities have been estimated from the Lorentz width of the Balmer emission lines [5,6].

In this work, we observe and analyze high resolution spectra of triboluminescence generated when a sucrose crystal is fractured in air or in a hydrogen gas to estimate such plasma parameters.

2. Experiment

Figure 1 shows a schematic illustration of the experimental set-up. The apparatus is composed of fracturing and spectroscopic systems. In the fracturing system, we fracture a sucrose crystal by dropping a brass weight of 1.3 kg from 30 cm above the crystal. The system is connected to open air or a hydrogen gas cylinder from one side and to a vacuum pump from the other side for the purposes of exchanging the gas and adjusting its pressure.

We focus the triboluminescence on the entrance slit of a spectrometer (Jobin Yvon, HR640, focal length: $f = 640$ mm, 2400 grooves/mm) with a quartz lens ($f = 150$ mm). We record the emission spectra with an image intensified CCD camera (Roper Scientific, ICCD-576-LDS). We measure a single spectrum for a single weight drop.

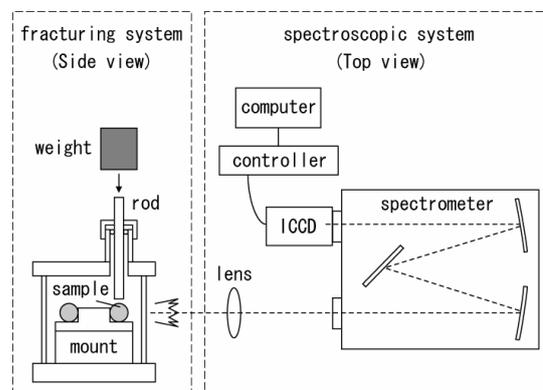


Fig. 1. A schematic illustration of the experimental set-up.

In the air triboluminescence experiment, we set the air pressure to be 0.0026, 0.026, 0.13 and 1.0 atm. We carry out 14 measurements for each air pressure.

In the hydrogen triboluminescence experiment, we also set the gas pressure to be 0.0026, 0.026, 0.13 and 1.0 atm. We observe H α and H β emission lines. We carry out 8 and 8 measurements for the H α and H β emissions, respectively, for a single gas pressure.

3. Results and discussion

Figure 2 (a) shows an example of the observed

nitrogen spectra at an air pressure of 1.0 atm. We fit the observed spectrum by the calculation with adjustable parameters of the rotational and vibrational temperatures [3,7-9]. The fitting is done for the results of 14 measurements at a single air pressure. We calculate the mean value of the temperature and estimate the error bar as the standard deviation from the 14 experiments. Figs. 2 (b) and (c) show thus estimated temperatures as a function of gas pressure.

The rotational temperature is about 400 K and its pressure dependence is not clearly observed. The vibrational temperatures at 0.026, 0.13 and 1.0 atm are about 1000 K, and are within the error bars. The vibrational temperature at 0.0026 atm is found to be much higher than the other cases.

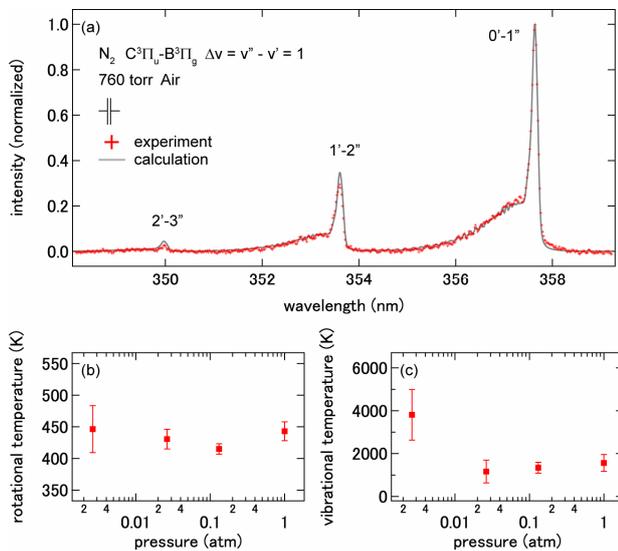


Fig. 2. (a) An example of the observed spectra of the nitrogen molecule second positive system at an air pressure of 1.0 atm. + : data points. The line is the fitted result. (b) Rotational and (c) vibrational temperatures of nitrogen molecules as a function of the gas pressure.

For the experiment of the hydrogen triboluminescence, we show the results only for 0.026 atm because the emission intensities were too weak for the spectral shape to be analyzed at 0.13 and 1.0 atm and the spectra at 0.0026 and 0.026 atm were similar to each other. Figs. 3 (a-1) and (b-1) show examples of the observed H α and H β spectra, respectively, for a single weight drop. Since the scatter of the data point is large, we average over 8 spectra to analyze the line profile. Figs. 3 (a-2) and (b-2) show the results for the H α and H β lines, respectively.

We fit the spectra with a Voigt function to estimate the Lorentz width of the H α and H β lines. The fitted results are shown by the curves in Figs. 3 (a-2) and (b-2). We assume that the Lorentz width is

mainly caused by atom collisions and Stark effect, and that the electron temperature is 40000 K [10]. The width due to atom collisions is related to the hydrogen atom density, n_a [11], while that due to Stark effect is related to the electron density, n_e [12]. From these relations different for the H α and H β lines, we estimate n_a and n_e to be about $3 \times 10^{24} \text{ m}^{-3}$ and about $4 \times 10^{19} \text{ m}^{-3}$, respectively.

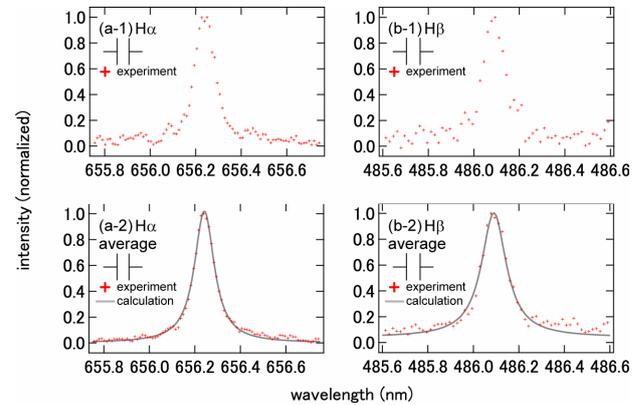


Fig. 3. Examples of the observed (a-1) H α and (b-1) H β spectra at a hydrogen gas pressure of 0.026 atm. The average of 8 spectra of the (a-2) H α and (b-2) H β lines. + : data points. The lines are the fitted results.

Acknowledgments

This work was partly supported by Grant-in-Aid for Scientific Research (B) (No.21340170).

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