Measurement of Electron Temperature and Density in Pulsed-Discharge Plasma above Water with Different Conductivities

Keisuke Iwasaki*, Kohki Satoh and Hidenori Itoh

Division of Information & Electronic Engineering, Muroran Institute of Technology, Muroran, 050-8585, JAPAN
s1724007@mmm.muroran-it.ac.jp

Agenda
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2. Experimental Apparatus & Conditions
3. Methods of Calculation
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Introduction

Water pollution which is caused by releasing non-degradable hazardous substances, such as trichloroethylene, tetrachloroethylene etc., have been a serious issue around the world.

Various methods and techniques to treat these pollutants have been developed.

Advanced Oxidation Processes (AOPs)

This methods, such as ozone-UV oxidation, photo catalytic oxidation, pulsed-discharge etc., have been used to purify polluted water.
Introduction

Pulsed-discharge

✓ Lukes et al. have reported that the species, which have high oxidation potential, such as OH radicals, O, O$_3$ etc., are produced by a pulsed-discharge plasma generated above a water surface$^{[1]}$, and proposed that the species can dissolve into the water, then react with pollutants in the water.

✓ Also, the pollutants can be decomposed by the high energy electrons and UV radiation generated by the pulsed-discharge plasma$^{[2]}$.

Effective water purification can be done by using pulsed-discharge plasma above a water surface.

- Substitutes of non-degradable hazardous substances had been treated using pulsed-discharge plasma, and these decomposition characteristics have been reported by many researchers.

- Characteristics of discharge plasmas have significant influence to pollutants decomposition, however, reports about plasma diagnosis are few as far as we know.


\[ V=14kV, \ d=4\text{mm}, \ exposure\ time\ T=1s, \ in\ Ar \]

Objective

To investigate fundamental characteristics of pulsed-discharge plasma.

We measure optical emission from the pulsed-discharge plasma, and deduce electron temperature and density in the discharge plasma by spectroscopic analysis.

Before starting this work, we checked recent work about diagnosis of pulsed-discharge plasma.

Namihira et al.[1] Electron temperature and density in pulsed-discharge plasma generated in water are $1.5 \times 10^4$ K and $10^{18}$ cm$^{-3}$, respectively.

In this presentation
Deduced electron temperature and density in pulsed-discharge plasma generated above a water surface with variations of water conductivity are reported.

Experimental Apparatus & Conditions

- High voltage pulses are generated by a Blumlein pulse-generator using two coaxial transmission lines.
- The coaxial transmission lines are charged up to 14 kV.
- Helium gas is used as a background gas, and is fed into the chamber at a constant flow rate of 3 L/min.
- Conductivity of test liquid is varied from 2 to 100, 200, 300, 400 and 500 µS/cm by NaCl addition.
- A gap length, namely, distance between a tip of needle and a surface of test liquid is fixed at 1 mm.
Discharge Plasma

Ocean photonics
Maya2000-Pro
 Resolution: $0.33 \text{ nm}$
A filament-like discharge is generated across the gap, and the discharge split into several branches.

Optical emission from the discharge is measured by a spectrometer with resolution of 0.33 nm.
Methods of Calculation – Line-Pair Method –

Theoretical intensity \( I_{ij} \) is represented by

\[
I_{ij} = \frac{hcA_{ij}N_i}{\lambda_{ij}} \tag{1}
\]

If measured plasma is assumed to be local thermal equilibrium, temperatures of electrons, positive ions and neutral molecules are equal in each other.

\[
T = T_e = T_i = T_n \tag{2}
\]

Since each energy levels about same kind of particles are dominated by Boltzmann’s distribution, density ratio between \( N_i \) and \( N_k \) is represented by

\[
\frac{N_i}{N_k} = \frac{g_i}{g_k} \exp\left( -\frac{E_i - E_k}{kT} \right) \tag{3}
\]

Eq.(3) is represented by substituting eq.(1) as shown

\[
\ln\left( \frac{I_{ij} \lambda_{ij}}{A_{ij} g_i} \right) = -\frac{1}{kT}E_i + \ln C \tag{4}
\]

\( h \) : Planck’s constant [Js]
\( c \) : Light velocity [m/s]
\( A \) : Transition probability [s\(^{-1}\)]
\( N \) : Particle density [m\(^{-3}\)]
\( \lambda \) : Wavelength of emission by a transition [m]
\( g \) : Statistical weight
\( E \) : Energy [J]
\( k \) : Boltzmann’s constant [J/K]
Methods of Calculation – Line-Pair Method –

Parameters of Cu atoms, emission intensity, wavelength, transition probability, statistical weight and energy are substituted into eq.(4).

Electron temperature is deduced from gradient of approximated line to plots of value of \( \ln\{I_{ij}/(λ_{ij}/g_i)\} \) versus \( E_i \).

Methods of Calculation – Analysis from Stark broadening –

**Stark broadening**

This spectrum broadening, which is caused by interaction between external electric field and electric dipole moment of an atom in discharge plasma, is main broadening and depends on the electron density.

*Blue line* represents theoretical Stark broadening calculated by Griem, and *red line* represents theoretical one recalculated by considering resolution of spectrometer used in this work.

Electron density is deduced directly from Stark broadening of H$_\beta$ spectrum.

Fundamental Characteristics of Pulsed-Discharge Plasma

![Graph showing electron temperature $T_e$ and electron density $n_e$ as functions of conductivity.]

- **2 µS/cm**
- **100 µS/cm**
- **200-500 µS/cm**

- Electron temperature $T_e$ drops with increasing conductivity.
- Electron density $n_e$ increases with increasing conductivity.
Electron Temperature in Pulsed-Discharge Plasma

Electron temperature is constant about $1.4 \times 10^4$ K regardless of variations of liquid conductivity.
Electron Density in Pulsed-Discharge Plasma

- Electron density decreases from $2.4 \times 10^{16}$ to $1.1 \times 10^{16}$ cm$^{-3}$ with increasing liquid conductivity, and tends to be constant in range from 200 to 500 $\mu$S/cm.

- Thickness of each discharge-branch tends to be uniform gradually with increasing liquid conductivity.

It is found that thickness of discharge-branch has relationship with electron density.
Conclusions

We generated pulsed-discharge plasma above water with difference conductivities. Then electron temperature and density are deduced by spectroscopic analysis.

- Electron temperature, which is calculated by line-pair method, is constant about $1.4 \times 10^4$ K regardless of variations of water conductivity.

- Electron density, which is deduced from theoretical Stark broadening of $H_\beta$ spectrum, tends to be constant about $1.1 \times 10^{16}$ cm$^{-3}$ in range from 200 to 500 $\mu$S/cm.

- Thickness of each discharge-branch tends to be uniform gradually with increasing water conductivity.
Thank you for your attention.