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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In the last 10-20 years, atmospheric-pressure plasma has become relevant in numerous new fields. This plasma is in thermal non-equilibrium with electrons of several electronvolt and neutral particles and ions around room temperature. This makes it a touchable plasma that is found to have uses in e.g. the medical, agricultural and food industry. Given the wide range of use of this cold atmospheric-pressure plasma, thorough understanding of its behavior is essential. Since the electrons are the only high-energy particles, they are usually responsible for the desired reactions inside the plasma. However, due to the relatively short history of this plasma, understanding of the electron energy distribution and the development of accessible electron diagnostics tools has not completed.

In this work, a novel electron diagnostics method for cold atmospheric-pressure plasma is developed that is capable of determining a partial arbitrary electron energy probability function (EEPF) from optical emission spectroscopy (OES) measurement. For this, the continuum emission spectrum is used, which is measurable with conventional OES equipment at atmospheric pressure. The continuum spectrum is dominated by electron-neutral free-free bremsstrahlung in the visible range. The intensity of neutral bremsstrahlung over the OES measurement range is related to the EEPF through an incomplete Volterra-like integral equation. Since no existing solving method was found for inverting this type of equation, a statistical method is created to obtain the EEPF from the continuum spectrum. Using EEPF simulation and statistical analysis accelerated by machine learning, a partial EEPF can be recovered by full utilization of a single OES measurement. For this, intensity-calibrated OES equipment is required as well as the relevant electron-neutral momentum-transfer cross section data.

In order to isolate the continuum spectrum from an OES measurement, a general method is developed to automatically remove the line spectrum from the OES measurement. This method relies on peak detection instead of an emission line database and replaces the detected peaks by a linear interpolation with optimized start- and end point for smooth connection.

With the simulated EEPF population, their corresponding continuum emission can be calculated. This is compared to the experimentally obtained isolated continuum spectrum. This provides the statistical information required to iteratively improve the simulation results and converge to the final EEPF result. Theoretical verification was successfully performed with an EEPF resolution of 0.15 eV and relative error below 1%. Two sets of experimental spectra were used. A pure argon dielectric barrier discharge (DBD) OES measurement set with changing discharge voltage from 3.6 to 6.3 kV and argon-helium mixture discharge measurement set with changing mixture ratio from 25% argon to 100% argon. It is observed that the continuum spectrum in pure argon with increasing discharge voltage increases in intensity uniformly with no significant changes to the shape of the continuum. On the other hand, with increasing argon fraction in the argon-helium mixture discharge, the spectrum intensity increased and its shape changed significantly. It is shown that this is not a result of the difference in momentum-transfer cross section, but rather a change in EEPF. The arbitrary EEPF of both sets was determined successfully using the developed method. It was observed that the obtained EEPF resemble a two-temperature Maxwell distribution. Using this two-temperature distribution, the electron temperature and relative number density of the bulk and high-energy electron groups could be obtained separately. For absolute electron number density determination, absolute intensity calibration of the OES setup is required.

From an OES spectrum, a partial EEPF has been obtained. This was used to make appropriate assumptions about the EEPF shape, leading to electron temperature and relative number density results, making electron diagnostics using the presented method successful.

The main limitation that should be considered is the EEPF determination range. This is mostly

determined by the OES measurement range. For example, a 300-800 nm wavelength spectrum corresponds to 1.5-4 eV photon energy, which will yield an EEPF with high resolution in the 1.5-4 eV electron energy region and low resolution in the higher electron energy region. A certain amount of information on the EEPF has to be present in the available continuum spectrum in order to reliably determine the EEPF. A wider OES measurement is desired since it includes a larger portion of the continuum spectrum, increasing the total amount of EEPF information available. In addition to the visible spectrum, the infrared spectrum would allow EEPF determination in the <1.5 eV electron energy region and the ultraviolet spectrum contains EEPF information on the >4 eV electron energy region.
In conclusion, electron diagnostics was successfully performed using the presented method. Since only an OES measurement and the momentum-transfer cross section is required, this method is highly accessible.