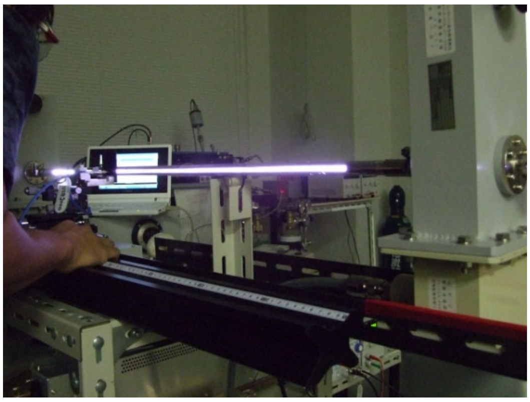
Introduction of Plasma Engineering Laboratory

Laboratory Director: Prof. **Akimitsu Hatta**, (Dr. Eng.)
Department of **Electronics and Photonics** Systems Engineering
School of Systems Engineering
Kochi University of Technology

At the Plasma Lab, we work on the generation, control and application of gas discharge plasma. Plasma is called the 4th state of matter. When the energy state of matter increases, it changes from a solid to a liquid, to a gas, and when the energy state increases further, the gas molecules are ionized into electrons and ions to become plasma.

High-energy plasma states are generated by gas discharges. By controlling the pressure and flow of the gas and supplying electrical energy through an electromagnetic field or electromagnetic waves, the gas molecules are ionized and become plasma.

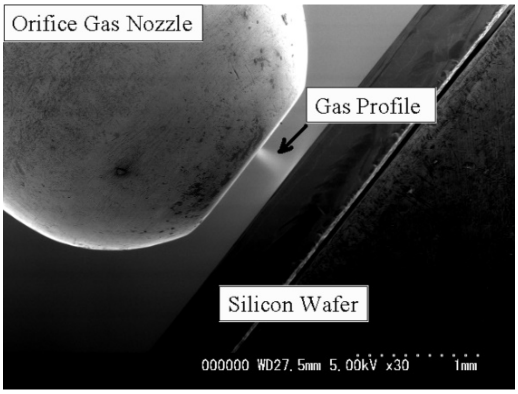


High energy states, especially low temperature plasmas where only the electron temperature is high, are widely used. Excitation and emission by high energy electrons is used in discharge lamps such as fluorescent lamps and ultraviolet lamps, chemical reactions by high energy electrons are used in the dry process of semiconductor manufacturing, and also as a surface treatment technology for various materials[4]. Plasma generated in the atmosphere is expected to have new applications in biomedical and medical fields. Plasma nuclear fusion research is being conducted using large plasma devices, and it is expected to become a future energy source for mankind. At the PlasmaLab, we develop small laboratory-sized plasma equipment and explore new fields of application, as follows.

1. Development of novel plasma generation and control technologies

Three elements are important for generating gas discharge plasma: a method for supplying the discharge gas, a method for supplying electrical energy, and a mechanism for generating and maintaining the discharge. While various methods for supplying electrical energy, such as high-voltage pulses and high-frequency electromagnetic waves, are widely used, there are few variations in the method for supplying the discharge gas, and there have not been many novel challenges. At the Plasma Lab, we are challenging ourselves to develop unique methods for supplying the discharge gas and novel mechanism of gas discharge, aiming for new applications.

(1) Plasma in SEM



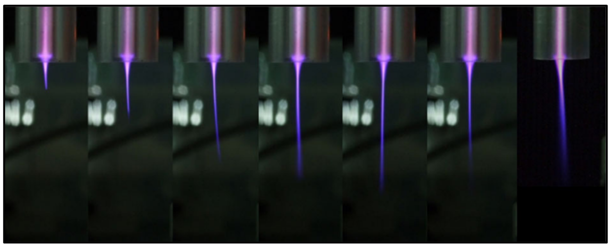
Inside the chamber of a scanning electron microscope (SEM), which must be kept at a high vacuum, a discharge plasma can be generated by a local gas supply while the electron microscope is in operation, and the plasma can be irradiated onto the sample being observed. [8]

