Control of self-organized luminous pattern formation in atmospheric-pressure dc glow discharge by using external electric field

T. Miyazaki , N. Shirai and K. Sasaki

Division of Applied Quantum Science and Engineering, Hokkaido University, Sapporo, Japan

Abstract: A self-organized luminous pattern formation is sometimes observed above a liquid or metal anode in an atmospheric-pressure dc glow discharge. In this work, we investigated the change in the luminous pattern by applying external electric field. We observed the external electric field changed the luminous pattern when helium with a flow rate of 150-300 sccm was surrounded by O_2 sheath gas. We did not observe the change in the pattern when the helium flow rate was higher than 300 sccm.

Keywords: Atmospheric-pressure plasma, Self-organization, Plasma-liquid interaction

1. Introduction

Self-organized luminous pattern formation is sometimes observed above liquid or metal anodes in an atmospheric-pressure dc glow discharge. However, the formation mechanism has not been understood well. In general, any self-organized patterns can be mathematically described by simultaneous partial differential equations with two variables, which is called "the reaction-diffusion system". It requires two formation factors whose densities increase or decrease as a result of the reaction and the diffusion (the transport) [1]. Previous studies observed changes in the pattern formation when changing the type of the anode (an aqueous solution or a metal) and the gas condition. It has been found that the presence of electronegative gases such as water vapor and oxygen is important for the pattern formation [2]. Therefore, we expect that the the negative ion and electron densities are the two quantities in the reaction-transport system, and the radial electric field plays an important role in the transport. In this work, we focused on the influence of the radial electric field on the pattern formation, and tried to change the pattern formation by applying the electric field to the discharge. We will report the pattern changes by increasing the helium flow rate and by the electric field. In addition, we will report the relative negative ion relative density in the plasma estimated by laser photodetatchment.

2. Experimental procedure

Figure 1 shows the experimental setup for generating an atmospheric-pressure dc glow discharge with a miniature helium flow. 1% NaCl aqueous solution or a stainless-steel plate was used for the anode. The cathode was made of brass with a narrow hole of 500 μm diameter which was used for flowing helium toward the anode. To control the ambient gas atmosphere, nitrogen or oxygen was flowed as the sheath gas around the helium flow. The flow rates of helium and the sheath gas were 150-350 and 1000-2000 sccm, respectively, and the discharge current was changed between 20-50 mA. The metal ring electrode was placed nearly above the anode, and it was used for applying the radial electric field. The detection of negative ions by laser photodetachment was similar to that reported in the reference [3], and the relative negative ion density in the plasma was obtained by measuring the pulsed increase in the discharge current at the timing of the pulsed laser injection due to the photodetachment reaction ($X^- + h\nu \rightarrow X + e^-$).

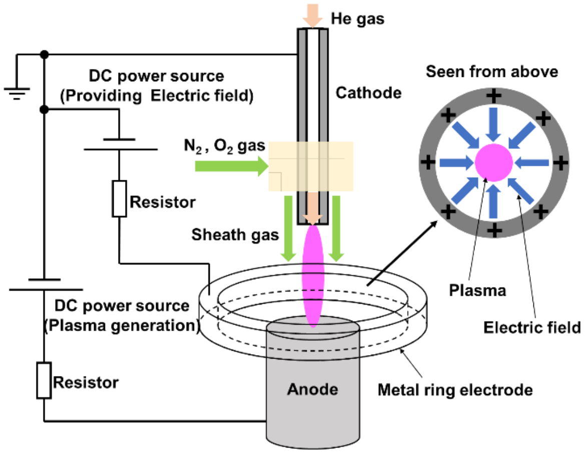

Fig.1 Experimental setup.

3. Results and Discussion

Figure 2(a) shows a luminous pattern observed above the liquid anode of the discharge generated in air. The pattern disappeared with the N_2 sheath gas around the discharge, as shown in Fig. 2(b). When the sheath O_2 gas was applied, we observed the different patterns from those observed without providing the sheath O_2 gas, as shown in Fig. 2(c). When we applied +1 kV to the ring electrode, we never observed the change in the patterns when the discharge was generated in air and with the N_2 sheath gas. In contrast, the pattern was affected by the radial electric field when the discharge was generated with the O_2 sheath gas. Figure 3 shows changes in the patterns when the external electric field was applied to the discharge with the O_2 sheath gas. The patterns were changed by the electric field at helium flow rates of 150-300 sccm. However, the pattern never formed and changed by the electric field at helium gas flow rates higher than 300 sccm. In addition, the pattern formation tended to be inhibited when a negative voltage was applied to the ring electrode. This result indicates that the pattern formation does not occur when the outward transport of negative charges is suppressed by the electric field, suggesting the validity of the reaction-transport system including electrons and negative ions. Figure 4 shows the relative density of negative ions as a function of the helium flow rate. The negative ion density in the plasma increased with the helium flow rate, and it was particularly high at helium flow rates above 300 sccm. Note that the luminous pattern formation was not observed at helium flow rates higher than 300 sccm. In our previous work, we observed a low negative ion density in the plasma with the N_2 sheath gas. Since the pattern formation was not observed with the N_2 sheath gas, as shown in Fig. 2(b), we concluded the importance of negative ions for the pattern formation. The present result suggests the importance of electrons, since the pattern formation does not occur if the negative ion density is too high. This is consistent with the speculaton that electons and negative ions work as the two variables in the reaction-transport system, and a suitable density balance between the electron and negative ion densities is necessary for the luminous pattern formation.

