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TRANSLATIONAL, ROTIONAL AND VIBRATIONAL TEMPERATURES OF A GLIDING ARC DISCHARGE AT ATMOSPHERIC PRESSURE AIR

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Gliding arc discharges have generally been used to generate non-equilibrium plasma at atmospheric pressure. Temperature distributions of a gliding arc are of great interest both for fundamental plasma research and for practical applications. In the presented studies, translational, rotational and vibrational temperatures of a gliding arc generated at atmospheric pressure air are investigated. Translational temperatures (about 1100 K) were measured by laser-induced Rayleigh scattering, and two-dimensional temperature imaging was performed. Rotational and vibrational temperatures (about 3600 K and 6700 K, respectively) were obtained by simulating the measured emission spectra of OH.

1 Introduction

A gliding arc discharge can be used to generate non-equilibrium plasma at atmospheric pressure, providing good chemical reactivity for practical applications [1-3]. They have been widely applied to surface treatment [4], combustion enhancement [5] and chemical processes [6]. Among these practical applications, temperature fields of gliding arcs are important both for fundamental plasma research and for practical applications.

In equilibrium plasmas atoms, molecules, electrons and ions are in thermodynamic equilibrium, and they have the same unique temperature. For plasmas not in thermodynamic equilibrium, however, temperatures have to be identified for translational, rotational and vibrational temperatures.

It has been reported that translational temperatures of plasmas can be measured by Rayleigh scattering [7-12]. Rotational and vibrational temperatures are acquired by simulating the experimental emission spectra [13, 14]. Rotational temperature of a gliding arc in humid air has been investigated [15]; however, translational and vibrational temperatures of a gliding arc were not investigated in these studies. To the best of our knowledge, detailed information about translational, rotational and vibrational temperatures of a gliding arc discharge together has not been reported, and this paper aims to provide this. Two-dimensional translational temperature imaging as well as rotational and vibrational temperatures of a gliding arc will be discussed.

2 Experimental setup

A gliding arc is generated between two diverging electrodes and extended by an air flow. The two tubular electrodes with an outer diameter of 3 mm are made of stainless steel and internally cooled by water. The air flow is fed through a 3 mm-diameter circular hole in a Teflon plate to blow the generated arc gliding along the electrodes. The flow rate is fixed at 17.5 standard liter per minute (SLM) in our measurements. The gliding arc is driven by a 35 kHz alternating current (AC) power supply (Generator 9030E, SOFTAL Electronic GmbH, Germany). A photo of a gliding arc at a flow rate of 17.5 SLM is shown in Fig.1(a).

Fig. 1(b) shows experimental arrangements for laser-induced Rayleigh scattering measurements. A frequency-doubled Nd:YAG laser (Brilliant B), which supplies about 180 mJ at 532 nm, is sent into the gliding arc (GA) by two high reflectivity mirrors (HR). A laser sheet is produced by a combination of a cylindrical lens (CL, f=-200 mm) and a spherical lens (SL, f=500 mm). Rayleigh scattering signals are collected by an ICCD camera (Princeton PI-MAX II) equipped with a UV lens. The camera is placed at the top of the gliding arc system. A beam dump is used to capture the unwanted laser energy.

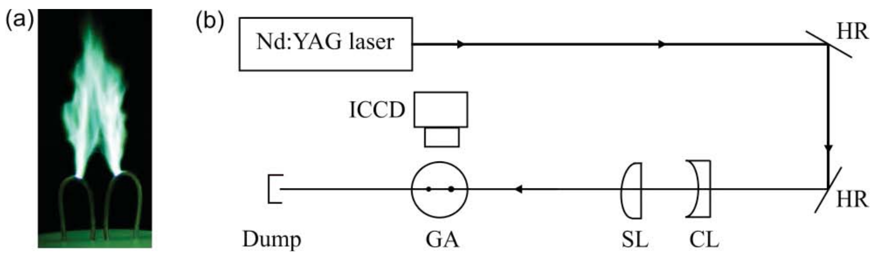

Figure 1: Experimental setup. (a) a photograph of the gliding arc discharge with exposure time of 1/30 s; (b) experimental arrangement of Rayleigh scattering measurements; HR, high reflectivity mirror; CL, cylindrical lens; SL, spherical lens; GA, gliding arc.

