LIF spectroscopy of OH radicals and the electron temperature in the effluent of atmospheric RF JET in Ar-H$_2$O mixtures

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The measurements of the spatial distribution of OH radicals and electron temperature in an atmospheric RF Ar-H$_2$O plasma jet is carried out by means of laser induce fluorescence (LIF) and absolute line intensity (ALI) measurements. Plasma with 0.3% H$_2$O is characterized by highest LIF signal where, accordingly, the second peak of Te appears around the same water content. The dominant radical production mechanism is dissociation electron-ion recombination in the atmospheric RF plasma jet.

Atmospheric pressure plasma jets (APPJs) characterized by high concentration of radicals and low gas temperatures are suitable for many applications [1,2] particularly for the localized modification of sensitive surface[3] where treatment can be implemented without the requirement of complicated and expensive vacuum systems. The increasing interest in the application of APPJs heightened the need for quantification and mechanistic studies of the plasma species in APPJs. The experiments can be based on several different diagnostic techniques that can be further divided into active and passive spectroscopy. This paper focuses on the LIF measurements of an absolute densities of OH, electron temperature derived from absolute line intensity (ALI) measurements and the effect of H$_2$O content on the formation process of excited species in the atmospheric radio frequency jet.

A schematic diagram of the system used for laser spectroscopic diagnostics is presented in Fig. 1 a)- b). The capacitively coupled plasma jet with L-matching impedance box was sustained in open air. Discharge was operated in diffuse $\alpha$-mode at low input power (13.46 MHz, typically 10 W). The image on the right-up corner shows a contiguous, stable and noiseless plasma jet measuring 8 mm long and 2 mm wide. The gas flow through the glass tube is kept constant at 2 SLM with pure argon and a small admixture of water (0%~1%).

A 10 Hz Nd:yttrium aluminium garnet pumped dye laser was used to generate the nanosecond laser pulses at around $\lambda = 284$ nm for excitation of OH radicals from ground state (X$^2\Pi$, $v^\prime=0$) to (A$^2\Sigma^+$, $v^\prime\prime=1$) state with three different transition P$_1$(4), P$_2$(3) and P$_2$(6) in the excited volume. The LIF signal is accumulated by a SR430 photon counter at the frequency of the YAG:Nd laser during 1000 pulses and the space resolved two-dimensional cross section of OH fluorescence was detected by an ICCD camera synchronized with the laser pulse. For the spectroscopic diagnostics, several Argon 4p lines were recorded in the range of 700~780 nm. The optical system is calibrated by replacing the RF jet with a standard tungsten ribbon lamp, operated at an accurately known electric current.

Fig. 1 c) shows the uncalibrated spacial distribution of OH concentration in the x-y-plane with P$_2$(3) transition while the jet is operated with 0.1%, 0.3% and 0.5% H$_2$O admixture. The cross-section images are recorded with in the gate time of 300 ns after the accumulation of 50 laser pulses. The highest density was observed in closest distance to the plasma core at position of (0, 0, 1) and steeply decreases within a range of 1 mm in the x-y plane. Moreover, even at the distance of 8 mm away from the nozzle, there are still the detectable LIF signal. Futhermore, the discharge with 0.3% H$_2$O has the strongest LIF signal and the most contracted plasma.

The sum intensity of the measured LIF signal, reduced by the unit laser energy, of OH radicals as a function of the water content is shown in Fig. 2 a). For all excited transitions, the maximum LIF intensity always appears when the admixture of water is around 0.3%. Meanwhile, the combination of
absolute line intensity (ALI) measurements and a colisional radiative model (CRM) give the electron temperature of \(~1\) eV with a margin of 10\%. Fig. 2 b) shows the results of \(T_e\) as a function of water content. It can be seen that substantial difference of \(H_2O\) effect on \(T_e\) between inside nozzle and in the atmospheric air. Inside the glass tube, a nearly linear decrease of the electron temperature with increasing water is observed. The effect of \(H_2O\) content on \(T_e\) inside nozzle supports that the discharge was operated in diffuse \(\alpha\)-mode. However, out of the nozzle, after the steep decreasing of electron temperature until \(~0.2\%\) \(H_2O\), the second peak of \(T_e\) appears around \(0.3\%\) \(H_2O\) where the reaction between \(N_2\) from air and metastable \(Ar\) should be taken in to account as well. Due to the comparably low gas temperature of \(500\pm50\) K in RF plasma jet estimated by optical emission spectroscopy of OH band and according to the relevant reaction rates [4], the dominant radical production mechanism is electron-ion recombination in the atmospheric RF plasma jet and the diminishment of LIF signal above \(0.3\%\) water content due to water quench.

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