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플라즈마 표면 처리시 전도성 그리드를 통한 표면 입사 이온 에너지와 입사량 증대에 관한 분석 및 그 응용

조용성, 최원영, 박현동, 최준영, 이해준, 이호준, 박정후
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Analyses of incident ion energy and flux in plasma based surface treatment using a conducting grid

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Abstract - As Plasma Immersion Ion Implantation (PIII) using a conducting grid is very useful to reduce the effect of capacitance and charging in surface modification. If the bias voltage applied to the conducting grid is in the range of hundreds of volts, the effects of surface charge and space charge substantially affect the incident ion energy and ion current to the surface. In this paper, through an 1d and a 2d PIC simulation the time varying formation of the space charge and surface charge is analyzed. Experiment with the optimally designed grid on the basis of the simulation results is conducted, and the results of both cases with grid and without grid are compared. In our work with Poly Urethane(PU), the improvement of adhesion is yielded by increasing surface roughness and decreasing Si component of PU.

1. INTRODUCTION

The Plasma Immersion Ion Implantation (PIII) method is useful for modifying the surface of materials due to high ion flux, high sample throughput and its cost effectiveness. The fields adapting the method have been broaden in the biomedical and polymeric industries[1]. However, still now there is much room for technical improvement in PIII. When the material to be treated is an insulator, the voltage on the surface is reduced due to the dielectric capacitance and charge accumulation on the surface, which is an obstacle to the effective surface treatment[2][3].

As one of the solution Matossian et al. have proposed the novel method of PIII using a conducting grid above the surface of a material in the dielectric treatment[4]. This is very useful to enhance the ion implantation energy by high voltage biasing to the grid. Voluminous experiments applying the concept for the effective surface treatment have been conducted in high voltage bias system since then[5][6][7].

In this paper, plasma-based ion beam generated by using the conducting grid is applied to the sputtering and local restructuring of the atomic arrangement of Poly Urethane to improve the adhesion. The biased voltage level used in this study is much lower than that used in ion implantation, because in some specific materials like Poly Urethane the optimization of surface properties is satisfied better with low energy ions, on the order of hundreds of eV, than high energy ions[8]. This surface treatment system is promising when the material has very low value of relative permittivity or it is very thick, resulting in reduction of the surface voltage[9]. In addition, it is costly effective because it doesn't need high voltage power system. However, more delicate numerical and theoretical analyses are needed to acquire the effective surface treatment. Though the forces among the particles moving to the surface can be ignored in ion implantation of high voltage level, they become a dominant factor in low energy level. Thus, the effect of surface charge and space charge is very crucial to the sheath dynamics in the process of low energy level.

2. SIMULATION

2.1 Particle-In-Cell (PIC) Simulation

The sheath dynamics with a conducting grid is studied in this research through a one-dimensional and a two-dimensional PIC simulation. The simulation setup is schematically illustrated in Fig. 1. The conducting grid is configured by using transparency concept not considering the size of grid holes in one-dimensional simulation.

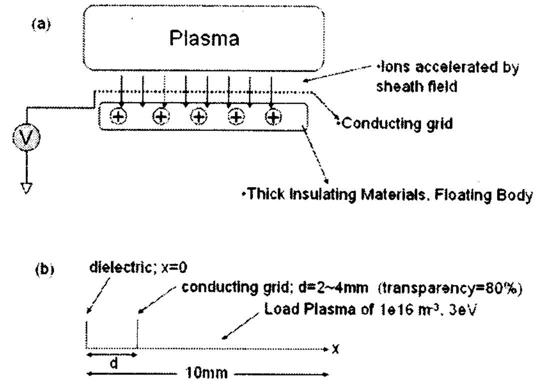

Fig. 1. (a)Conducting grid assisted plasma treatment system (b)One dimensional geometry

2.2 Results

Fig. 2 depicts the evolution of sheath dynamics right after biasing a negative voltage pulse(-200V). As soon as the bias is applied to the conducting grid, ions accelerated across the sheath toward the gird and electrons are driven away from the grid. Initially accelerated ions rush to the insulating surface without any effect of space charge and surface charge. Ions that leave the grid later are affected by the space charge formed by the preceding ions, and cannot reach the surface due to deceleration by potential barrier.

Ion energy and currents (Fig. 3) on the insulating surface depend on the bias voltage applied to the conducting grid. When the bias voltage to conducting grid increase, the ion energy and currents also increases. However, the increasing rate is not in proportion to the bias voltage. The reason is as follows. The time that ions are fully accelerated when a pulse applied is related to the ion transit time in sheath region[10].

$$\tau_i = \frac{3s}{v_o} = \frac{3s}{\sqrt{\frac{2eV_o}{M}}} = 221\,ns \qquad (1)$$

where s is the sheath width

Meanwhile, the peak of the ion current passing through the grid is observed at about 30 ns which is much shorter than the ion transit time.

$$J = \frac{\sinh T}{\cosh^2 T} + \frac{2}{9} \times \frac{1 + T\sinh T - \cosh T}{\cosh^2 T} \qquad (2)$$

where $J=j/en_0u_0$ is the normalized current density and $T=w_{pi}t$ is the normalized time[11].

