Generation of line-shaped atmospheric pressure plasma on planar surface with diffuse coplanar surface barrier discharge

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Abstract. A line-shaped uniform atmospheric pressure plasma was generated by diffuse coplanar surface barrier discharge on a planar surface. In this work, the plate is assumed as a wall panel in operation rooms. The wall panel sample, powered and grounded electrode lines were arranged alternately. Applying an negative high voltage pulse of $V=-4$ kV and $f=13$ kHz, a uniform atmospheric pressure plasma was observed between electrodes on the panel surface. The plasma had chemically active species of nitrogen molecule and nitrogen molecule ion which are effective for sterilization.

1. Introduction
Atmospheric pressure plasmas have received much attention as novel techniques for bio-application such as sterilization and bacteria inactivation [1-3]. In the application, reactive species originated from oxygen, nitrogen, and hydroxyl radical assume a key role [3].

In operation room of a hospital, wall panels are wiped off and cleaned by cleaning person after an operation in order to maintain cleanliness. This cleaning method has two problems. The one is that the labor force is needed for this work. The next is that an artificial error arises for the cleaning accuracy. In this study, a brand-new method for the cleaning of wall panels is proposed by using line-shaped atmospheric pressure plasma.

Figure 1 shows a schematic illustration of a wall panel in the proposing method. The wall panel, which is a dielectric material, has some line electrodes in the body. The adjacent electrodes are powered by pulsed high voltages, resulting in generation of line-shaped atmospheric pressure plasma on the wall surface by diffuse coplanar surface barrier discharge (DCSBD) [4-7]. In addition, the line-shaped plasma can be moved to the next electrodes by switching connection of the voltage and electrode lines. The switching of electrodes results in reduction of power supply capacity and cooling of the wall panel. The wall surface is exposed by the line-shaped atmospheric pressure plasma. Therefore the wall surface can be cleaned and sterilized automatically.

In this paper, a miniature-size wall panel sample, which has electrodes of DCSBD, was developed experimentally. Discharge property and optical emission spectrum of the generated plasma in a mixed gas of air and helium was evaluated.

2. Experimental procedure

2.1. Wall panel sample
Figure 2 shows a schematic cross-sectional view of a miniature size wall panel sample and electric circuit of DCSBD. The wall panel sample is made of polytetrafluoroethylene (PTFE) as a dielectric material. The wall panel sample has a size of length 197 mm x width 100 mm x thickness 10.3 mm. Some parallel stripline electrodes are embedded in the wall panel sample. Powered and grounded electrode lines are arranged alternatively. The electrode has a length of 157 mm, width of 1.0 mm, and thickness of 0.035 mm. The gap length between the powered and grounded electrodes is 1.0 mm. A distance between the electrode and the panel surface is 0.3 mm. The powered electrode lines are connected to a pulsed high voltage supply through reed relay switches S1-Sn. Turning on the switch S1 and turning off the switches S2 and S3, the plasma #1 is formed on the wall surface. Then the plasma #2 is formed by turning on the switch S2 and turning off the switches S1 and S3. Similarly, the plasma #3 is formed by turning on the switch S3 and turning off the switches S1 and S2. In this study, the only one switch of S1 is turned on experimentally, resulting in formation of the plasma #1.

2.2. Generation and measurement of diffuse coplanar surface barrier discharge plasma

Figure 3 shows an electrical circuit of diffuse coplanar surface barrier discharge generation and measurement. A wall panel sample was located in an acrylic acid case with the size of 200 mm x 200 mm x 50 mm. Helium gas, regulated by a flow meter (RK-1650, KOFLOC) was tentatively introduced into the case through a thin flex tube of φ6 mm in order to break down at lower applied voltage. Residual air was exhausted through a thin flex pipe of φ6 mm to the outside of the box. A pulsed negative high voltage generated by a collector resonance circuit was applied between a pair of electrode in the wall panel sample. The applied voltage was measured with a voltage divider (HV-P30, IWATSU) and a digital oscilloscope (TDS2024C, Tektronix). A current with discharge was measured with a current probe (A621, Tektronix) and the digital oscilloscope. Power consumption for the plasma generation was estimated by voltage-charge Lissajous plot. Electrical charge due to discharge was measurement as a voltage of a capacitance 0.1 μF.