(2) Plasma in the deep sea

For in-situ analysis of seawater composition, plasma is generated under a pressure of 20 MPa, which is equivalent to a depth of about 2000 m in the ocean. Small steam bubbles are generated by impulse current, and discharge plasma can be generated inside the bubbles. [7]

(3) Plasma in the atmosphere

Helium gas is effective for atmospheric pressure discharge because it can maintain a stable discharge. Since helium gas rapidly diffuses into the atmosphere and mixes with the ambient air, it is important to supply the gas in a laminar flow in the atmosphere. With a laminar gas supply, the atmospheric pressure plasma jet can be easily extended. [6]



(4) Photoemission induced plasma

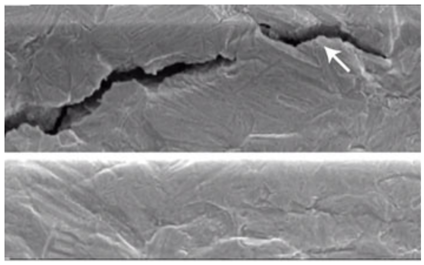
Most plasmas are generated by a gas discharge mechanism called glow discharge. Discharge by photoelectron current from a photocathode is expected to be a novel gas discharge mechanism that can generate a stable discharge under a wide range of conditions, regardless of the type of gas or pressure. Unlike glow discharge, the electron temperature and electron density, which are important for controlling plasma reactions, can be controlled independently by the photoelectron current density and the strength of the electric field. [3]

2. Development of new plasma application fields and plasma reaction control methods

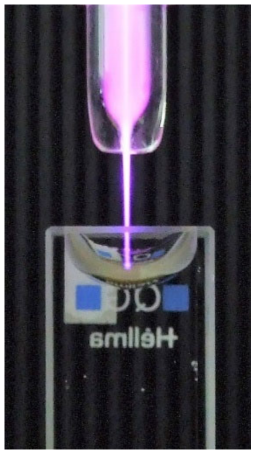
Plasma is characterized by its extremely high electron energy, which makes it easy to induce chemical reactions and excite substances. If stable plasma can be generated in the atmosphere, it is expected to be applied in a variety of fields, including biology and medicine. Each application requires ingenuity in how to utilize the electron energy and how to process materials and targets.

(1) In-situ observation of hydrogen embrittlement

Hydrogen embrittlement, in which metals become brittle when exposed to reduced pressure



hydrogen gas, remains a challenge in hydrogen energy technology. Hydrogen embrittlement, which occurs over a long period of time in high pressure hydrogen gas, can be reproduced in a short period of time using atmospheric or low pressure plasma treatment. It is now possible to observe and analyze the hydrogen embrittlement process in real time, and it is expected that the mechanism of hydrogen embrittlement will be better understood. [1]



(2) Plasma treated water

When water is exposed to plasma in the atmosphere, large amounts of reactive substances containing oxygen and nitrogen are produced. The products in the water can be monitored in real time using ultraviolet absorption spectroscopy. It is expected that specific active substances can be selectively controlled by changing the plasma generation method and irradiation conditions. The results of analysis of plasma-treated water provide many insights into the effects of plasma irradiation on living animals and plants. [2, 5]

3. Energy and environmental education using electrical and electronic circuits

As part of our contribution to society based on our research results, the Plasma Lab is also working on energy and environmental education using power control circuits. We are applying the high-voltage switching circuit technology required for discharge circuits. We have developed a highly efficient bicycle-type human-powered generator, which we provide to schools as a teaching material to help students experience that one person's power is about 100W.

Recent Publications

[1] Rev. Sci. Instrum. 94 (2023) 023707.
[2] Plasma 6 (2023) 103.
[3] Appl. Phys. Express 15 (2022) 116001.
[4] Materials Chemistry and Physics 282 (2022) 125974.
[5] Plasma 5 (2022) 233.
[6] Appl. Phys. Express 12 (2019) 036001.
[7] IEEE Transactions on Plasma Science 47 (2019) 1841.
[8] Micromachines 8 (2017) 211.