Spectroscopy of Plasma Produced in a Kitchen Microwave Oven

Yamato Ueno[1,2], Ryo Yasufuku[1,3], and Syuji Miyazaki[1,4*]

[1] *ELCAS, Kyoto University, Kyoto 606-8501, Japan*
[2] *Kouyou Junior & Senior High School, 127 Ohta, Wakayama 640-8323, Japan*
[3] *Hyogo Prefectural Nagata Upper Secondary School, 2-5 Ikeda-tanimachi, Nagata-ku, Kobe-shi, Hyogo 653-0821, Japan*
[4] *Graduate School of Informatics, Kyoto University, Kyoto 606-8501, Japan*
**E-mail address: miyazaki.syuji.8m@kyoto-u.ac.jp*

(Received September 29, 2021; Accepted December 7, 2021)

Conducting thin rods with a length of half the wavelength of microwaves produced by the kitchen microwave oven, such as dress pins or mechanical pencil leads, absorb microwaves efficiently. Electrons in rods accelerated by microwaves are emitted from both ends of the rods, collide with surrounding gas molecules, and create plasma. Spectra with a single bright emission line at a wavelength of about 587 nm in the visual light range were observed, regardless of the material the rod was made from.

Key words: Microwave, Plasma, Brightline spectrum

1. Introduction

In the framework of the Experience-based Learning Course for Active Students, abbreviated as ELCAS, at Kyoto University, two high-school students, Yamato Ueno and Ryo Yasufuku, under supervision of Syuji Miyazaki, performed advanced studies that do not follow the curriculum guidelines of high schools set by the Ministry of Education, Culture, Sports, Science and Technology. One of the other advanced studies has been already reported (Maeda-Miyazaki, 2019). A related topic was also considered (Miyazaki, 2019).

A kitchen microwave can be used as an educational tool under comprehensive guidance and supervision by a teacher. The application of microwaves to a disk such as CD, DVD, BD, or a compact mirror instantaneously yields a branching electric discharge also called the Lichtenberg figure, as shown in Fig. 1. Small neon tubes placed inside a glass of water on the microwave oven turntable blink on and off, which indicates the position of the nodes and antinodes of standing microwaves, as shown in Fig. 2. The model number of the neon indicator lamp is SNL0197, RS Components, whose lead wires are cut off. Water is poured into the glass in order to maintain a temperature below 100 degrees Celsius. Since the water boils in a short time, the water surface is agitated and unclear. The depth of water is about 1 cm. Much larger volume of water makes it difficult for microwaves to reach and turn the small neon tubes on.

The frequency of the Japanese kitchen microwave is $f = 2.45$ GHz, and the propagation speed of microwaves is approximated by light speed in a vacuum $c = 3 \times 10^8$ m/s. Thus, the wavelength λ is estimated to be $\lambda = c/f = 12.2$ cm. The distance of microwave oven's standing waves between neighboring nodes or antinodes is equal to $\lambda/2$, which is also nearly equal to the length of a mechanical pencil lead or a marking pin, which reminds us of a half-wave dipole antenna.

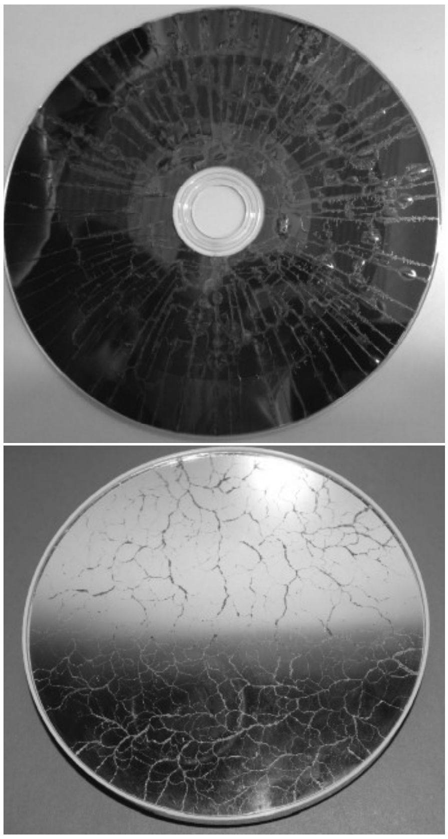

Fig. 1. Lichtenberg figures. (Upper) Blu-ray Disc (BD). The recording surface has a concentric pit structure, such that discharge occurs mainly in radial and angular directions. (Lower) Compact mirror. The reflecting surface is uniform, such that branching or fractal discharge occurs.