A digital camera (DMC-GF5, Panasonic) was used for direct observation of diffuse coplanar surface barrier discharge plasma. Optical emission of diffuse coplanar surface barrier discharge plasma was evaluated by a multichannel spectrometer (SEC2000, BAS).
Figure 3. Electrical circuit of diffuse coplanar surface barrier discharge generation and measurement.

3. Result and discussion

3.1. Electrical property of diffuse coplanar surface barrier discharge

Figures 4 shows time evolutions of (a) applied voltage and (b) discharge current. The applied voltage has a peak value of -4 kV, pulse width (FWHM) of 15 μsec, and frequency of 13 kHz, respectively. The discharge current rises with the voltage. The peak value of the current is -0.3 A and the pulse width (FWHM) is 10 μsec. A positive current of 0.2 A and 18 μsec flows after the negative current.

Figure 5 shows a voltage-charge Lissajous plot of the diffuse coplanar surface barrier discharge plasma generation. Voltage-charge Lissajous plots of dielectric barrier discharge, generally, have a
parallelogram shape. The large gradient of the parallelogram indicates an equivalent capacitance of
dielectric material. Another gradient indicates a total capacitance of discharge area and dielectric
material. In figure 4, the total capacitance of the pair electrode system was estimated to be 156 pF. In
addition, the area of the voltage-charge plot gives energy consumption for the plasma generation. The
energy of 31.2 mJ was estimated as a consumed energy per a voltage cycle.

3.2. Observation of diffuse coplanar surface barrier discharge plasma

Figure 6 shows direct observation of the panel surface (a) without and (b) with applying the high
voltage. The photographs indicate the upper end of the panel in figure 3. As shown in figure 6 (b), a
line-shaped uniform plasma can be observed on the wall panel surface. The width of the plasma was
estimated to be 4 mm.

Figure 7 shows an optical emission spectrum of the diffuse coplanar surface barrier discharge
plasma on the wall panel sample. In the spectrum, some peaks originated from nitrogen and helium are
observed. The peaks of nitrogen molecules $N_2(C^3\Pi_u-B^1\Pi_g)$ are located at 315.8 nm, 337.1 nm, 353.6
nm, 357.6 nm, 371.0 nm, 375.4 nm, and 380.4 nm. The peaks of $N_2(C-B)$ are observed at 399.7 nm
and 405.8 nm. In addition, peaks of nitrogen molecule ion $N_2^+(B^2\Sigma_u^+-X^2\Sigma_g)$ are located at 391.4 nm
and 427.8 nm. The excited nitrogen molecules was generated the diffuse coplanar surface barrier discharge
in the mixed helium and air. In figure 7, chemically active species of originated from oxygen and
hydroxyl radical are not observed.

The excited nitrogen molecules radiate ultraviolet ray [3]. The UV emission are effective for self-
sterilization of the wall panel sample.

![Figure 6](image1.png)  ![Figure 7](image2.png)

**Figure 6.** Direct observation of diffuse coplanar surface barrier discharge plasma on the wall panel
surface.

**Figure 7.** Optical emission spectrum of diffuse coplanar surface barrier discharge plasma.
4. Conclusion
In this paper, atmospheric pressure plasma has been experimentally generated with diffuse coplanar surface barrier discharge. When the wall panel sample was powered by pulsed voltage of -4 kV and 13 kHz, line-shaped uniform plasma was formed on a wall panel sample surface. The diffuse coplanar surface barrier discharge plasma has excited nitrogen molecules and ions. The nitrogen molecules are effective for self-sterilization of wall panel sample surface since the molecules radiate ultraviolet rays.

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