【Grant-in-Aid for Scientific Research (S)】

Innovative technology for controlled synthesis of reactive species by elucidating spatio-temporal dynamics of plasma-gas-liquid interfacial reactions

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Purpose and Background of the Research

●Outline of the Research

Since the invention of low-temperature atmospheric pressure discharge plasma, the interdisciplinary fields of medical, plant, and environmental science using atmospheric pressure discharge plasma have rapidly developed. When dealing with biomolecules such as cells and proteins, reactive species generated by plasma irradiation of a liquid containing cells are used, and it has been reported that short-lived reactive species with a lifetime of less than one second are particularly important.

The interface between plasma and liquid phase (plasma-gas-liquid interface) is a new interface involving plasma (Fig.1). For complete control of reaction products in the bulk liquid, the interface layer between the gas and liquid phase is an unknown factor, as shown in Fig.2, and understanding this interface layer is extremely important. However, this interface layer is a "missing link" that has not been studied experimentally or theoretically.

In this study, in order to fill this missing link, we will measure the spatio-temporal dynamics of the reactive species, charge, electric field, gas flow, and liquid shape interacting in the plasma-gas-liquid interface layer to clarify the unique chemical reaction processes and realize completely controlled synthesis of reactive species in the bulk liquid.

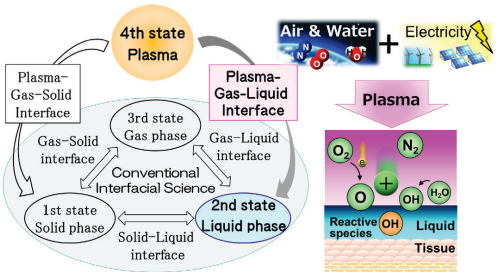

Figure 1. Plasma gas-liquid interface

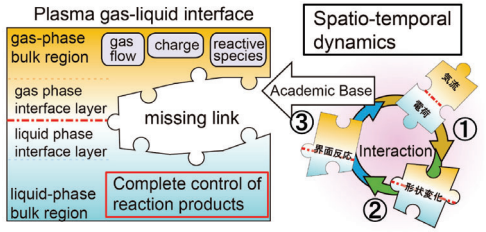

Figure 2. Importance of plasma-gas-liquid interface

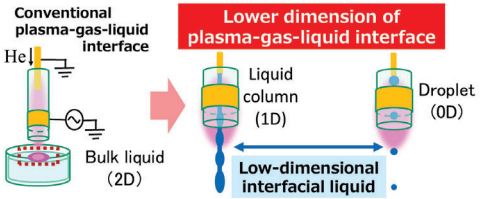

Figure 3. Plasma-gas-liquid interface studies using low-dimensional interfacial liquids

●Plasma-gas-liquid interface studies using low-dimensional interfacial liquids

In this study, we focused on "low-dimensional interfacial liquids" which are liquid columns that are axisymmetric and one-dimensional, and liquid droplets that are spherically symmetric and zero-dimensional (Fig.3). By using this low-dimensional interfacial liquid, various phenomena can be simplified and modeled, and the interaction of the three elements of charge/gas flow, liquid shape change, and interfacial reaction can be verified for the first time, and the spatio-temporal dynamics of the plasma-gas-liquid interfacial layer can be clarified.

Expected Research Achievements

●Technical and academic tasks to be performed

(1) Independently controlled supply of plasma-generated reactive species and charges to low-dimensional interfacial liquid (Fig.4)
Establish a new method for independent control of charge and reactive species by bringing "charge-controlled plasma" and "reactive species-controlled plasma" into contact with low-dimensional interfacial liquids.

(2) Various measurements at the plasma-gas-liquid interface (Fig.4)
[Flow velocity] The micro PIV system is used to measure the flow velocity.
[Electric field] The electric field is measured by EFISH method.
[Shape] Liquid shapes are measured using a high-speed camera with the shadow method.
[Charge & Potential] The liquid surface potential and the amount of charge are measured using an electrostatic probe.
[Reactive species] Short-lived reactive species are measured by reacting with selective chemical probes.

(3) Integrated simulation at the plasma-gas-liquid interface
Based on the experimental results, an interface reaction and charging model is constructed to simulate the behavior of liquid column flow and liquid droplets transporting short-lived reactive species that are generated and localized on the column/droplet surface layer by the interface reaction (Fig.5).

(4) Clarification of spatio-temporal dynamics and completely controlled synthesis of reactive species
We will elucidate the interfacial reaction dynamics through the interaction of electric charge, gas flow, and liquid shape change at the plasma-gas-liquid interfacial layer. Based on the results, we will establish an innovative chemical reaction process at the interfacial layer and realize a completely controlled synthesis technology of reactive species in the bulk liquid.
As a result, only the required reactive species can be selectively used, enabling the development of applications in many fields such as medicine, agriculture, environment, and materials, with extremely large ripple effects.

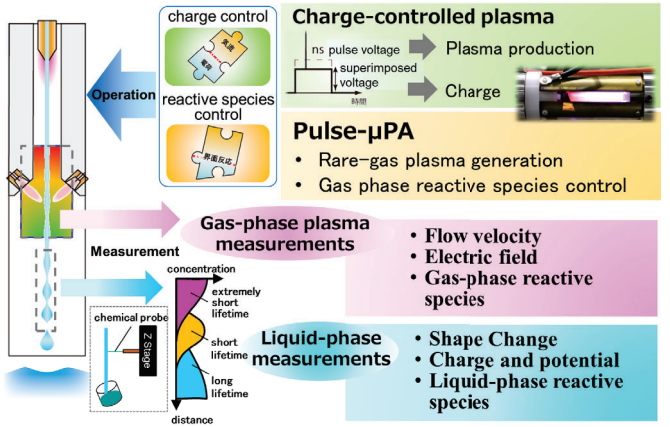

Figure 4. Controlled supply of charge and reactive species to low-dimensional interfacial liquids and plasma-gas-liquid interface measurements

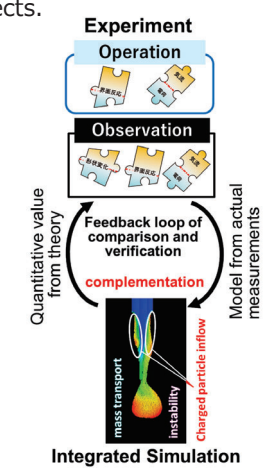

Figure 5. Simulation of liquid column flow and droplet behavior

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