S10-1 Generation and Control Techniques for Microplasmas
マイクロプラズマの生成と制御

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Solid, liquid, and gaseous materials with a small volume were used to generate microplasmas by electrical discharges. Atmospheric glow discharge developed in a dc discharge with a miniature gas flow from a nozzle electrode. Pulsed discharge mode appeared also in the discharge. When a microdrop of ethanol came into the gap between the needle electrodes, where dc voltage was applied, ultra-fast pulsed discharge developed and the spherical microdrop deformed to spray or a filament of liquid. The efficiency of energy input to powder particle discharges was improved by increasing the rate of current rize.

1. Introduction

Microplasmas are generated by electrical discharges between the electrodes where a material with a small volume is placed in open space. We name it a “mass-limited mode” of the discharge in which the volume of microplasmas is determined by both the mass of initial material and the separation of the electrodes, because there is no surrounding wall. Where spatially isolated small structure is obtainable, any state of matter such as solid, liquid, or gas can be used in this mode. To generate microplasmas, we used a powder particle for solid, a microdrop for liquid, and a miniature gas-flow. We characterize these three methods of microplasma generation.

2. Experimental Set-up

In the powder particle discharge[1], a copper particle with a diameter of 100 μm was placed between tungsten electrodes of 300 μm in diameter. The discharge was powered by a capacitor of 200 nF charged to 3 kV. In the microdrop discharge[2], a microdrop of ethanol generated by a micro dispenser (MJ-020 by MET Co.) was dropped into the discharge space. The droplet was sphere with the diameter of 300 μm at the minimum volume of 10 nl. A needle-to-needle and a sphere-to-sphere electrode system were used. The discharge appeared when the microdrop came near to the electrodes. In the miniature gas-flow discharge[3], helium or argon flowed longitudinally from a stainless nozzle with a 200 μm in inner and 350 μm in outer diameter to stainless mesh of 350 mesh/inch. Both the nozzle and the mesh worked as the electoredes, of which separation was varied from 100 to 1000 μm. The discharge was powered by a regulated dc power supply with a ballast resistor ranging from 0.1 to 5 MΩ connected in series to the nozzle electrode. All of the experiments were carried out in air.

3. DC Glow Discharge in Air

An atmospheric glow discharge is observed in the dc discharge with the helium gas flow. There are both bright and dark regions near the mesh cathode. A uniform bright region appears between the anode and the dark space. Its length increases with increasing the electrode separation. On the contrary, the lengths of the bright and dark region near the cathode do not change. The profile shows the glow discharge structure, which consists of a cathode glow, a Faraday dark space, and a positive column. When the electrode separation is varied from 200 to 1000 μm, the length of the positive column increases linearly.

The sustaining voltage increases with increasing the discharge current. The average power of the discharge ranges from 0.2 to 0.5 W. The voltage increases and the current decreases with increasing the electrode separation. The intensity of helium atomic lines emitted from the cathode glow is stronger than that from the positive column. At both the regions, the emission spectra of nitrogen molecules are observed. The gas flow affects both the lengths of the positive column and the cathode region. We observed their polarity effect by the direction of the gas flow. The change in length of the positive column is not clear for the electrode separation of 500 μm, when the helium flows toward the mesh cathode. However, it is pronounced for the discharge with the shorter electrode separation.

4. Self-driven Pulsed Mode of Microdischarges

Pulsed discharges develop in the gas flow and the microdrop discharge without any high-voltage pulse generator. The dc discharge with the gas flow was operated in such a way that the applied voltage was increased always from zero. When gas breakdown is initiated during the voltage increase, the voltage across the electrode shows a sudden drop and then a pulsed current with a peak of tens milliampere flows. The pulse-width of the current is tens nanosecond. The voltage starts to increase exponentially after the pulsed discharge has ceased. When the voltage recovers to the breakdown level, the pulsed discharge appears again. When the applied voltage is kept constant which is more than the breakdown voltage, the successive process mentioned above takes place repeatedly. The pulsed discharge is powered by parasitic capacitance, which is charged through the ballast resistance with an RC time constant related to the repetition period. The parasitic capacitance is determined to be 12 pF in our experiment. Fig.1 shows the dependence of the peak current and the repetition period on the capacitance and the ballast resistance. The repetition period becomes longer as the capacitance and the resistance increase.

In the microdrop discharge, pulsed discharge develops between the electrodes, to which a capacitor is connected in parallel. Ultra-fast pulsed discharges are possible because no switching device is necessary; therefore the residual inductance can be reduced substantially in the discharge circuit.

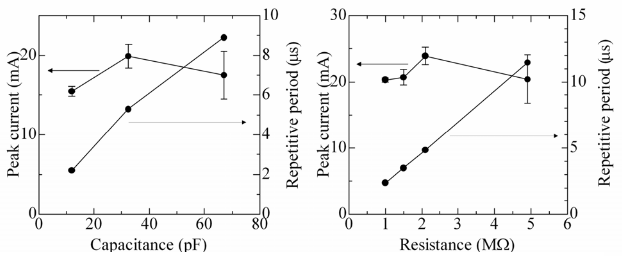

Fig.1. Dependence of peak currents and repetitive periods on capacitance and ballast resistance. Helium gas flow rate: 100 sccm.

5. Efficient Power Input to Microplasmas

The microdrop and the powder particle are heated by electrical discharges so that they show the phase transition from liquid or solid to gas and are finally ionized. The input energy is transferred to the materials in different ways according to their phase transition processes. The faster the rate of current rise is and the higher the accumulated energy between the electrodes is supplied before the vaporization of powder particle. The fast current discharge is realized by making the discharge system as small as possible to reduce the residual inductance.

The power loss in the ballast resistor is a drawback of dc discharges. The loss is reduced in the pulsed mode observed in the gas flow discharge, because the current is used only to charge the parasitic capacitance.

6. Control of Initial Structure of Small Matter

The initial shape of the materials is usually a small cylinder or a sphere in our experiments. We found that microdrop deform to spray or a filament by an electrostatic force acting between the electrodes. The deformation develops from the surface of electrode on which a small amount of liquid exists. Fig.2 shows a filament of ethanol bridging the gap between sphere electrodes. The filament protrudes from the tip of the Taylor-cone. When the electric field is higher, the electro-spray appears in a needle-to-needle electrode system. One can make an electrical discharge by using these initial shapes of liquid state.

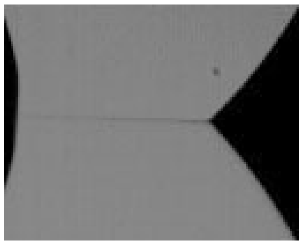

Fig.2. Filament of ethanol protruding from the tip of the Taylor-cone formed on the sphere anode; Gap separation is 700 mm.

7. Conclusion

The generation of microplasmas with the "mass-limited mode" using gas, solid, and liquid shows the features that are specific to the microplasma. Employing these features, a number of future applications are possible.

Acknowledgments

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References

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