EFFECT OF PLASMA DENSITY ON RESIDUAL BACTERIAL NUMBER AND APPLIED VOLTAGE

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Abstract: *Plasma basic ion implantation (PBII) with high negative voltage pulses has been applied to test specimens in a sterilization process as a technique suitable for three-dimensional workpieces. Pulsed high negative voltage was applied to the electrode in this process at the gas pressure of oxygen. It was reported that the PBII process reduced the numbers of active Bacillus pumilus cells using self-ignited plasma N_2 gas generated by only pulsed voltages. The number of bacteria survivors was reduced by 10^{-5} with a few min exposure. As the ion energy is the most important processing parameter, a simple method to estimate the oxygen ion energy calculated using distribution for oxygen in Si implanted by PBII was estimated. In this work, the Effect of Plasma Density on Residual Bacterial Number and Applied Voltage is studied.*

Keywords: ELECTRONS, IONS, PLASMA BASED ION IMPLANTATION (PBII), OXYGEN, PLASMA DENSITY

1. Introduction

Plasma is an ionized gas, which is a fourth state in addition to solids, liquids and gases. Technology that makes use of plasma is wide-ranging, especially that used in semiconductor manufacturing technology. As one example of this, there is thin film forming technology and microfabrication technology. These technologies have been developed in response to the higher integration and higher performance of integrated circuits and accompanying miniaturization of circuit patterns.

In addition to semiconductors, much research is being conducted on plasma application technology, including environmental improvement technology and medical related technology. In particular, application to biotechnology and medical care is being carried out [1] [2].

The plasma ion implantation method (PBII method), which is one technique that uses plasma, is applied to sterilization technology in the sterilization of medical equipment, etc. There are some plasma devices used for sterilizing medical equipment that use hydrogen peroxide [3].

However, it has been pointed out that there are effects on health. In order to find the technology needed to replace it, experiments on sterilization by the PBII method have been attempted [4].

Besides medical devices, microorganisms adhering to foods are also considered as objects for sterilization. In general, sterilization of food is done by heat sterilization. However, there is a danger that food quality will be impaired through the heating process. Thus, a new kind of non-heat sterilization method is attracting attention as a sterilization technique.

In this study, the energy of the implanted ions was evaluated in the sterilization using active gas (O_2) by the PBII method [5].

2. Bacteria culture method

Bacillus stearothermophilus was used as a test bacterium, and was cultured at 55 ° C for 1 to 2 weeks using a sporulation medium. The spores formed were confirmed with a microscope then the spores were collected with a platinum loop. The collected spores were heated at 80 ° C for 10 minutes, washed three times with a phosphate buffer using a centrifuge (room temperature, 1 minute, 12000 rpm), and the spores were heated again at 80 ° C for 10 minutes to obtain 1.0 × CFU / ml. This was used as test spore fluid.

3. Experimental device - method

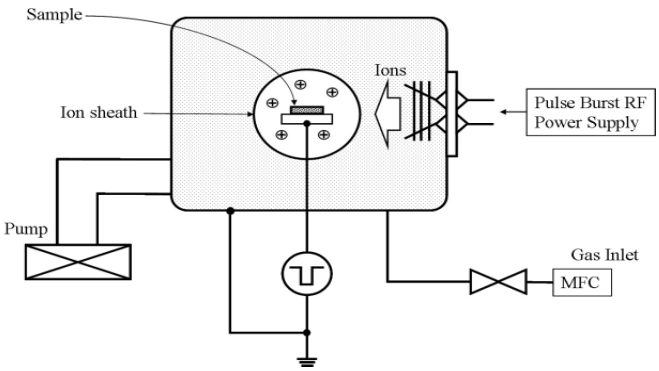

Fig. 1 *Schematic diagram of the experimental apparatus.*

The chamber size of this device is 485 mm in height, 590 mm in width and 470 mm in depth. The SUS target electrode has a diameter of 140 mm and a thickness of 20 mm, is insulated from the grounded chamber, and is installed at the center of the chamber. The high-pressure modulator (manufactured by Kurita Seisakusho Co., Ltd.) used in this experiment can irradiate the target with a pulse voltage of 2 to 30 μs with a pulse voltage of up to 15 kV with a maximum capacity of 1000 pps and a maximum of about 8 A.

For vacuum evacuation, use a rotary pump with a mechanical booster pump and mass flow together, evacuate the chamber to 10 Pa, and introduce oxygen gas (purity 99.99995%) to 1 kPa. After that, conditions are set by the computer control system and discharge is performed.

