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Atmospheric Pressure Micro Inductively Coupled Plasma Light Source towards Portable Spectrometry System

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1. Introduction

Miniaturizing plasma source is required in various fields such as material processing, chemical analysis, medical/biological treatments, *etc*. Plasma light source is one of promising applications. For example, inductively coupled plasma (ICP) is used for optical emission spectrometry, which is one of highly sensitive methods that can detect inorganic materials contained in samples. The size of typical desktop ICP source is several cm in diameter. Power supply is several tens of MHz and consumes ~1kW. The light emitted is used for the spectrometry. However, most of the light is screened at the entrance slit (open width: ~10μm) of the spectrometer without the usage. Miniaturizing light source to fit the plasma region into the slit shape can improve the optical efficiency and make the setup compact. Concentrating the input power in the small volume can increase the power density saving the input power. The bulky and high power supply system does not match with the portable system.

Now, microplasma gathers attentions because it is localized high-density plasma [1-4]. Microplasma is usually generated under atmospheric pressure condition. Following the Paschen's low, plasma generation is characterized with the parameter of product of pressure *P* and characteristic length *d*. In the case of low pressure plasma, which is used in semiconductor device fabrication, *P* is 1–10Pa and *d* is 0.1–1mm. When *P* increases to atmospheric pressure (~101kPa), *d* becomes 10–100μm. In addition, plasma generation under atmospheric condition achieves electron density of $10^{13}\sim10^{18}\mathrm{cm}^{-3}$ even if the ionization ratio is low (cf. conventional low pressure ICP: $10^{12}\mathrm{cm}^{-3}$) [3]. Such density is advantageous to achieve high density optical fluxes.

In this study, a new micro-ICP light source is fabricated toward portable spectrometry system. Basic characteristics of plasma ignition, spectra of micro-ICP, and durability are investigated.

2. Design of micro-ICP Light Source

Figure 1 shows design of our micro-ICP light source. U-shape Cu electrode is obtained by milling glass epoxy substrate. This structure can play roles of a center trench for flowing gas and an ICP antenna coil. Thin metal wire is set in the trench. The cover glass on U-shape Cu electrode is for making the channel and for obtaining emission light. 100MHz power supply is for decreasing collision loss of electrons at the trench surface. When high frequency current flows in U-shaped Cu electrode of ICP coil, magnetic field is induced around the coil. The metal wire in the trench is activated by inductive coupling. Thermal electrons are supplied for plasma ignition. In this optical layout, the line profile of the optical emissions normal to the substrate is hardly affected by the self-adsorption because the plasma thickness is thin. This is ideal for the light source. Moreover, this linear and planar structure can fit with the slit-shape of the spectrometer. The emitted light can couple with the spectrometer with high efficiency. This planer device structure can be placed on the cooling plate with high thermal conduction.

3. Fabrication

A glass epoxy substrate (FR-4) with bothside Cu films (t: ~35μm) is patterned by milling machine. In specification, glass epoxy substrate can bear 260°C for more than 60s. The length and the width of U-shape Cu electrode are 50mm and 9–20mm, respectively. The center trench is 1.5mm in width and 1.2mm in depth. The volume of the trench is ~0.1ml. U-shape Cu electrode is soldered with Cu thin plates and connected with a high frequency power supply.

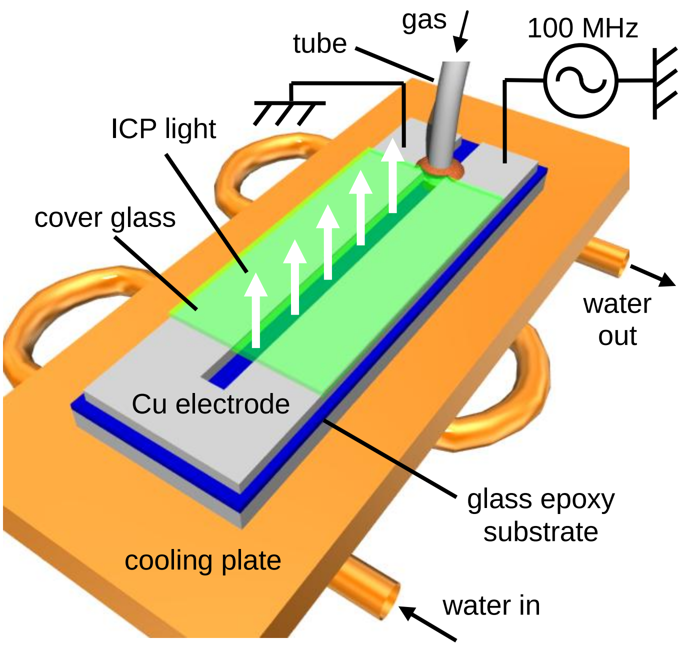

Fig. 1: Schematic drawing of micro-ICP light source.

4. Results and discussions

Micro-ICP light source is set on a water cooling plate. He gas is first introduced in the trench at 1.2L/min for ignition. He plasma is ignited at ~18W. At 35W, plasma spreads over the whole trench as shown in Fig.2(a). Using He gas and thin metal wire, this micro-ICP source does not require an external igniter (*ex.* high voltage DC power supply). This is important for using plasma source inside the system. Once stable He plasma is obtained, changing the gas is easy. He is gradually replaced with Ar. The optical emissions changes to the more brilliant state (Ar flow: 0.6L/min, Fig. 2(b)).

