Spatiotemporal Pattern Formation in an Atmospheric Plasma Discharge

Cormac Corr, Rod Boswell, Nicolas Balcon, Cameron Samuell, and Patrick Kenneally

***Abstract*—We have developed a radio-frequency-powered nonequilibrium argon gas discharge consisting of two parallel electrodes, with at least one being covered with a thin dielectric layer. The atmospheric discharges that take place in such an experimental device are of different types, depending on the experimental conditions, particularly on the product pd of gas pressure p and discharge width d. Spatiotemporal pattern formations and microdischarge phenomena occurring in this atmospheric plasma discharge have been studied by using a high-resolution video camera. In particular, we observe moving fingerlike structures, occurring as the argon plasma expands radially across the electrodes, which are indicative of fluidlike behavior. Other spatiotemporal phenomena include traveling localized and starlike discharges. All of the observed phenomena can be controlled by varying the RF input power, gas flow, and discharge gap size.**

***Index Terms*—Atmospheric plasma, pattern formation, radio frequency, self-organization.**

PLASMA DISCHARGES operating at atmospheric pressure have been receiving an increasing amount of attention in recent years, both from academic research groups and from industries wishing to modify the surface properties of materials. Atmospheric discharges would provide a cheaper and more convenient alternative in comparison with low-pressure plasma discharges. Typically, different discharge modes can be obtained at atmospheric pressure such as filamentary, self-organized, or a glow discharge. These modes can be obtained by controlling the experimental conditions of gas flow, input power, and discharge gap size.

The formation of self-organized patterns in complex systems, such as atmospheric discharges, has attracted a great deal of attention [1]–[5]. Patterns can be formed when a number of microdischarges or small diffuse discharge areas are arranged regularly under certain operating conditions. The understanding of pattern formation in atmospheric plasmas has been broadened with experimental observations of a large variety of self-organized patterns including hexagonal, spiral, and concentric ring patterns. Studies of pattern formations are important not only because of their intriguing similarities with those in other scientific disciplines but also because of their potential to uncover a previously uncharted operating regime that offers active plasma chemistry and stability simultaneously. The spatiotemporal pattern formations and microdischarge phenomena occurring in our atmospheric plasma discharge have been studied by using a high-resolution video camera. In particular, moving fingerlike structures, occurring as the argon plasma expands radially across the electrodes, have been observed, which are indicative of fluidlike behavior such as in a Hele-Shaw cell. Self-organization of microdischarges and filaments in atmospheric plasma systems has also been observed.

The atmospheric plasma discharge consists of two parallel electrodes, with the distance between them being adjustable up to 5 mm. The upper grounded showerhead electrode consists of an array of 100 holes of 0.5 mm in diameter through which the argon gas flows. The RF power supply (ENI 600 W–13.56 MHz) is coupled via a PI-matching network to the lower electrode. This lower powered electrode consists of a circular copper mesh sandwiched between two Pyrex (dielectric) plates of 4-mm thickness. This enables the spatial profile of the plasma to be investigated with the digital video camera. Generally, the discharge is operated in a pulsed mode, with the pulse period and the pulse duration being varied from 50 to 350 μs and from 1 to 25 μs, respectively, so as to prevent the Pyrex from breaking. The voltage applied to the electrode is measured with a Tektronix high-voltage probe. Spatiotemporal phenomena were captured by using a high-definition 5.1-megapixel Sanyo digital camera focused on a mirror that was positioned underneath the lower electrode.

In this atmospheric plasma system, both filamentary and glow modes are observed. These filamentary modes are probably those observed in previous measurements in our atmospheric system when operating with a steel lower electrode [6]. An example of the filamentary mode is shown in Fig. 1(a) and (b). Depending on the operating conditions, self-organized phenomena of these filaments are observed. A mode change to a glow-type discharge is observed with an increasing pulse-width [6].