Optical emission spectroscopy is employed to measure OH emission spectra, which was used to infer the rotational and vibrational temperatures by comparing experimental results with the simulated spectra. An imaging spectrometer (SP-2300i, with a 1200 groves/mm grating) equipped with an ICCD (Princeton PI-MAX III) camera is used to record OH emission spectra from 300 and 320 nm. The ICCD based imaging spectrometer has an acquisition time of 16 μs. The simulated spectra are obtained using SPECAIR, which is a commercial program for emission and aborption spectra simulation of air plasma [13].

3 Results and discussion

Fig. 2(a) and 2(b) shows Rayleigh scattering images and two-dimensional temperature images, respectively, of the gliding arc in vertical direction at the height range of 65 mm ~75 mm above the Teflon plate. The acquisition time of the ICCD camera was 1 μs, and therefore plasma emission can be captured by the ICCD camera. One can see the volumn of hot region heated by the plasma from these images, especially in this case where the laser sheet cross the hot line of the diacharge volumn. A plasma column is identified from both the Rayleigh image and the temperature image. The gas around the plasma column is hot, and the gas temperature, namely translational temperature, is calculated by comparing the Rayleigh scattering signal of a gliding arc with that of air at room temperature. It is reasonable to neglect the scattering signal from electrons and other excited species since the gliding arc is weakly ionized and Rayleigh signal from the air is dominating. Note that there is also a Mie scattering signal, but it is eliminated by using a filter in the data anaylsis. As shown in Fig. 2 (b), translational temperatures of the gas around a gliding arc are indicated by the color bar. The temperature is about 1300 K along the plasma column. It is noted that the temperature in the plasma column is severely under-predicted due to the plasma emission.

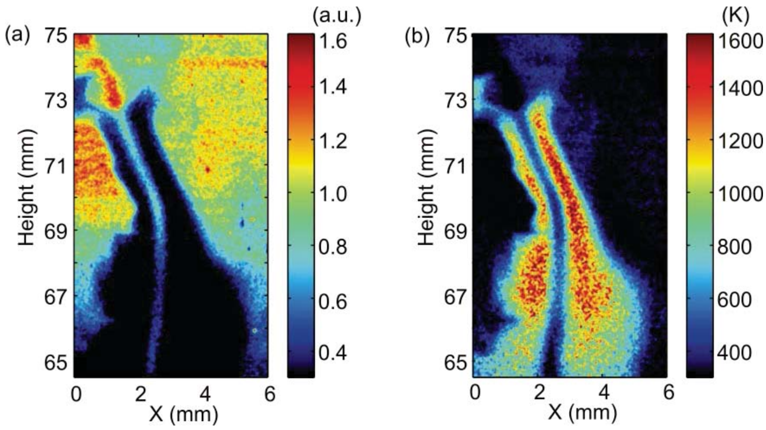

Figure 2: Translational temperature of a gliding arc in vertical direction where plasma emission is captured with 1 μs acquisition time; (a) Rayleigh scattering signal; (b) temperature image.

In order to suppress plasma emissions and calculate the temperature in the plasma column more accurately, the acquisition time of the ICCD camera was set to 30 ns. Moreover, the laser sheet was oriented horizontally to make sure that the gliding arc discharge volumn could be crossed. Fig.3 (a) shows the relative position between the gliding arc and the laser sheet. The delay time between the laser sheet and the gliding arc ignition is fixed at 10 ms, and the distance between the laser sheet and the plate of gliding arc setup is 78 mm. The laser sheet propagates in the Y direction. The Rayleigh scattering signal was collected by the camera placed at the top of the gliding arc system, and the view field of the camera is marked in the rectangle in Fig.3 (a).

Fig.3(b) and 3(c) respectively shows Rayleigh scattering images and two-dimensional temperature images in horizontal direction at a height of 78 mm. In Fig 3(c), two high-temperature areas can be seen, which corresonpond the two parts of the plasma column shown in the view field marked in Fig.3(a). The average temperature in the labeled circle is about 1100 K. Note that the temperature uncertainty is about 200 K. This is due to the fluctuation of laser energy, instability of gliding arc, Mie scattering interference and background subtraction.

