Spatially-resolved measurement of electron density in a microwave-excited Ar/Kr split-ring resonator microplasma

Bang-Dou Huang, Xi-Ming Zhu, Wen-Cong Chen, Yi-Kang Pu*

Department of Engineering Physics, Tsinghua University, Beijing 100084, People's Republic of China
(*)email: puyikang@mail.tsinghua.edu.cn

A microwave-excited microstrip split-ring resonator is investigated by using spatially-resolved OES diagnostics, focusing on the self-organized striations in Ar/Kr discharge at atmospheric pressure. Spatially-resolved emission intensity of several lines from Ar and Kr 2p levels is measured, from the ratio of which the electron density distribution is obtained with a collisional-radiative model. The electron density varies periodically in the microplasma, leading to a pattern of emission intestines.

Atmospheric-pressure microplasmas have many potential applications, such as UV radiation sources, environmental sensors, and biomedical treatment. Microwave-excited split-ring resonator (SRR) microplasma has the advantage of low power consumption and easy operation. However, discharge inhomogeneity or pattern formation is widely observed in several kinds of atmospheric-pressure microplasmas. In order to understand the patter formation mechanism, spatially-resolved diagnostics of plasma parameters is needed.

In this work, we do a spatially-resolved measurement of the electron density (n_e) and mean electron energy in a SRR microplasma with self-organized striations. The SRR is powered by a microwave source at a resonance frequency of 1.8 GHz, with absorbed power by the SRR about 1 W. The discharge gap width is about 100 μm (see figure 1).

Microplasma is generated in a vacuum chamber filled with argon (720 Torr) mixed with a small amount of krypton (10 Torr). During the experiment, up to six striations have been observed in the gap of the SRR. Spatially-resolved emission intensity of certain lines (Ar $2p_2$->$1s_5$, 696.54 nm, Ar $2p_3$->$1s_5$, 706.72 nm, Ar $2p_6$->$1s_5$, 763.51 nm, Ar $2p_7$->$1s_4$, 810.37 nm, Ar $2p_4$->$1s_2$, 852.14 nm, Kr $2p_3$->$1s_3$, 785.48 nm) is obtained through a chromatic-free optical magnifying system with narrow bandpass interference filters and an intensified charge-coupled device, with a magnification of about 12 [1]. The spatial resolution of the whole imaging system is less than 10 μm.

n_e is obtained from the measured line-ratios of Ar(2p) levels, according to an atmospheric-pressure collisional-radiative model [2]. Here the main kinetic processes of Ar(2p) levels are the electron-impact excitation from the 1s levels and the electron-impact and atom-collision population transfer. When the electron density is very high (> ~10^{17} cm^{-3}), the electron-impact population transfer is the dominant depopulation process. As a result, the Ar(2p) levels are in Boltzmann-like population distribution, and the densities of Ar($2p_2$) and Ar($2p_3$) (n_{2p2}, n_{2p3}) are similar due to their similar electron-impact excitation and depopulation rate coefficients. When the electron density is low (< ~ 10^{11} cm^{-3}), the atom-collision population transfer becomes the dominant depopulation process. As a result, the Ar(2p) levels are in extremely non-equilibrium distribution with $n_{2p2} >> n_{2p3}$, since the atom-collision depopulation rate coefficient of Ar($2p_2$) is much smaller than that of Ar($2p_3$). In the middle region, the ratio of n_{2p3} and n_{2p2} increases significantly with n_e. Therefore, we can obtain n_e from their line-ratios. On the other hand, we estimate the mean electron energy from the line-ratio of Kr 785.48-nm line and Ar lines, by considering the different electron-impact excitation threshold energies of Ar and Kr 2p levels.

Figure 1(a) shows the spatial distribution of density ratio of Ar($2p_3$) and Ar($2p_2$). The spatial distribution of electron density is displayed in figure 1(b). As shown in figure 1(b), in the central regions of the striations n_e is about 2.3×10^{14} cm^{-3}, which decreases to about 0.8×10^{14} cm^{-3} at the edge. This characteristic of n_e is reproduced periodically along the gap of the SRR (direction Y). The spatial distribution of the mean electron energy has the similar spatial periodism as n_e; however, it has higher values at the edge and lower ones at the center. These observed variations of electron density and mean electron energy are in agreement with those predicted by a Turing model for the self-organized microplasma in [3].

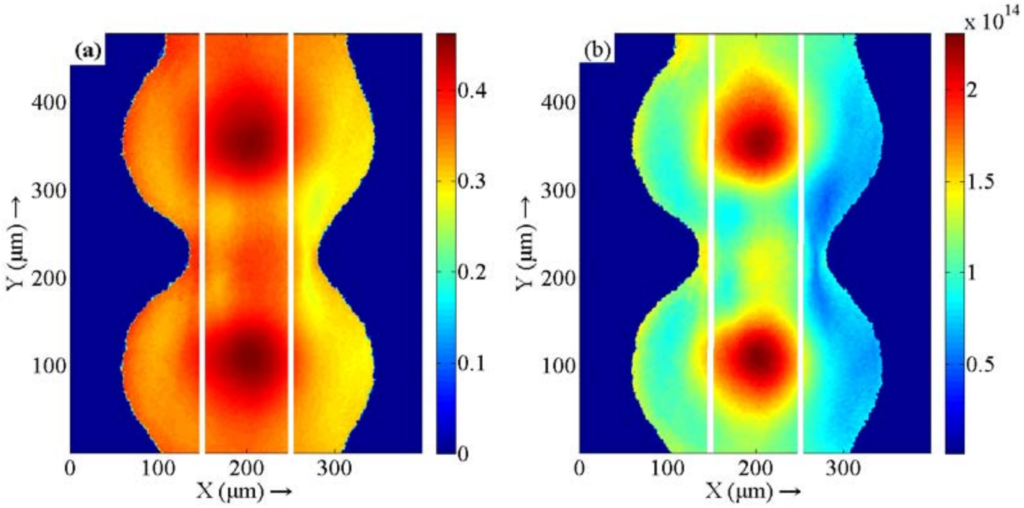

Fig. 1: (a) Spatial distribution of the population ratio of $Ar(2p_2)$ and $Ar(2p_3)$. (b) Spatial distribution of the electron density (cm^{-3}). The vertical white lines in (a)-(b) represent the edges of the gap.

References

[1] L. Zhu, W. Chen *et al*, *Rev. Sci. Instrum.* **80** (2009) 023105-1
[2] X. Zhu, Y. Pu *et al*, *J. Phys. D: Appl. Phys.* **42** (2009) 142003
[3] X. Chen, Y. Zhou *et al*, (2011) http://arxiv.org/abs/1101.3471