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Evolution of the Light Emission Profile in Radio-Frequency Atmospheric Pressure Glow Discharges

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***Abstract*—Time-resolved images of the light emission profiles of RF atmospheric pressure plasmas are presented. As the current increases, the emission profile evolves from bell shaped to double humped. At moderate currents, bright layers above each of the electrodes are observed, and it is found that both layers light up and fade simultaneously during the RF cycle.**

***Index Terms*—Atmospheric plasma, CCD imaging, glow discharge, RF discharge.**

ATMOSPHERIC pressure glow discharges (APGDs) have received growing attention in recent years for their potential application in many scientific disciplines [1], [2]. Despite recent advances, the physics governing these discharges is not fully understood. In this paper, the dynamic evolution of the optical emission of He and He + O_2 RF (sinusoid 13.56 MHz) APGDs is investigated by means of high-speed (5-ns exposure time) images.

The experimental setup consists of two parallel stainless-steel disk electrodes, each being 2 cm in diameter. The discharge gap is fixed at 2 mm, and the system is housed in a Perspex box. Working gases (He and He + O_2 mixtures) are flowed at 5 slm into the box. A function generator (Tektronix AFG 3102), an RF power amplifier (Amplifier Research 500A100A), and a house-built matching network are used to deliver power to the discharge. The current flowing through the discharge and the voltage across the electrodes are measured with a wideband current probe (Pearson Current Monitor 2877), a wideband voltage probe (Tektronix P5100), and a digital oscilloscope (Tektronix TDS 5054B). An intensified charge-coupled device camera (Andor i-Star DH720) is used to take the images presented in this paper [3]. The electron temperature and density were not measured in this set of experiments. The gas temperature (estimated from the rotational temperature of OH) increases from 310 K at 60 mA to 430 K at 180 mA in He and from 340 K at 90 mA to 470 K at 208 mA in He + O_2.

Fig. 1 shows the current–voltage characteristics of the He and He + O_2 (0.5%) discharges from (dotted lines) prebreakdown to (open symbols) glow discharge and up to the (red stars) point immediately before the plasma constriction. In both cases, right after the discharge ignites, the voltage required to sustain the plasma decreases (solid pink lines in Fig. 1). Due to the high electron affinity of O_2 and its molecular nature, a higher voltage is required to ignite the discharge even when only 0.5% of O_2 is added into the flow.

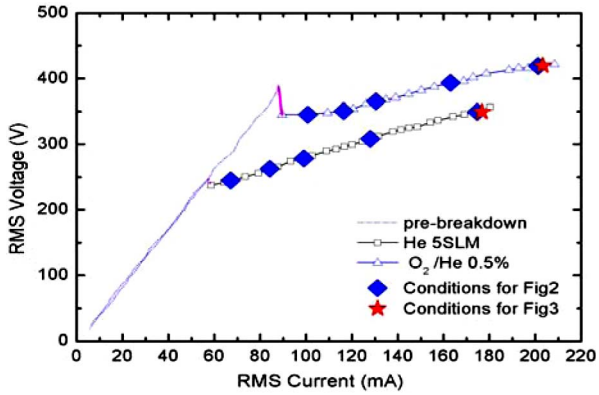


Fig. 1. Current–voltage curve of RF APGDs in He and He + O_2.

The time-integrated light emission profile of the discharge as the current (or power) increases is shown in Fig. 2. Each image was captured by using an exposure time of 500 ns (~7 RF cycles), and the corresponding points in the current–voltage characteristic are highlighted by blue diamonds in Fig. 1. Immediately after breakdown, the plasma is weak and covers the electrodes only partially. As current is increased, the plasma expands until it covers the entire electrodes. The light emission profile evolves from bell-like to double-hump profile as the current increases. The latter presents two distinct bright emission layers above each of the electrodes (Fig. 2). This structure is also observed when O_2 is added into the discharge, although the overall intensity of the discharge decreases significantly. It is of interest to note that the decrease of light emission with O_2 admixtures happens even though higher power is delivered to the plasma.

To resolve the time evolution of the plasma emission, single-shot images with an exposure time of 5 ns were taken at different phases of the RF cycle (Fig. 3). Both discharges (He and He + O_2) operate at the maximum current before constriction (red stars in Fig. 1). As it was observed in previous works [4], the emission is periodic, and the maximum light is recorded

