Effect of Micro Hydrodynamic Flow in Microgap Discharge at Atmospheric Pressure

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The effect of gas flow on the characteristics of a microgap discharge was investigated experimentally. In a gap length of 0.7 mm, the spatial structure and spectrum of light emitted from the discharges in helium gas were observed to be changed with the gas flow velocity. The transition of the discharge from a transversally uniform structure to a silent discharge structure in a high flow velocity region is found to be caused by air contamination in the gas flow channel. The edge effect on the transition is confirmed from the light emission pattern of the discharge.

Keywords: micro plasma, dielectric barrier discharge, gas flow, discharge transition

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Microgap dielectric barrier discharges at atmospheric pressure change from a traversally homogeneous structure to a silent discharge type with decrease in the electrode space. It is known that the discharge transition is caused by edge effect [1]. With the introduction of a gas flow along the surface of dielectrics orthogonal to the electric field, the discharge mode is prone to change from a silent discharge to a transversal homogeneous discharge due to the edge effect [2]. When the gas is introduced into the microgap, the average flow velocity of the gas increases due to the narrow microchannel sectional area. Beskok and Karniadakis [3] give the range for the Knudsen number in a slip-flow regime as K_n = 0.001-0.1. With regard to the microchannel, the gas flow in the region where the microgap dielectric barrier discharge is generated is complex, because the Knudsen number reaches a value close to the lower boundary of K_n = 0.001. In this study, the influence of gas flow on the transition of the microgap dielectric barrier discharge at atmospheric pressure and the role of nitrogen and oxygen contamination from the atmosphere are investigated.

Figure 1 shows a schematic diagram of the microgap, which consists of a powered electrode, upper dielectrics, a spacer, lower dielectrics, and a grounded electrode. A cover glass (Matsunami: micro cover glass No. 1, relative permittivity 6.7, and thickness 0.14 mm) was used as the barrier dielectrics and the spacer. An indium tin oxide (ITO) film deposited on the barrier dielectrics is used for the powered electrode to observe discharge configuration. The gap length, gap width, and channel length are 0.7 mm (5 cover glasses), 5 mm, and 24 mm, respectively. A buffer area is installed upstream of the microgap, and gas is introduced into the buffer using a syringe with a stainless needle. The downstream is open ended, and helium is released directly to the atmosphere. Helium gas with a purity of 99.9999 % is used in the experiment, and a flow rate is measured by a purge flow meter (KOFLOC). The bottom electrode is grounded, and the top electrode is connected to a 100 kHz RF source. The applied voltage and current are monitored by a digital oscilloscope (Tektronix TDS3054B) through a high-voltage probe (Tektronix P6015A) and Rogowski coil (Pearson CT2877), respectively. A photomultiplier tube (Hamamatsu 1P28) and an optical emission spectrometer (Ocean Optics USB2000) are used to measure the light emitted from the discharge.

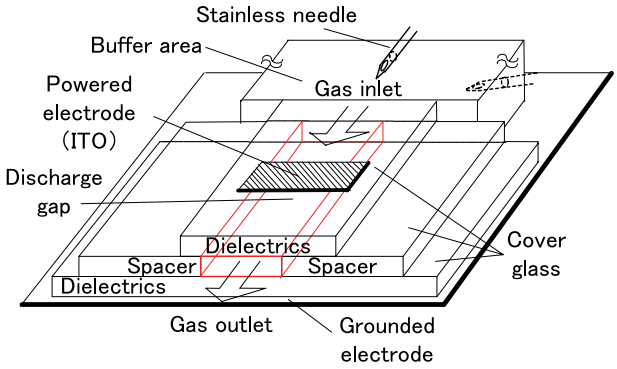

Fig. 1 Schematic diagram of microgap.