4. Calculation of plasma density

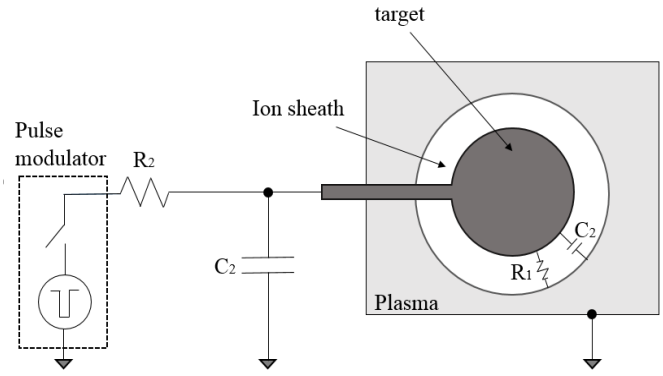

Fig. 2 *Modulator Equivalent Circuit.*

The constants representing the sheath are R_1 and C_1 in Fig. 2. Here we deal with a case where the ion sheath structure is flat, and the calculation of these constants will be described.

Generally, the ion sheath resistance R is determined by using the resistivity ρ, the length s of the object and the area A of the object.

$$R_1 = \rho \frac{s}{A} \quad (1)$$

Collision does not occur in the sheath. If the mass m of the ion species, the applied voltage V_p of the target, the electronic charge e, and the ion velocity v in the sheath,

$$\frac{1}{2} m v^2 = eV_p \quad (2)$$

$$v = \sqrt{\frac{2eV_p}{m}} \quad (3)$$

is obtained. On the other hand, the current density j at the target surface is expressed by conductivity σ and electric field E as:

$$J = en_i v = \sigma E = \sigma \frac{V_p}{s} \quad (4)$$

then, from:

$$en_i \sqrt{\frac{2eV_p}{m}} = \sigma \frac{V_p}{s} \quad (5)$$

$$\rho = \frac{1}{\sigma} = \frac{V_p}{s} \cdot \frac{\sqrt{m}}{en_i \sqrt{2eVp}} \quad (6)$$

comes

$$\rho = \frac{\sqrt{m}}{en_i s} \cdot \frac{\sqrt{V_p}}{\sqrt{2e}} \quad (7)$$

and

$$R_1 = \rho \frac{s}{A} = \frac{1}{en_i A} \sqrt{\frac{mV_p}{2e}} \quad (8)$$

is desired. Expression (8) shows that it is not dependent on sheath length. Also, by giving V_p to equation (8), plasma density n_i (ion density in sheath) on the target surface can be obtained by knowing R_1 by experimental values, etc.

Using the ion density n_i [m^{-3}] and the volume C [m^3] of the chamber, ~~for~~ the number of ions N [pieces] is:

$$N = C \times n_i \quad (9)$$

Using the frequency f [Hz], processing time t [s], and equation (3), the number of injected ions X [pieces] is:

$$X = f \times t \times Cn_i \quad (10)$$

$$Ie = X \times V_p \quad (11)$$

The energy per 1 eV $\backsim 1.602 \times 10^{-19}$ is subjected to ion energy and the unit is changed from [eV] to [J].

On the other hand, the ratio p [%] hitting the bacteria is calculated from the area S [m^2] of the fungus and the area A [m^2] of the target:

$$p = \frac{S}{A} \times 100 \quad (12)$$

to find the ion energy V_B [J] hitting the fungus from here:

$$V_B = Ie \times 1.602 \times 10^{-19} \times p \quad (13)$$

assuming that the number of sterilization is N_s [pieces], the energy Y [J] necessary for killing one bacterium is:

$$Y = \frac{V_B}{N_s} \quad (14)$$

5. Results and discussion

***Table 1**: Measurement conditions (pulse width).*

Gas	O_2
Gas Pressure [Pa]	3
Pulse Rate [pps]	500
Pulse Width [μs]	5,10,15,20
Pulse Voltage [kV]	-6
Delay time [μs]	50
RF Power [VA]	240
Exposure Time [min]	10

***Table 2**: Measurement conditions (delay time).*

Gas	O_2
Gas Pressure [Pa]	3
Pulse Rate [pps]	500
Pulse Width [μs]	5
Pulse Voltage [kV]	-6
Delay time [μs]	30,40,50,60,70
RF Power [VA]	240
Exposure Time [min]	10