The door of the kitchen microwave usually has a window for ease of viewing, with a layer of conductive mesh some

doi:10.55653/forma.2022.001.001

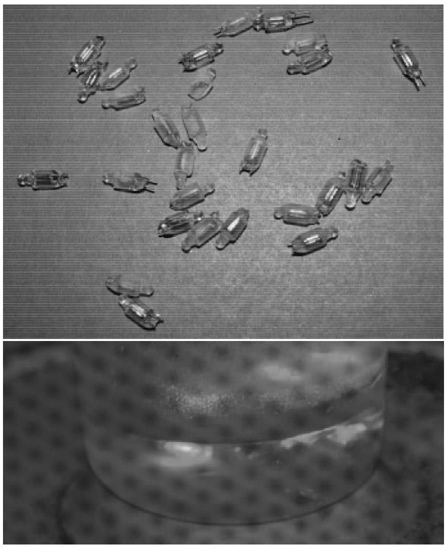

Fig. 2. (Upper) Small neon tubes, whose lead wires are cut off. (Lower) Small neon tubes in a glass of water blink on at antinodes of standing microwaves, and blink off at nodes in a kitchen microwave.

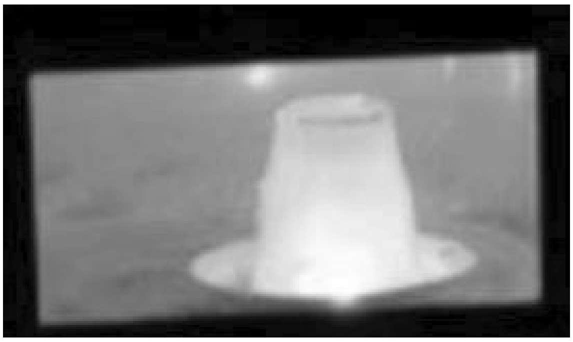

Fig. 3. Plasma produced in a kitchen microwave oven.

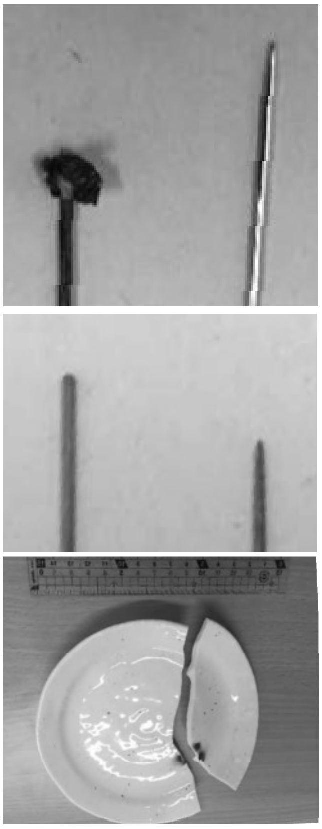

Fig. 4. High-temperature effects on the rod and container. (Upper) Both ends of the pin before (right) and after (left) the experiments. The latter is melted and deformed. (Middle) Both ends of the lead before (left) and after (right) the experiments. The latter is sharpened. (Lower) A ceramic plate, that has direct contact with the rod, may break into pieces. The length of the ruler is about 15 cm.

distance from the outer panel to maintain shielding. Because the size of the perforations in the mesh is much less than microwaves' wavelength, microwave radiation cannot pass through the door, while visible light can due to its much shorter wavelength. Tatsuo Shoji (Nagoya University at that time) conducted the following experiment. After the outer panel was detached, a piece of straight conductive wire was inserted through a hole in the mesh at a right angle. At an insertion length of half the wavelength, the end of the wire started to spark. As the insertion length became longer, it stopped sparking. As shown in the next section, conducting thin rods with a length of half the wavelength of the kitchen microwave, such as dress pins or mechanical pencil leads, create plasma.

In the second section, we describe an experiment. In the third section, we present our spectroscopy data. The final section is devoted to concluding remarks.

2. Experiment

We use a 700-watt kitchen microwave as a microwave generator (magnetron). A rod, such as a mechanical pencil lead or marking pin, whose length is nearly equal to half the wavelength of standing microwaves, absorbs microwaves well. We put the rod on a ceramic plate, and cover it with a see-through glass. The electrons inside the rod are considered to be resonantly excited, and emitted from both ends of the rod, which can leave nitrogen or oxygen molecules ionized. As a result, we can observe very bright visible light, as shown in Fig. 3.

Plastic cups and plates should not be used as they may melt. High-temperature effects on the rod and container are shown in Fig. 4. The use of a heat-resistant container is necessary for safe plasma confinement. It is recommended to prepare sand or a ceramic chopstick rest, *hashioki* in Japanese, on the plate, to avoid direct contact between the plate and rod. In the case of sand, plasma production increases pressure in the container, and sand particles and air are forced through the narrow space between the plate and rim of the glass, contaminating the whole plate. Thus, it may be more appropriate to use a ceramic chopstick rest. The discharge causes a particular odor after the experiment, which will be described later.