Figure 2 shows typical photographs of discharge patterns at different gas velocities under the condition of a constant applied voltage of 800 V. The variation of colors in the emission appears according to the flow velocity of gas ((a) and (c):blue, (b):red). For instance, the color change from blue to red appears when the flow velocity and applied voltage are 0.48 m/s and 800 V, respectively, and that from red to blue is observed when the flow veloc-

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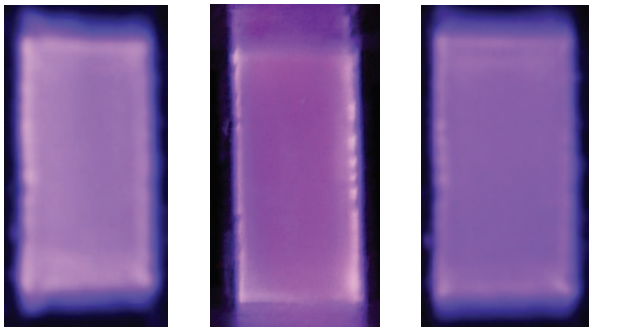

Fig. 2 Plasma pattern in change of gas flow velocity (800 V).

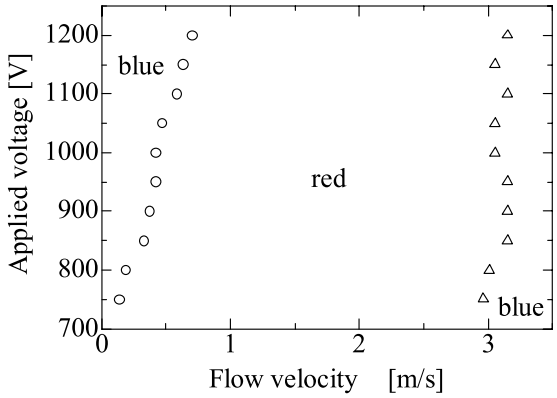

Fig. 3 Phase diagram of the emission transitions in parameter space of flow velocity-applied voltage.

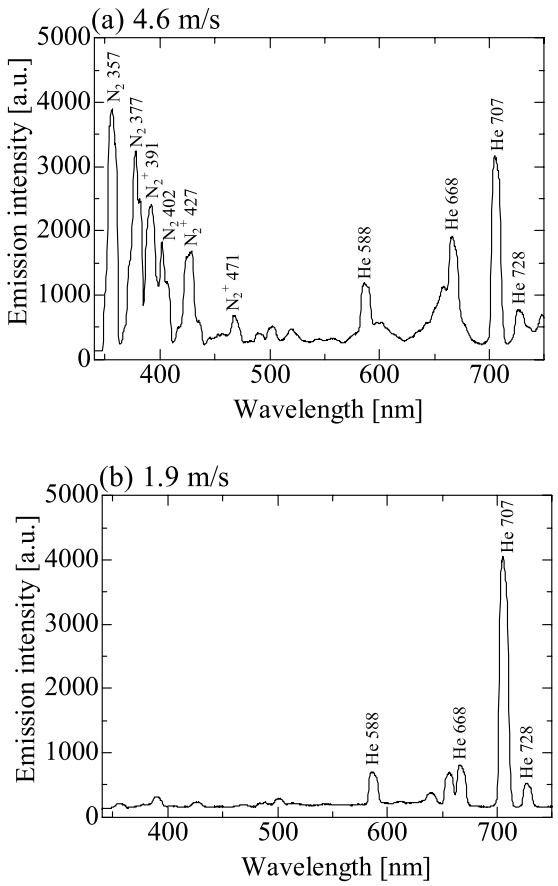

Fig. 4 Current waveform and PMT output in change of gas flow velocity.

ity and applied voltage are 2.9 m/s and 800 V, respectively. In the blue mode, a thick blue emission appears around the electrode edge. The discharge area begins to shrink when the flow velocity decreases below 0.48 m/s. In the range where the flow velocity is much larger than 2.9 m/s, the discharge pattern becomes unstable and a "no-discharge" area appears.

Figure 3 shows the phase diagram of the emission transitions in the parameter space of flow velocity -applied voltage. The gap width and gap length are 5 mm and 0.7 mm, respectively. With regard to the transition from blue to red on the left side, the critical flow velocity increases with the applied voltage. In this region, a smaller flow velocity leads to the shrinking of the discharge area. On the other hand, the critical flow velocity of the right transition line depends very little on the applied voltage. In the right blue region, the discharge pattern becomes unstable when the flow velocity is large. When the orientation of the injection needle that introduces helium gas into the buffer area is changed, the critical velocity of the right transition line is affected, whereas that of the left one is not. This fact indicates that the transition in the range of high flow velocity is caused by the state of gas flow.