Spectrum of the He micro-ICP is shown in Fig. 3. Sharp peaks are observed. Besides the lines of He, the lines derived from O and OH are observed. Since O is contained in the glass epoxy substrate, it is reasonably understood that O is emitted from the trench surface exposed to the plasma. Figure 4 shows time variations of the line intensities. After the ignition, intensities of O lines increase during first 20 min and then saturate. Intensities of He lines continue to increase. In the similar experiments of Ar micro-ICP, intensities of O and Ar lines continue to increase.

Temperature of the micro-ICP light source is observed with thermography. During the ICP discharge, temperature of the cover glass plate reaches ~90°C. After 10min ICP discharge, the surface of the ICP light source becomes ~60°C while backside becomes ~55°C. These temperatures are much smaller than the maximum heat-resistive temperature of the glass epoxy substrate (260°C). The bottom surface of the trench is observed before and after ICP discharge (Figs. 5(a) and 5(b)). The trench surface shows little damage even after total discharge time of 5h (Fig. 5(b)). It is noted that the size of the demonstrated micro-ICP is limited by the resolution of the milling machine, not by the physical law. With the micro-ICP light source with Si microstructure, the device performance will be improved enhancing higher power density.

5. Summary

Micro-ICP light source is fabricated by milling glass epoxy substrate. Demonstrated minimum size of U-shape electrode is 9mm in width and 50mm in length. Micro-ICP is generated at RF power of ~35W with He and Ar gas flow. Micro-ICP shows O and OH peaks in addition to He or Ar sharp peaks. The micro-ICP light source has durability for more than 5h operation.

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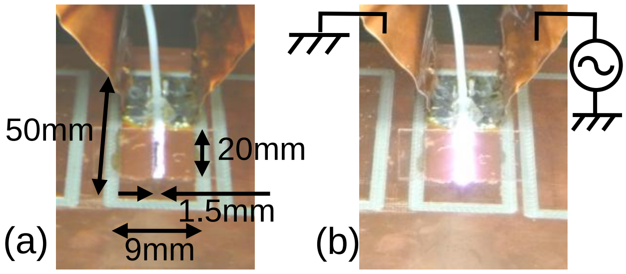

Fig. 2: ICP emission with (a) He and (b) Ar gases.

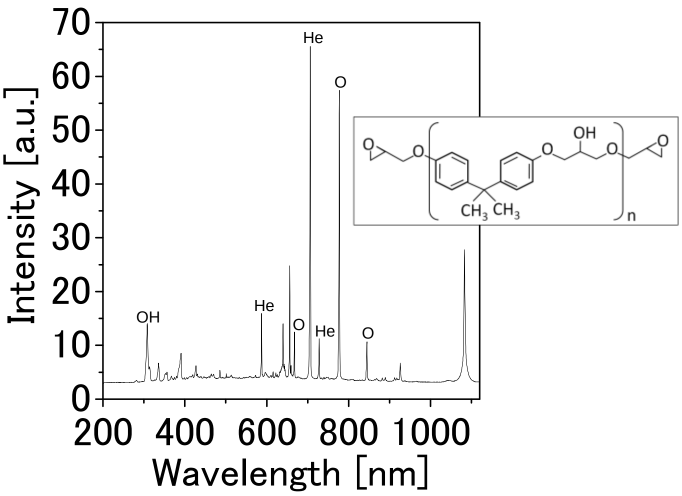

Fig. 3: Emission spectrum of micro-ICP of He. RF power: 40W. Inset is molecular structure of epoxy resin.

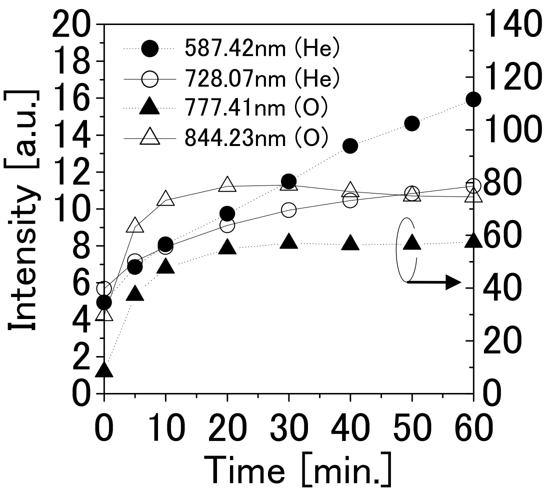

Fig. 4: Time variation of intensities of emission peaks.

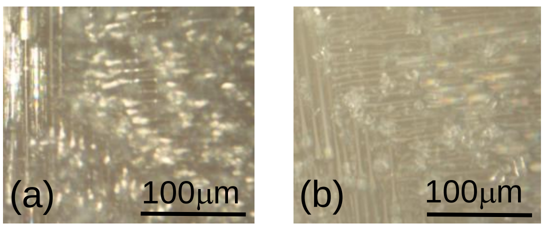

Fig. 5: Trench bottom surfaces (a) before and (b) after 5h discharges.