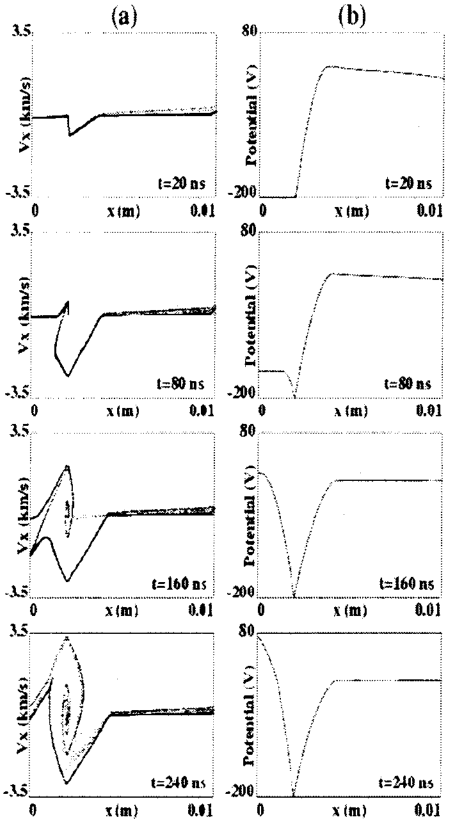

Fig. 2. t-evolution of (a)ion velocity and (b)potential after a negative voltage pulse has been applied

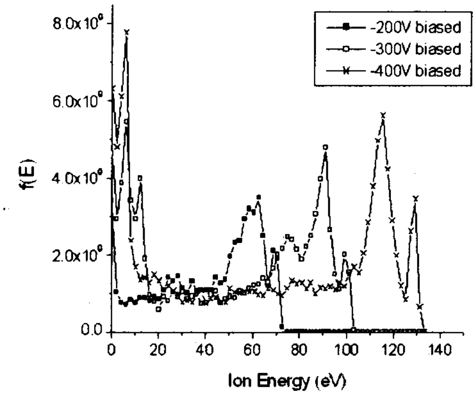

Fig. 3. Ion Energy Distribution Function (d=2mm)

In this analytical solution, the maximum ion current occurs at about 40 ns, which is similar to the numerical solution. Thus, the ions which are not fully accelerated move toward the surface.

Fig. 4 shows the IEDF with respect to the distance between the surface and the grid. The shorter the distance is, the moving ions are less affected by space charge, resulting in increase of ion currents. It is observed an unprecedented phenomenon that the number of ions with higher energy is increasing in the case of long distance. It is explained that as

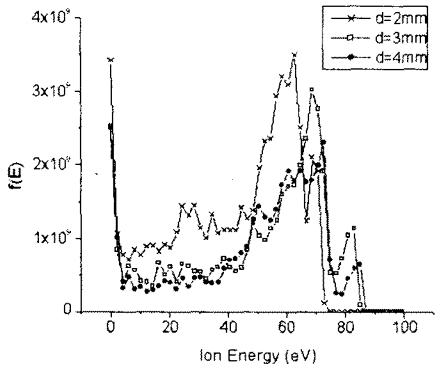

Fig. 4. Ion Energy Distribution Function w.r.t. the grid location

mentioned above, ions not fully accelerated form the space charge when move to the surface, and it prevents the following ions with high energy from moving to the surface with decelerating them. In the process, the preceding group of ions are accelerated toward the surface from grid.

Two-dimensional simulation is also conducted to consider the effect of the conducting grid hole size in surface modification. The hole size is very critical factor that controls the ion flux from plasma bulk region to the insulating surface. And it should be designed to be able to remove the accumulated charge on the surface for continuous treatment. Hence, it is shorter than the sheath length to prevent electrons from influx through the grid during the negative voltage pulses applied time and longer than Debye length at least to neutralize effectively by attracting electrons into the surface as soon as the conducting grid is grounded. In this article we simulated in cases of the hole size of 0.4×0.4, 1×1, 2.2×2.2 mm^2. As seen in Fig. 5, though the ion energy is the highest in the case of 0.4×0.4 mm^2, the current is too low. And in the case of 2.2×2.2 mm^2, the ion energy is the lowest.

3. EXPERIMENT

3.1 Experimental Apparatus

The system used to improve the adhesion power of Poly Urethane of which thickness is 10 mm is shown in Fig. 1. The surface treatment using a conducting grid was carried out in a 5 mTorr binary gas (Ar/O$_2$ = 50:50) atmosphere at a rf power of 500 W. The bias applied to the conducting grid constitutes series of negative pulses in the range of hundreds of volts.