3. Spectroscopy

The bright light was analyzed using the following spectral apparatus: Spectrometer KNK 0068B-02-003 manufactured by LLP Kyoto Nijikoubou (`http://www.kyoto-nijikoubou.com/`). The wavelength resolution $\Lambda/\Delta\Lambda$ was 300. The light emission

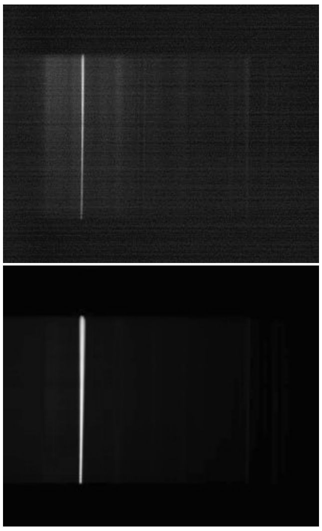

Fig. 5. CCD images of the pin (upper) and lead (lower) obtained from the spectrometer.

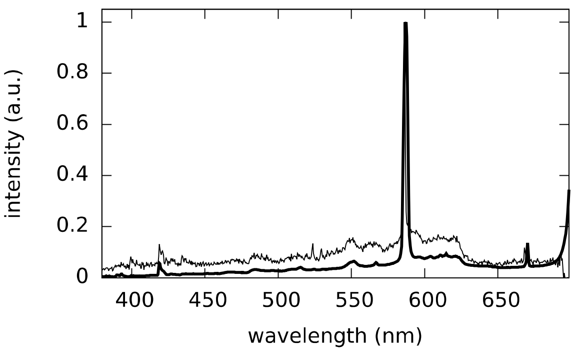

Fig. 6. Spectroscopy data of the pin (thin line) and lead (thick line).

was transformed to digital data through a charge-coupled device (CCD). The CCD images are shown in Fig. 5.

As shown in Fig. 6, the spectra were obtained using the above-mentioned spectroscope after the wavelength calibration had been adjusted.

4. Concluding Remarks

In the second section, we mentioned a particular odor after the experiment, which signifies the emission of a low concentration of ozone. If ozone and nitrogen oxides are produced from nitrogen and oxygen molecules in the air during the experiment, molecular spectra attributed to chemical reactions or excitations of these molecules may be observed. The intensities of the two background spectra shown in Fig. 6 behave as a function of the wavelength in a similar manner. Based on the table of persistent band heads of molecular spectra (Pearse-Gaydon, 1976), the nitrogen-molecule or nitrogen-ion related wavelengths are 670.48 (N_2, the first positive band), 557.48 (N_2), and 428.81 (N_2^+, the first negative band) nm. These values are similar to those of the wavelengths at the small local peaks at 669, 551, and 421 nm shown in Fig. 6, respectively. There are still many uncertainties regarding the origins of this background spectra.

A single bright emission line at a wavelength of 586.0 (587.8) nm for the lead (pin) in the visual light range was observed. Since the wavelength resolution $\Lambda/\Delta\Lambda$ is equal to 300, a measurement error around 600 nm is estimated as 2 nm. We conclude that the positions of the bright line are independent of the material the rod is made from. The origins of the single bright line as well as background spectra are open questions. These are good themata for advanced studies of high-school students.

A single-layer recording surface of a DVD or BD can be used for diffractive grating, whose wavelength resolution, $\Lambda/\Delta\Lambda$, can be larger than 300. It is also a good task for high-school students to construct a high-resolution spectroscope consisting of a DVD or BD.

Acknowledgments. We thank Tatsuo Shoji for introducing us to various experiments using a kitchen microwave oven, and Hitomi Kobayashi for technical support based on knowledge of spectroscopy. We also thank ELCAS of Kyoto University (`https://www.elcas.kyoto-u.ac.jp/`), Hirameki Tokimeki Saiensu of the Japan Society for the Promotion of Science (`https://www.jsps.go.jp/hirameki/`), and Kansai Kagakujuku (`http://www.kansai-kj.org/`) for financial support.

References

Maeda, Y. and Miyazaki, S. (2019) Spectroscopy of Hydrogen, Helium, Neon and Mercury Low-Pressure Discharge and a Barcode-like Periodic Table Based on Energy Levels, *Forma* **34**, 1–3.

Miyazaki, S. (2020) A Pale View of Shizuo Ishiguro's Research –Abiki, the 1953 North Sea Flood, and Beyond– *Forma* **35**, 37–39.

Pearse, R. W. B. and Gaydon, A. G. (1976) The identification of molecular spectra 4th edition, Chapman and Hall.