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Simultaneous irradiation device of low-temperature plasma and ultraviolet light for surface treatment and sterilization

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Abstract: In recent years, since it has become possible to generate low-temperature plasma (LTP) ranging from room temperature to about 100°C under atmospheric pressure, it is starting to be applied not only in industrial fields, but also in medical and life fields. In this study, a prototype of a LTP-based device was developed, which is capable of simultaneous irradiation with low-temperature plasma and ultraviolet (UV) light. The prototype was evaluated and reactive species in the plasma that contribute to surface treatment and sterilization were measured.

Keywords: Atmospheric plasma, ultraviolet, sterilization, hydrophilization

1. Introduction

Recently, atmospheric low-temperature plasma has been widely applied in industrial and medical fields such as sterilization and adhesive strengthening. Dielectric barrier discharge (DBD) can generate large-area plasma at atmospheric pressure, thereby it is regarded as a highly efficient method. In DBD configuration, one/two dielectric materials such as glass plates are placed on the surfaces of two opposite electrode plates, and pulsed plasma between the electrodes can be generated when a high AC voltage is applied. Due to the thickness of the plasma zone that can be generated is generally several mm, it is used for treatment of sheet-like materials. However, because the plasma density is low in DBD, there is a problem that it cannot generate abundant active species that contribute to surface treatment and sterilization. Therefore, a novel method to improve the efficiency of DBD is required.

2. Simultaneous irradiation of plasma and UV light

Since the deep UV rays have sterilization effect like the plasma, the treatment efficiency is expected to be improved by the simultaneous irradiation of plasma and UV light. Although, it is difficult to excite and ionize the gas molecules in the ground state by ultraviolet rays of about 280 nm which can be obtained by the LED, if the atoms and molecules in the plasma are excited and ionized to the upper level by this ultraviolet irradiation, the plasma can be boosted into a higher energy state. Therefore, we proposed a DBD device using transparent electrode. The schematic view is shown in Fig. 1.

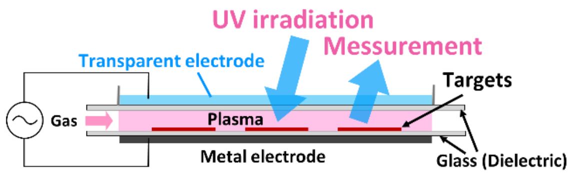

Fig. 1 Schematic of DBD device using transparent electrode

3. DBD device using transparent electrode

The plasma of conventional DBD device with metal electrode plates covered cannot be irradiated by UV light. Therefore, the DBD device using transparent electrode was designed and developed, which can realize simultaneous irradiation of plasma and UV light, even other lights. In addition, spectroscopic measurements of the plasma can also be performed to confirm distribution and change of active species. The prototype of DBD device is shown in Fig. 2. In this DBD device, NaCl solution is used as the upper electrode. Since the upper dielectric is made of silica glass, it can transmit the UV rays of 280 nm. The plasma generation area of the prototype device is 120 × 120 mm. The discharge gap between glass was 3 mm.

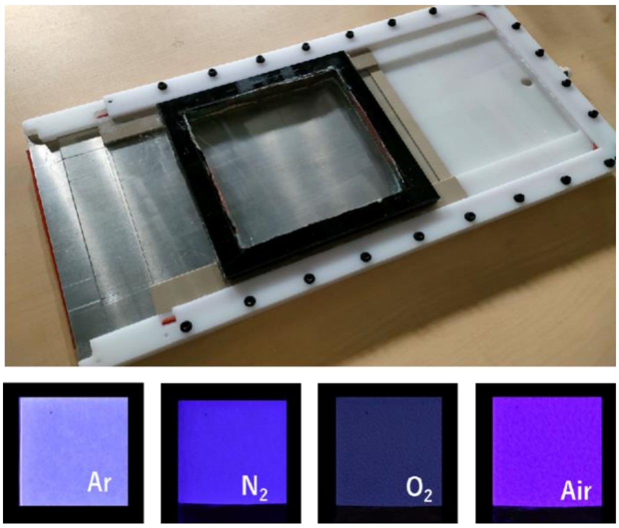

Fig. 2 Prototype of simultaneous irradiation device

3.1 Hydrophilization

In order to investigate the treatment uniformity and effect of the DBD device, plasma hydrophilization experiment was carried out for polyimide film with a size of 120 × 120 mm. Mapping of polyimide films treated with nitrogen plasma for 75 seconds was carried out. As a result, the polyimide surface was hydrophilized and the contact angle of water decreased from 69 to 27 degrees in all places. The relationship between the plasma treatment time and the contact angle of the polyimide surface is shown in Fig.3. It was confirmed that the longer the treatment time, the better the hydrophilicity of the polyimide. And when the contact angle was about 20 degrees, the hydrophilicity became saturated.