As mentioned above, design of conducting grid is very important because the grid should be able to control the flux delicately with respect to the applied

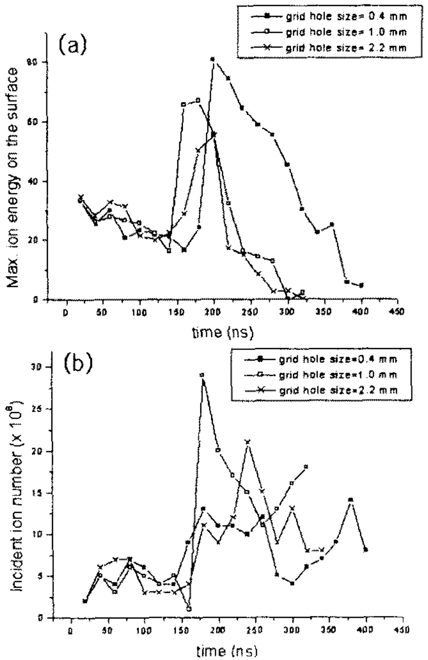

Fig. 5. t-evolution of (a)ion energy and (b)ion current on the surface after a pulse biased

voltages. Plasma density and electron temperature were measured first to determine Debye length and sheath length by Langmuir probe measurement [10][11][12].

Debye length

$$\lambda_D = \sqrt{\frac{\epsilon_o k_B T_e}{n_o e^2}} = 7430\sqrt{\frac{T_e}{n_o}} = 0.13\,mm \qquad (3)$$

Matrix sheath length

$$s = \left(\frac{2\epsilon_o V_o}{e n_o}\right)^{\frac{1}{2}} = \lambda_D\left(\frac{V_o}{T_e/2}\right)^{\frac{1}{2}} = 1.5\,mm \qquad (4)$$

Child law sheath length

$$s = \frac{\sqrt{2}}{3}\lambda_D\left(\frac{2V_o}{T_e}\right)^{\frac{3}{4}} = 2.4\,mm \qquad (5)$$

The size of the square holes of the conducting grid is decided optimally as the size of 1×1 mm^2 in this system (n_e=1×10^{16} m^{-3}, Te=3 eV), and the location is several millimeters above the surface of Poly Urethane.

3.2 Results

As Fig. 6 shows, the incident ion energy into surface is much more enhanced by using grid, resulting in the elevated roughness of surface. The RMS roughness is (a)75nm, (b)89nm, and (c)147nm

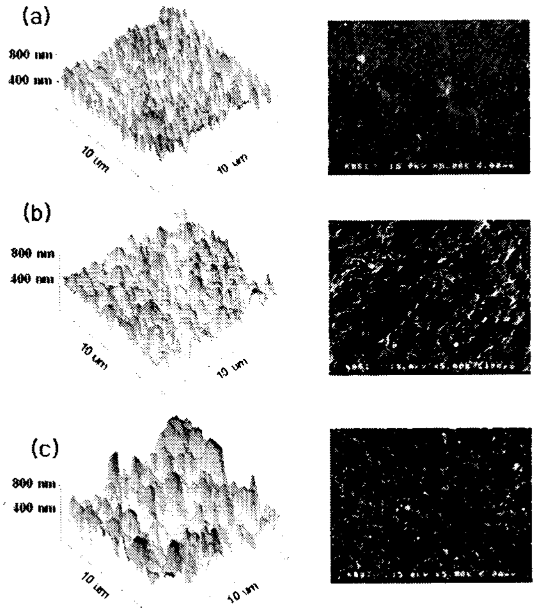

Fig. 6. (10×10)um 3d-AFM images and SEM images of Poly Urethane surface (a)raw material (b)plasma treatment without grid (c)plasma treatment with grid

respectively. Additionally, the Si component which weakens the adhesion power of PU is decreased by using the conducting grid from XPS data. As a result, the adhesion power is enhanced by 57 % in materials which are hard to be modified and destruction of the material is occurred in some soft materials in the adhesion power test, which means perfect surface treatment.

4. CONCLUSIONS

In surface treatment, the ion energy and currents are main factors, and control of those is possible relatively in easy method by using a conducting grid above materials without changing bulk plasma parameters. When the bias voltage is the order of hundreds of eV as handled in this paper, the analyses of sheath dynamics are needed in order to acquire accurate treatment. The rising time of pulses and the distance between the surface and the grid should be short in order to enhance the ion energy and increase ion currents. The square hole size of the conducting grid should be between Debye length and sheath length which are calculated from the plasma parameters in the system for adequate flow control and neutralization.

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