Figure 4 shows the spectrum of optical emission at each flow velocity. When flow velocity is 1.9 m/s, the intensity of the wavelength region in the vicinity of 700 nm (He) in the spectrum is large. A similar characteristic as this spectrum is obtained in the entire red region in Fig. 3. When the flow velocity is 4.6 m/s, the intensity of the wavelength region in the vicinity of 700 nm is large and the intensity of the wavelength region in the vicinity of 400 nm (N_2 second positive, N_2^+ first negative) is also large. In the left blue area of Fig. 3, even if the discharge area shrinks, a similar spectrum appears. In the right blue area of Fig. 3, a similar spectrum is obtained even if the discharge pattern is unstable. It is shown that nitrogen exists in the discharge gap in the blue emission case. The atomic oxygen spectrum (OI 777.2 nm, out of range) appears simultaneously with the spectrum of nitrogen when it appears strongly.

Figure 5 shows the current waveform and PMT signal at each flow velocity. When the flow velocity is 1.9 m/s (Fig. 5 (a)), the pulses of μsec order width in the afterglow region appear in the waveforms of the PMT output and discharge current. It was confirmed that a glow discharge is generated. A similar characteristic to this waveform is obtained in the entire red region in Fig. 3. When the flow velocity is 4.6 m/s (Fig. 5 (b), an unstable discharge pattern), many pulses with a duration of a few nanosec-

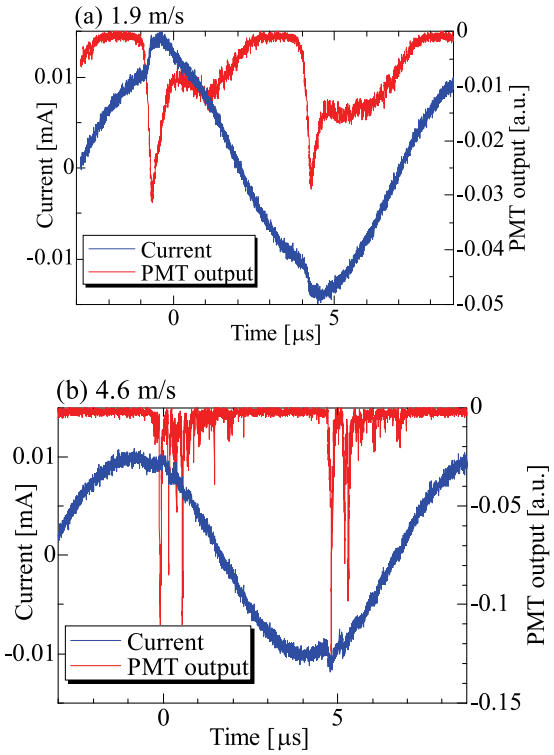

Fig. 5 Current waveform and PMT output in change of gas flow velocity.

onds order appear, indicating the occurrence of a silent discharge. Similar waveforms were obtained in the entire of two blue regions at high and low flow velocities in Fig. 3. In the case of glow discharge, the ionization mechanism is a two-step process (He metastable creation and Penning ionization: $He(2^3S) + N_2 \rightarrow N_2^+(B^2\Sigma_u^+) + He$), which slows down the ionization process. Thus, the formation of a large avalanche at the origin of filamentation is avoided [4]. Tachibana et al. [5] show that the loss of $He(2^3S)$ metastable atoms is attributed to the Penning ionization process due to the nitrogen impurities, based on measurements of the lifetime of $He(2^3S)$. Therefore, it appears that the contamination of nitrogen leads to the appearance of the silent discharge in our experiment.

In conclusion, there exists contamination of nitrogen and oxygen in helium not only in the low flow velocity region but also in the high flow velocity region. The transition of the discharge from a transversally uniform structure to a silent discharge structure occurs due to the contamination, and the edge effect is enhanced at the transition. When the gap length is 0.14 mm, the emissions from nitrogen and oxygen hardly appear in the region of high velocity (up to 50 m/s in our experiment), and the silent discharge does not appear. Therefore, the appearance of the silent discharge in the region of high flow velocity for a gap length of 0.7 mm is due to the contamination of nitrogen and oxygen in the flow of helium, and not due to the effect that the flow directly exerts on the discharge (such as elastic collision of neutral He atoms).

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