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Development of Temperature Controllable Atmospheric Plasma Jet Source
温度可変プラズマジェットの開発

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Atmospheric pressure plasma source in which the gas temperature of the plasma can be accurately controlled from below freezing point up to a high temperature have been developed. In it, the gas that is to be supplied to the plasma generator is first cooled by using a gas cooler and then heated by a heater. The temperature of the produced plasma is measured, and feedback is sent to the heater. Thus, plasma at a desired temperature can be generated. Gas temperature control of the plasma over a range from −28°C to +150°C with a standard deviation of ± 0.8°C was realized.

1. Introduction

Atmospheric pressure plasma does not require a vacuum chamber; therefore, processes can be performed continuously, the plasmas can be generated at higher densities than conventional low-pressure plasmas, and living bodies and large objects that cannot be put in a vacuum chamber can be processed. Consequently, benefits such as higher speed processing, lower costs, and a wider range of processing subjects are available. In particular, because the production of atmospheric pressure plasma at low temperatures—from room temperature to around 100°C—has been feasible for a number of years, there has been increasing use of atmospheric plasma in industry. [1] For example, the surfaces of semiconductors can be cleaned and hydrophilized by oxygen included plasmas; [2] oxide surfaces on metal can be removed with hydrogen included plasmas; [3] and plasmas have been used for sterilization, surface coating, and so on. [4,5]

Processing of materials that are sensitive to temperature, such as living bodies and polymer materials is difficult. In addition, most kinds of plasma processing are chemical reactions with radicals or high reactive spices, so that there are suitable temperatures for each process.

The conventional atmospheric plasma source shown in Fig. 1 generates plasma by an electrical discharge through a gas supplied at around room temperature, so the gas temperature of the generated plasma is somewhat higher than room temperature. When there is a need to suppress the temperature rise, a technique such as limiting the discharge power or increasing the gas flow rate is used. However, the energy per unit volume provided to the plasma is reduced by these techniques, and processing effectiveness of the produced plasma decreases.

In the developed temperature controllable plasma source, shown in Fig. 2, gas supplied from a cylinder is cooled by a gas-cooling device that uses liquid nitrogen (−196°C), after which the gas is heated to a desired temperature by a heater, and

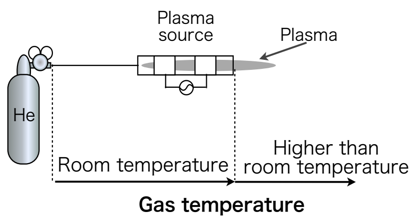

Fig. 1. Conventional atmospheric plasma source

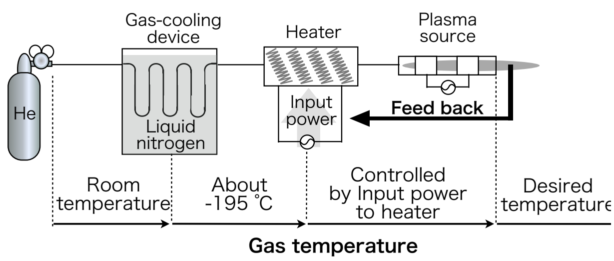

Fig. 2. Temperature controllable atmospheric plasma source

then plasma is generated. Feedback on the gas temperature of the generated plasma is sent to the heater, and the gas temperature of the plasma can be controlled to the desired value.

2. Experimental

In testing, helium plasma was generated. The flow rate of the helium gas was 10 slm, ring-shaped copper electrodes spaced 10 mm apart were provided at the periphery of a glass tube with 3 mm i.d. and 5 mm o.d., 9 kV electric power at 16 kHz was applied, and thus a plasma bullet was generated. Before generating plasma, the gas temperature was 22℃. After generating plasma, the gas temperature raised up to 36℃. From heat capacity of helium and temperature change, calculated power to heat plasma was 2.1 W.

3. Result and Discussion

Figure 3 shows the relationship between the input power to the heater and the gas temperature of the generated plasma. The gas temperature was measured with a thermocouple. When the heater was not used, the plasma gas temperature was −28°C. The gas temperature rose by heat loss between the gas-cooling device and the plasma source. When a water droplet was irradiated with this plasma, it was frozen in 10 seconds. As the input power of the heater was raised, the plasma gas temperature rose linearly, rising to 150°C at 84 W. Thus, with the device we have developed, by feedback of the temperature to the power applied to the heater, control of the plasma gas temperature over a range from −28°C to 150°C with a standard deviation of ±0.8°C was achieved. Figure 4 shows the relationship between the plasma gas temperature and the helium excitation temperature. The excitation temperatures were measured using Boltzmann's plot from a spectrum of 402.62 nm, 492.19 nm, 501.57 nm and 587.56 nm. The excitation temperatures were 3,600°C to 4,900°C higher than the gas temperatures. Thus, it was confirmed that the generated plasma is a kind of non-equilibrium plasma.

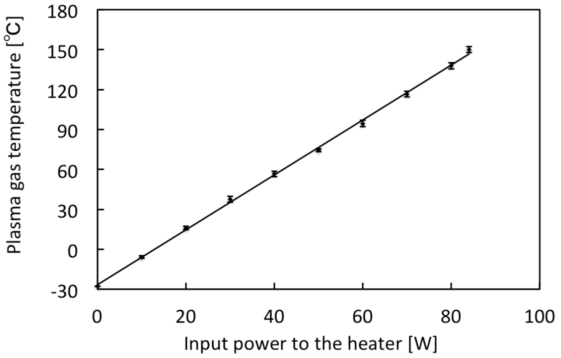

Fig. 3. Relationship between power applied to heater and plasma gas temperature

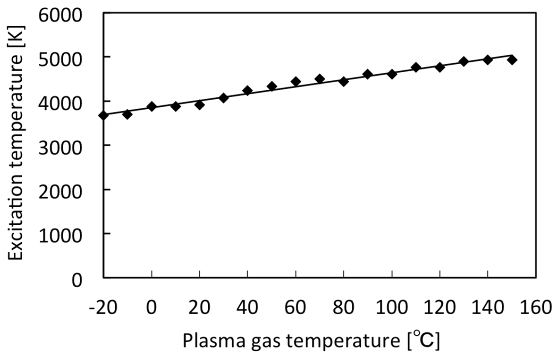

Fig. 4. Relationship between plasma gas temperature and helium excitation temperature

4. Summary

Atmospheric pressure plasma source in which the gas temperature of the plasma can be accurately controlled from below freezing point up to a high temperature have been developed. By it, Gas temperature control of the plasma over a range from −28°C to +150°C with a standard deviation of ± 0.8°C was realized.

With this plasma source, all kind of materials can be irradiated by the plasma that are weak in temperature rise, and the plasma irradiation can be performed under the optimum temperature for the process requires. As a result, plasma irradiation of materials with low melting points, which are difficult to treat with conventional devices, is possible.

Acknowledgments

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