Advanced Diagnostics of Atmospheric-pressure Micro-discharge and Effect of Admixed Water Vapour on Its Phychemical Property

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Abstract: The effect of admixed water vapour on the plasma properties including gas temperature T_g, electron density n_e and temperature T_e, and key reactive species of OH and H, in an atmospheric-pressure argon micro-glow discharge, were studied by multi-advanced diagnostic methods. Compared to a narrow hot discharge core characterized by the plasma emissions, a full gas temperature field was achieved by a calibrated schlieren approach. Based on that, the density maps of OH radicals and H atoms in the glow discharge were imaged by laser-induced fluorescence diagnostics. The patterns of discharge luminance, thermal field, distributions of OH and H, were compared and studied in details together with the effects of humidity in the argon gas.

Keywords: micro-discharge, advanced diagnostics, LIF, thermal field, humidity effect.

1. Introduction

Non-thermal plasmas generated at atmospheric-pressure with small scales in range of micrometre to millimetre, are typically called micro-plasmas [1]. This type of micro-discharges receives intensely interests for various novel applications, such as local medical treatment and material surface processing [2]. Sometimes large-scale treatments are possible in an array form of micro-discharges [3]. To control the plasma properties and achieve desired treating effects, it is indispensable to know the fundamental details of micro-discharges. However, due to small scale and especially that most micro-plasmas generated at atmospheric-pressure are under extreme non-equilibrium state with sharp gradients of temperature or/and species concentrations, diagnostics of this type of tiny discharges are commonly difficult. In this case advanced diagnostic techniques with high spatial resolution, are desired.

2. Experimental description and results

In this work, multi advanced diagnostic approaches are applied to visualize the physical and chemical details of a pin-to-pin micro-glow argon discharge. Firstly, the gas temperature T_g distributions were obtained and compared by two methods of spatial-resolved optical emission spectroscopy (OES), and calibrated schlieren (CS) photography [4]. It shows that the plasma emissions only characterize a narrow but hot zone corresponding the discharge core. This luminous zone covers about one third of the full T_g map obtained from the schlieren image, typically as shown in Fig. 1. This full visualization of gas temperature is important from the point of further diagnostics including for example reactive species concentrations by laser spectroscopy, as T_g is an indispensable parameter in the analysis process of latter. A significant overestimation of OH density from laser-induced fluorescence (LIF) signals was obtained if OES-determined T_g was applied to the wing-region of the discharge. Based on the Tg distribution from schlieren images, the spatial map of OH radicals was determined combined with Rayleigh scattering calibration for LIF signals. Typically, as presented in Fig. 1 under conditions of 0.4% water vapour in the argon discharge, a much broader distribution of OH radicals is visualized in order of 10^{13} to 10^{15} cm-3, compared to the OH(A-X) luminous pattern.

With rise of mixed water vapour contents from 0.4% to 2.4%, the thermal field of discharge expands and achieves a higher T_g level. This indicates more electrical energy deposited in the discharge column, is dissipated in form of heat. However, further analysis shows the thermal energy capturing by water molecules are almost ignorable to that of the whole thermal field of discharge, even under 2.4% H_2O. It demonstrates that the increase of thermal energy in discharge is induced by the rapid vibration-translation (V-T) energy transfer process of H_2O-H_2O and H_2O-Ar, which simultaneously enhances the motion of argon atoms through collisions [5], and finally increase the gas temperature of the whole discharge.

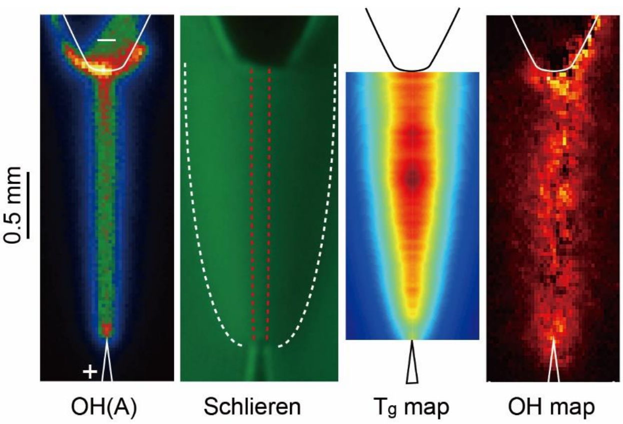

Fig. 1 Typical patterns of (from left to right) OH(A-X) emissions, discharge schlieren image, full field of T_g and OH density. In the schlieren image, the red-dash lines mark the edges of OH(A-X) luminance, and the white-dash lines correspond to the edges of schlieren signals. In the T_g map the gas temperature ranges from 300 K to 1400 K. And in the OH map, the concentration varies in orders of 10^{13} to 10^{15} cm^{-3}. The pin-to-pin discharge conditions are with 2 mm electrode gap, 16 mA current, 2 slm total gas flow of Ar+0.4%H_2O [5].

Although we obtained a decreasing trend of electron density with rise of water vapour by Thomson scattering detections and also by the H_β-line stark broadening method, the OH concentration presents a rise behaviour. That means more water molecules are dissociated, indicating indirectly more V-T process occur in the discharge at high content of water vapour, as dissociation process of molecules is typically strongly accompanied by vibrational and rotational transitions. Correspondingly, V-T processes of H_2O-H_2O and H_2O-Ar are enhanced therein to intensify the thermal field of the whole discharge. A similar increase trend of H density was obtained as well with the rise of H_2O ratio, and with an even broader radial profile than that of the OH radials. The wide H distribution is supposed to be attributed to its fast diffusion to the outer area. Combined by the diagnostics of electron density and temperature, the effects of admixed water vapour on the physical and chemical properties of studied argon micro-discharge were analysed in detail. This work provides a detailed reference to study micro-scale discharges by various advanced diagnostic techniques.

3. Acknowledgements

This work was in part funded by the State Key Laboratory of Advanced Electromagnetic Engineering and Technology (Grant No. AEET 2018KF003), the Fundamental Research Funds for the Central Universities (No. 2018CDXYTW0031), and the Construction Committee of Chongqing (No. 2018-1-3-6).

4. References

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