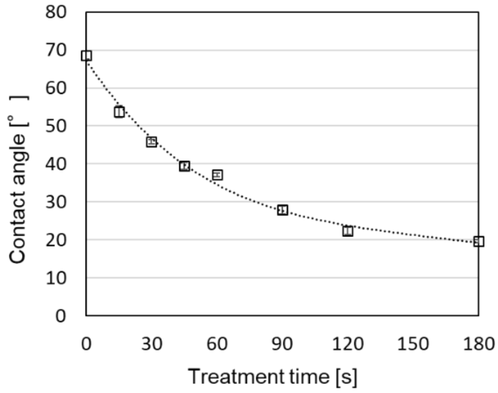

Fig.3 Contact angle change by N2 plasma treatment

In Fig. 4, the effects of plasma and UV treatment are shown. When treated only with UV, the polyimide surface was not hydrophilized. And plasma treatment effects of each gas species were different from each other. CO_2 plasma showed the highest treatment effect. While plasma and UV light irradiated simultaneously, the treatment effects of O_2 and Air plasma decreased and there was no change in other gases. The active species contributing to hydrophilicity in O_2 and Air plasma are considered to be decreased by the UV irradiation.

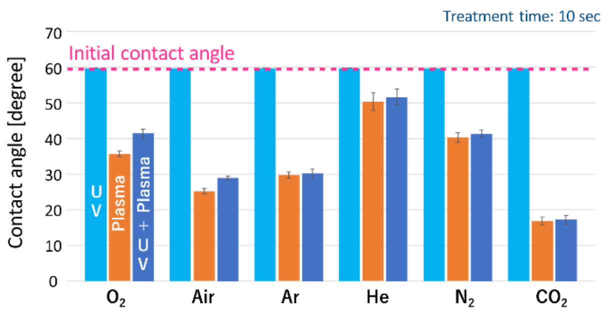

Fig.4 Hydrophilization effect by simultaneous irradiation of plasma and UV

3.2 Sterilization

Since DBD is able to treat planar object at a large area, Our group is conducting research on sterilization of banknotes. In previous study, it was shown that sterilization effect of DBD varies depending on gas type. And the sterilization efficiency of DBD was lower than that of general atmospheric pressure plasma. As described above, since UV light has ability of sterilization effect like the plasma, the sterilization effect by simultaneous irradiation of plasma and UV is investigated through the DBD device we developed in this study. Fig. 5 shows that the sterilization effects of O2 and Air plasma become about 2 times under the irradiation of UV. That means that the simultaneous irradiation device developed in this study has realized the enhancement of bactericidal efficiency. However, only based on the results of sterilization experiments whether there is a synergistic effect between plasma and UV cannot be confirmed. Molecules or atoms in the plasma are excited and more reactive species that are beneficial to sterilization are generated, which may produce a synergistic effect. Therefore, it is necessary to measure the change of reactive species in plasma under UV irradiation.

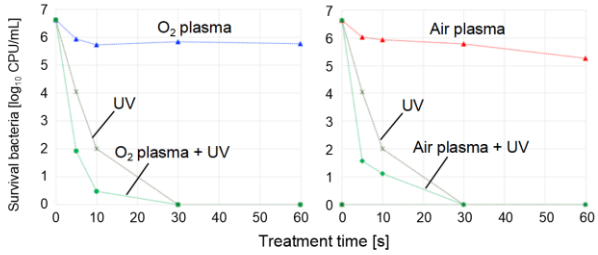

Fig.5 Sterilization effect under the irradiation of plasma and UV

4. Measurement of Reactive Species

It is reported that the mechanism of sterilization by plasma is centred on chemical destruction through reactive species with high oxidizing power generated by plasma[1]. Therefore, it is important to measure ozone and singlet oxygen generated by plasma. These reactive species are generally roughly divided into two categories by lifetime: long-lifetime and short-lifetime active species. On the one hand, the measurement of long-lifetime active species is usually performed by colorimetric analysis which is based on chemical color reaction. On the other hand, short-lifetime active species can be measured mainly by spectroscopic measurement. In this study, ozone, hydroxyl radical, singlet oxygen etc., are measured as shown in Fig. 6. By measuring these reactive species, evaluation and mechanism elucidation are expected about the sterilization effect with the simultaneous irradiation device. The change of plasma before and after UV irradiation can also be found out to evaluate whether a synergistic effect has occurred. In the presentation, we will compare the sterilization effect of plasma and UV simultaneous irradiation under various gases to evaluate the property of the simultaneous irradiation device, and report the measurement results of some reactive species.

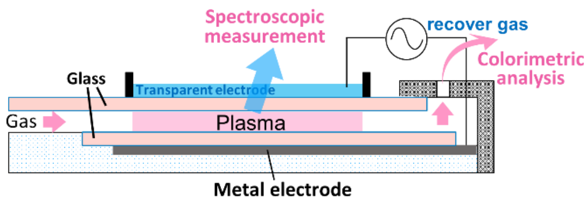

Fig.6 Measurement of reactive species

5. References

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