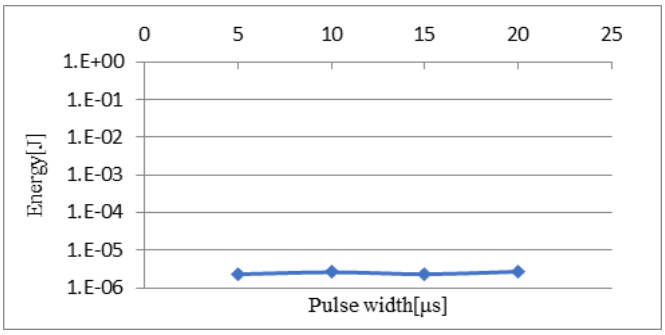

***Fig. 3** Pulse width - energy characteristics necessary to kill one bacterium.*

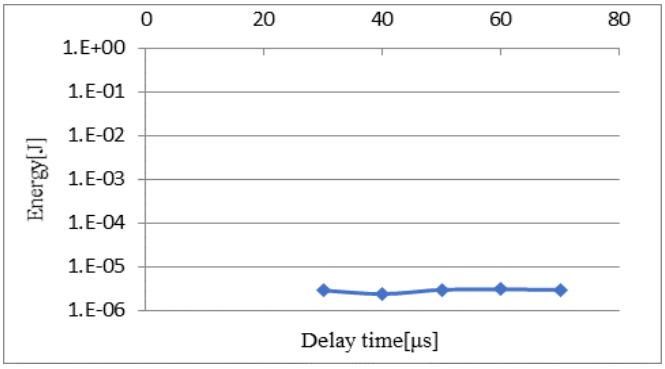

***Fig. 4** Delay time - energy characteristics necessary to kill one bacterium.*

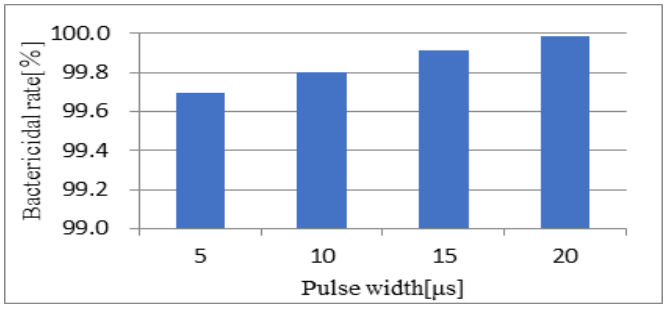

Fig. 5 *Bactericidal rate - pulse width characteristics.*

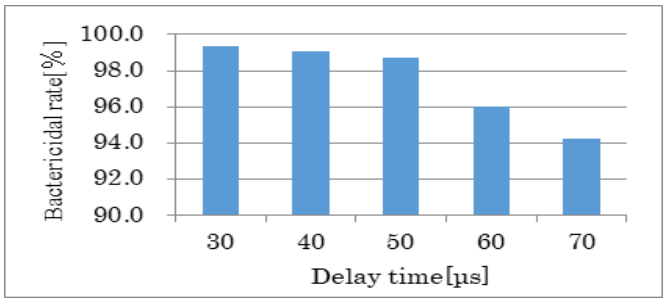

Fig. 6 *Bactericidal rate - delay time characteristics.*

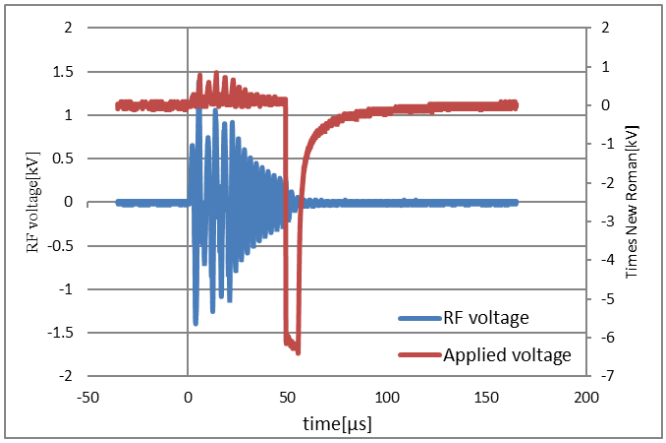

Fig. 7 *RF voltage and applied voltage.*

In Fig. 3, no significant change was observed between 30 and 70 μs.

In Fig. 4, no significant change was observed between 5 and 20 μs.

In Fig. 5, it can be seen that the sterilization rate increases as the pulse width increases.

Fig. 6 shows no significant change from 30 to 50 μs, but gradually decreases from 50 onward.

In Figures 3 and 4, the energy required to kill one bacterium is one and the same - between 2.35 x 10^{-6} [J] and 3.08 x 10^{-6} [J].

Therefore, it was found that even if the delay time and the pulse width were changed, the required energy was one and the same, so there was no change.

In Fig. 7, an external RF voltage is applied from 0 to 50 μs, and no RF voltage is externally applied after 50 μs.

From this, we see that there is a correlation between Fig. 5 in which the sterilization rate gradually increases between 5 and 20 μs, and in Fig. 6 in which this rate decreases after 50 μs.

6. Conclusion

Measurement was carried out with oxygen in this work. Superoxide, which is a free radical, shows sufficient activity in a short time and has high reactivity, microorganisms may be killed by the oxidizing action of these active molecules [7].

It is thought that the oxidizing action of ozone affects sterilization by sterilization under air and oxygen atmosphere [7].

From this, we would like to measure gas species from oxygen of active gas to inert gas such as nitrogen and argon in the future.

Also, if we change the number of bacteria, frequency and treatment time, we want to examine whether the energy required for killing one fungus is the same.

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