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Optical emission spectroscopic (OES) analysis of electron temperature and density in atmospheric-pressure non-equilibrium argon plasmas

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Nowadays, atmospheric-pressure non-equilibrium plasmas have been applied widely to practical engineering, such as surface modification of metallic or organic materials, and particularly, possible medical applications are examined like coagulation or wound treatment. However, the practical measurement of the plasma parameters is still not established to find their electron temperature and density, to say nothing about the electron energy distribution function (EEDF), which becomes necessary to estimate the number densities of desired reactive species.

In the authors laboratory, optical emission from the atmospheric-pressure discharge non-equilibrium argon plasma is spectroscopically conducted over the near-UV and visible wavelength region [1]. Figure 1 shows the schematic diagram of the discharge apparatus, whose further details were described elsewhere [1]. The 50-Hz AC discharge power was supplied by a step-up transformer with its maximum voltage ~ 9 kVp-p.

First, line-intensity analysis assisted with the Collisional-Radiative (CR) model is reported [2]. There are several possible methods to interpret the line intensities with the CR model. Among them, for the measurement of argon plasmas of atmospheric-pressure, excitation temperature measurement is convenient for 4p and 5p lines owing to their large intensity. It is found that the excitation temperature of 4p-5p levels are not much affected by the electron density or the gas temperature in the low-T_e region, about 0.7 – 1 3 eV. The analysis of the line intensities assisted with the argon CR model indicates that the electron temperature of this plasma is estimated to be about 0.74 eV, whereas the electron density is difficult to determine but estimated to be the order of ~ $10^{12} – 10^{14}$ cm^{-3}.

On the other hand, the continuum radiation from these plasmas are now being focused on. The continuum

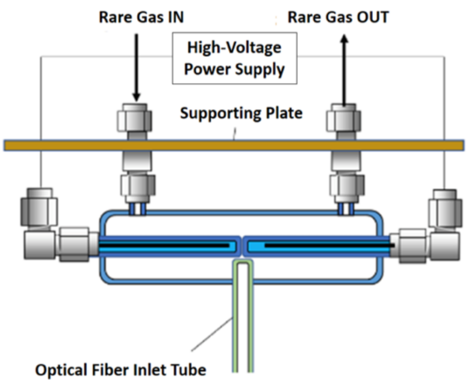

Fig. 1 Schematic diagram of the discharge tube. The electrodes are immersed in water in doubly sealed quartz tube. The outer tube is filled with the discharge rare gas.

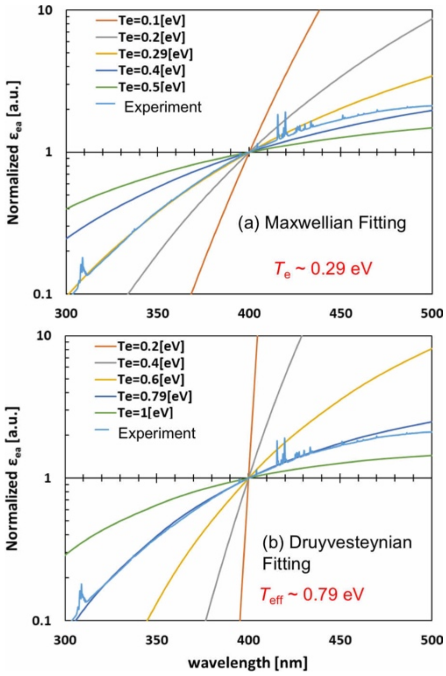

Fig. 2 Spectrum observed from the atmospheric-pressure non-equilibrium argon plasma for the wavelength range 300 – 450 nm, together with the theoretical fitting with (a) the Maxwellian EEDF and (b) the Druyvesteynian EEDF. In (b), T_{eff} is defined to be $kT_{eff} \equiv (2/3)\langle\varepsilon\rangle$, where $\langle\varepsilon\rangle$ is the electron mean energy and k is the Boltzmann constant.

emission is generated due to the bremsstrahlung of free electrons in the plasma against neutral particles with sufficient intensity in the near UV through visible wavelength range [3].

Figure 2 shows the OES result observed experimentally as a time average over a discharge period. By theoretical fitting procedure as explained later, we can determine the electron temperature for the Maxwellian EEDF, or the electron mean energy for the Druyvesteynian EEDF as the best fitting parameter. This fitting reveals that the experimentally observed spectrum is well described by the Druyvesteynian EEDF with the effective electron temperature $T_e = (2/3k)\langle\varepsilon\rangle \sim 0.79$ eV.

It is theoretically shown that the EEDF can also be determined from the OES measurement of the continuum emission from the atmospheric-pressure non-equilibrium plasma. This issue will be also remarked a little.

References

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