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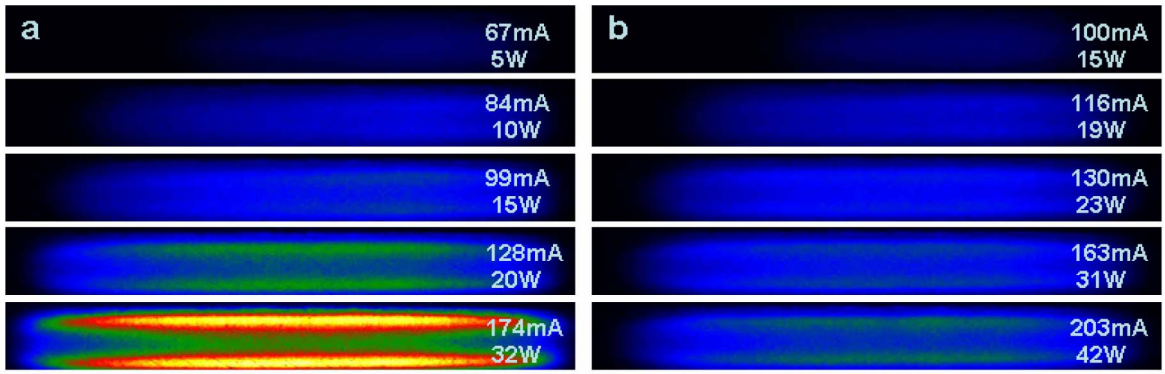


Fig. 2. Emission evolution as a function of the discharge current. Time-integrated optical emission of (a) He and (b) He + O_2 0.5% plasmas.

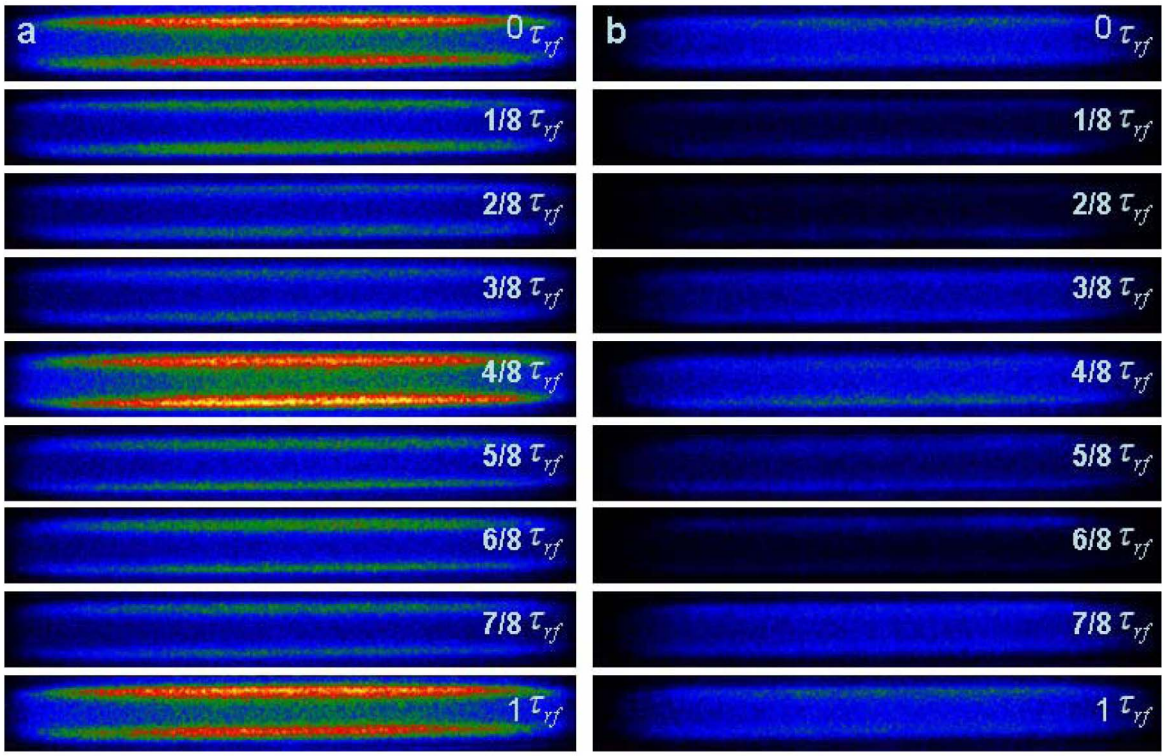


Fig. 3. Single-shot images (5-ns exposure time) over one complete RF cycle. (a) He discharge at 174 mA and (b) He + O_2 discharge at 203 mA.

with a period equal to half the RF period (τ_{RF}). It is interesting to note that the two bright layers above each electrode light up simultaneously and not in an alternating fashion. Although bright emission layers near the electrodes are often associated with the gamma mode, the simultaneous lightening of the layers and the lack of discharge constriction are signatures of operation in the alpha mode. Simulation results not presented here also support this conclusion. In the presence of O_2, the same observations hold although the intensity of the bright layers is less prominent.

In summary, the He and He + O_2 RF APGDs have been studied by means of single-shot images with 5-ns exposure time. As a rule, the presence of O_2 decreases the light emission even if more power is delivered to the discharge, and the emission profile evolves from bell-like to double-humped profile as the current increases. In all cases, the discharge operates in the alpha mode, and the bright layers that are observed above each electrode light up and fade simultaneously (not alternatively) with a period of $\tau_{\mathrm{RF}}/2$.

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