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# Studies of recombination processes of nano-second pulsed atmospheric-pressure plasmas using Thomson scattering
# トムソン散乱法を用いたナノ秒パルス大気圧プラズマの再結合過程研究

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Thomson scattering technique has been applied for measuring the spatiotemporal changes in the electron density ($n_e$) and electron temperature ($T_e$) of a capacity-coupled micro-discharge generated in neon gas at atmospheric pressure. A significant difference has been observed in temporal behavior between $n_e$ and $T_e$ in a recombination phase. The value of $n_e$ decreases monotonically after the plasma production. On the other hand, $T_e$ rapidly decreases to the region of 0.8 eV. These features are discussed based on the recombination processes.

## 1. Introduction

Non-thermal atmospheric-pressure plasmas have received attention as a result of their significant capacity for expanding the fields of application for plasmas, such as plasma medicine, and plasma chemistry. In applications of such plasmas, radicals generated in the plasma play key roles. Because the generation of radicals is strongly affected by free electrons in plasmas, measurements of the electron density ($n_e$) and electron temperature ($T_e$) are important for understanding plasma behavior.

In order to contribute to the understanding of non-thermal atmospheric-pressure plasmas, we have been developing a laser Thomson scattering (LTS) technique as a diagnostic method for measuring $n_e$ and $T_e$ in a micro-discharge produced in atmospheric pressure. A capacity-coupled discharge (CCD), which is a type of non-thermal atmospheric-pressure plasma, was selected as the target. Because the CCD can be designed more freely, controlling the position and generation starting time of the pulse is easier than controlling other discharge types, such as dielectric-barrier discharge (DBD).

In our previous research, the LTS technique has been applied to the CCD plasma. The results showed that the LTS technique is a powerful method for non-thermal atmospheric-pressure plasmas [1]. In this study, the same LTS technique has been applied to examine the spatial distribution and temporal variation of $n_e$ and $T_e$ in the CCD plasma.

## 2. Experimental Methods

The pulsed CCD electrical circuit is shown in Fig. 1, and a mono-polar steep voltage pulse was supplied to the needle electrode for 200 ns using a semiconducting switch (BEHLKE, HTS50-60). The discharge electrodes consisted of a needle electrode (φ = 1.6 mm, radius of curvature at the needle tip = 40 μm) and a hemisphere electrode (φ = 2.4 mm) with a gap length of 0.5 mm. Measurements were performed at five axial positions. Neon gas at a pressure of $5.3 \times 10^4$ Pa was used as a discharge gas.

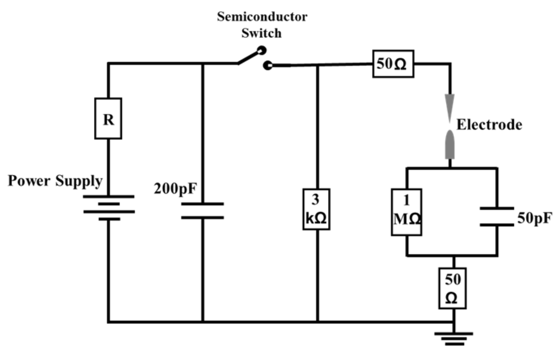


Fig. 1 Schematic of electrical circuit of capacity coupled discharge.

The LTS system was designed based on our Thomson scattering studies of atmospheric-pressure micro-plasmas.8, 9) The LTS light source was a second harmonics beam ($\lambda$ = 532 nm) of a Nd:YAG laser (Continuum, Surelite III). The laser beam, with an energy of 5 mJ (pulse duration of 10 ns, repetition rate of 10 Hz), was focused and injected to the electrode gap using a 200-mm focusing lens. In order to increase the signal-to-noise ratio, the LTS spectrum was accumulated over 2,000 laser-shot using the gated ICCD camera (Princeton, PI-MAX UNIGEN II, minimum gate width: 2 ns) and recorded by a computer-based data acquisition system.

The peak voltage and the current of the pulsed CCD were 3 kV and 13 A, respectively. The rise-up time of the discharge current was defined as $t$ = 0. The time jitter within + 2 ns was achieved for the repetitive discharge. This condition allowed us to keep reproducibility of the LTS signals at a fixed pulsed CCD time. A repetition rate of 10 Hz was set to be synchronized with the pulsed CCD with the incident laser beam.

## 3. Experimental results

Temporal variations of $n_e$ and $T_e$ was measured at the center of the discharge. As a result, it was found that the temporal variations of $n_e$ and $T_e$ were significantly differ. The electron density remained almost constant at a value of $4.5 \times 10^{22}$ $m^{-3}$ for the first 25 ns after the plasma production. Then, $n_e$ decreased monotonically to $1.4 \times 10^{22}$ $m^{-3}$ at 200 ns after the plasma production. Recombination can be considered to be the main process for decreasing $n_e$ since the power input to the discharge stopped at 20 ns after the plasma production. In this condition, two recombination processes should be considered: three-body electron-ion recombination and neon-dimer ion (Ne2+) formation followed by dissociative recombination.

## Reference

[1] K. Tomita, N. Bolouki, H. Shirozono, Y. Yamagata, K. Uchino, K. Takaki: J. Instrumentation 7 (2012) C02057.