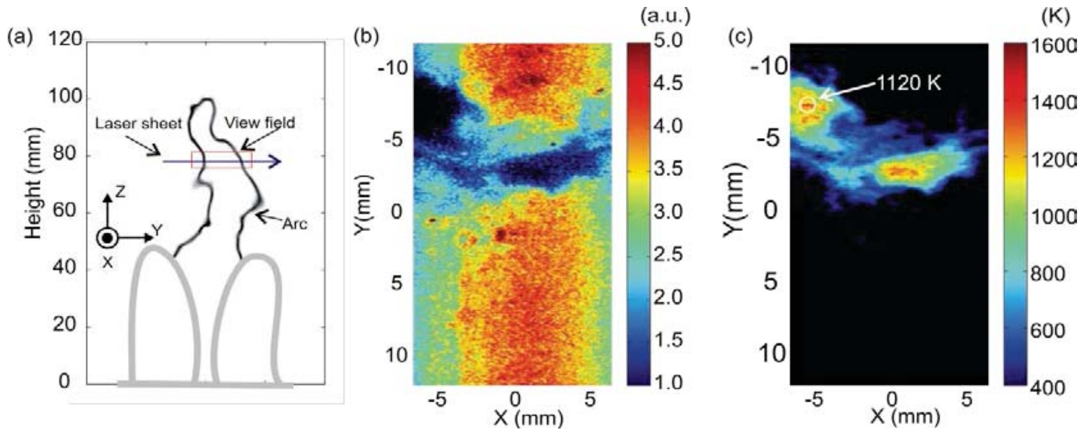

Figure 3: Translational temperature of a gliding arc in horizontal direction at a height of 78 cm; (a) relative position between the gliding arc and the laser sheet (b) Rayleigh scattering signal at 30 ns; (c) temperature image (the average temperature in the labeled circle is about 1100 K).

Rotational temperatures of the gliding arc was calculated by comparing the experimental spectra with the stimulated spectra. Fig.4 shows experimental spectra and simulated spectra. The simulated spectra were modeled using the SPECAIR. It is found that the experimental spectra agree well with the simulated spectra with rotational and vibrational temperature of about 3600 K and 6700 K, respectively. The rotational and vibrational temperatures of the gliding arc are much larger than the translational temperatures, which suggests that the gliding arc is working in non-equilibrium condition. Note that OH spectra in this wavelength range are fairly insensitive to the vibrational temperature.

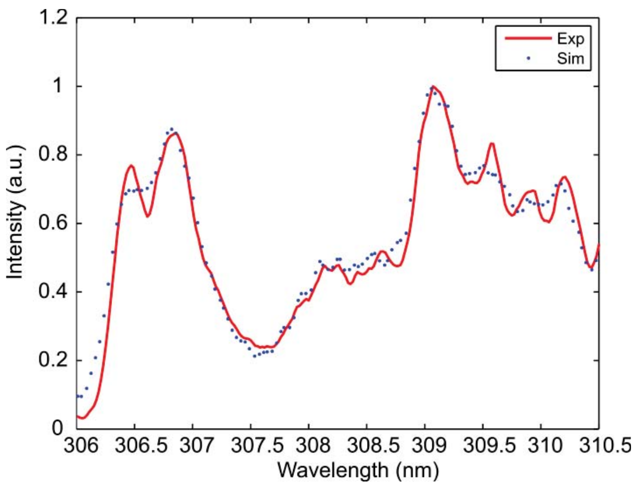

Figure 4: Experimental spectrum and simulated spectrum

4 Conclusions

In conclusion, the two-dimensional temperature imaging of a gliding arc was performed using laser-induced Rayleigh scattering. The translational temperature of the gliding arc is measured to be about 1100 K at a height of 78 mm. The simulated OH spectra of the gliding arc agree well with the experimental spectra, and the rotational and vibrational temperature of the gliding arc is about 3600 K and 6700 K, respectively. The translational, rotational and vibrational temperatures of the gliding arc suggest that the gliding arc works at high-degree non-equilibrium conditions.

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