By adjusting the gas flow and electrode spacing, and for variations in the power applied to the discharge, the plasma (in the glow discharge mode) does not expand and contract uniformly as expected. Rather, long thin tendrils of plasma propagated radially outward in complex patterns, as shown in Fig. 1(d). These tendrils are referred to here as fingers. At low input power, the discharge is observed to have starlike structures that appear to move in a random manner [Fig. 1(c)]. At

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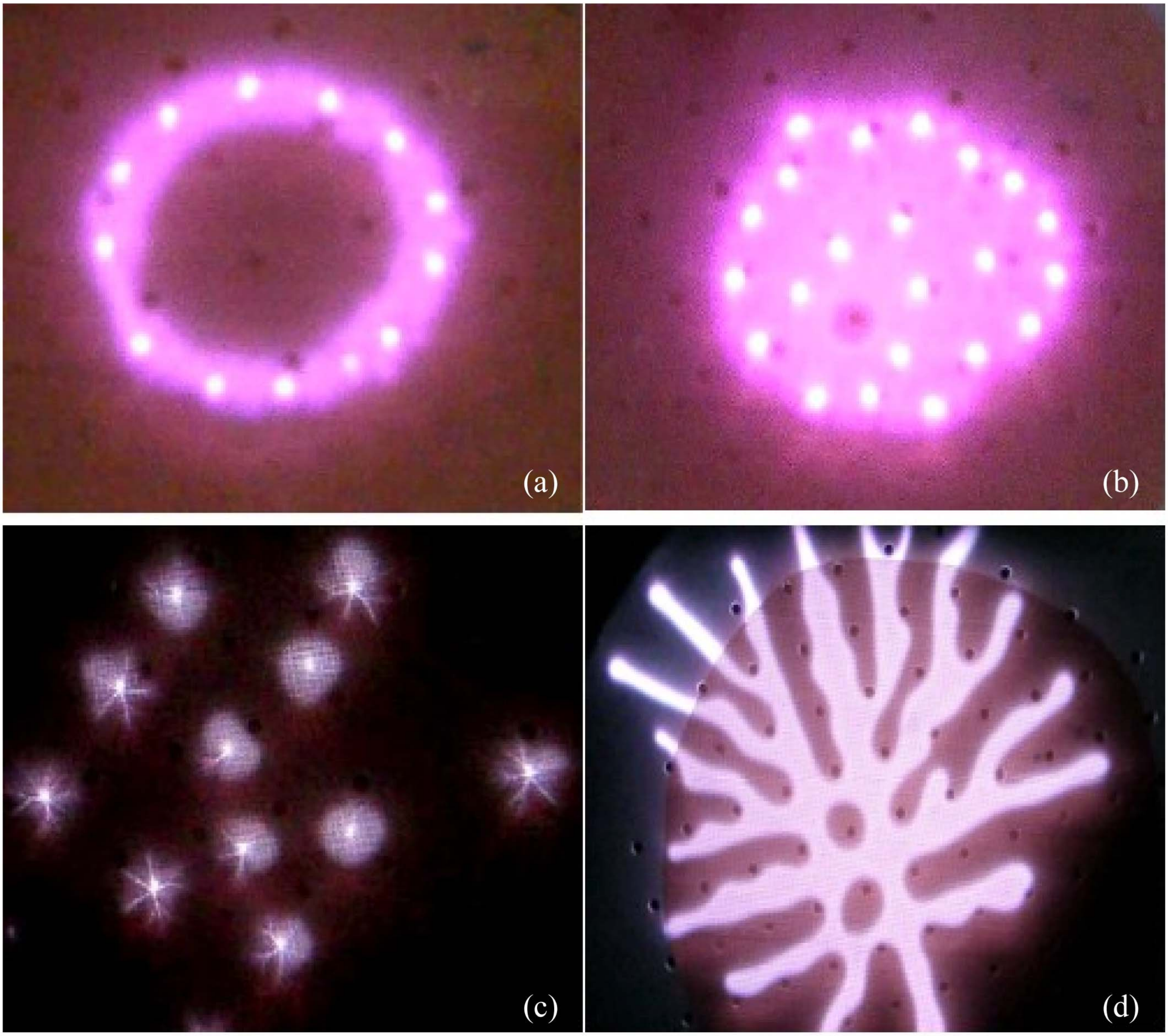

Fig. 1. Spatiotemporal phenomena in an atmospheric argon plasma. (a) and (b) Self-organization of filamentary discharges. (c) Starlike discharges. (d) Plasma fingering.

the higher power range and as a single finger extended outward, it was observed to branch a number of times into new fingers that would, for further increases in power, branch themselves. The plasma fingers appeared to avoid the showerhead holes wherever possible. In some instances, where the plasma density around the hole was too great, the plasma would impinge on the edges of the hole and eventually overcome it.

These finger patterns, which have not been observed previously, bear a great resemblance to the patterns formed in a Hele-Shaw cell due to the Saffman–Taylor instability when a highly viscous fluid displaces a less viscous one in a thin linear channel or cell.

Further work is underway to gain a deeper understanding of the viscous fingering and microdischarge phenomena.

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