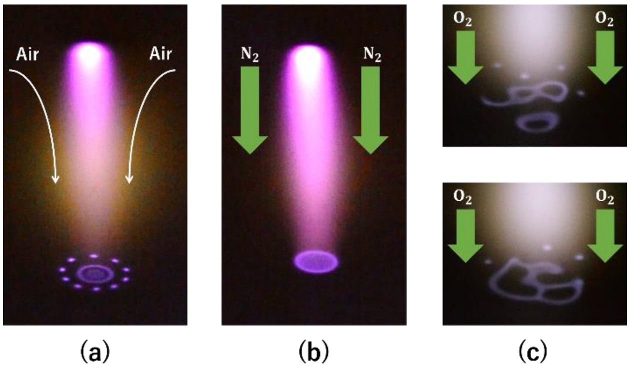

Fig.2 Influence of sheath gases on the pattern formation (a)Pattern forms in open air, (b)Pattern disappears with N_2 sheath gas, (c)Pattern changes with O_2 sheath gas

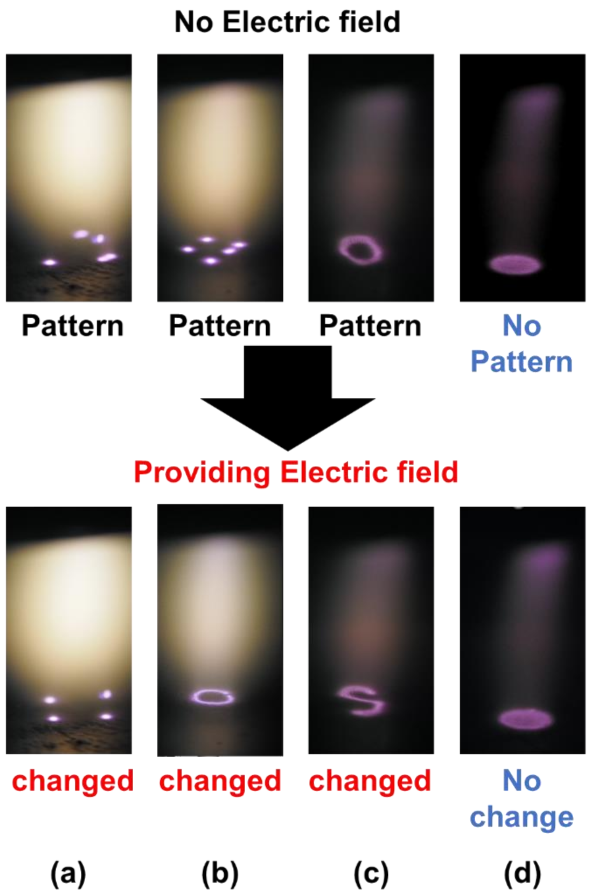

Fig.3 Changes in pattern due to the external electric field for each helium flow rate (a)200ccm, (b)250ccm, (c)300ccm, (d)350ccm (O_2 sheath gas flowed)

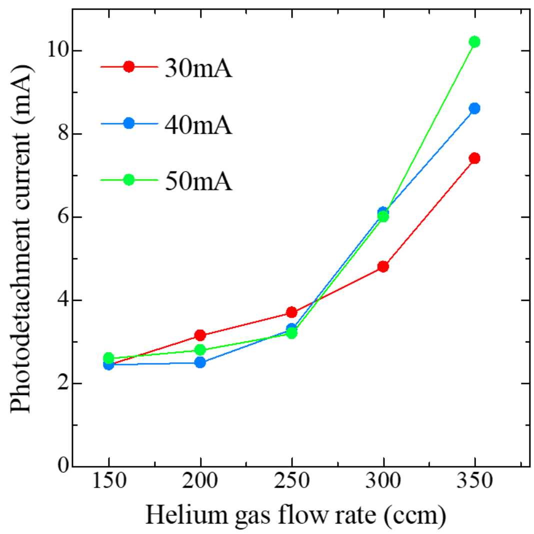

Fig.4 Relative density of negative ions with increasing helium gas flow rate

References

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