Atmospheric Pressure Plasma Ashing of Photoresist Using Pin to Plate Dielectric Barrier Discharge

***JaeBeom Park*[1], *JongSik Oh*[2] *and GeunYoung Yeom*[1,2]**
[1]**SKKU Advanced Institute of Nano Technology(SAINT), Sungkyunkwan Univ, Suwon, Kyunggi-do 440-746, South Korea**
Tel.:82-31-299-6562, E-mail: beummi@skku.edu
[2]**Dept. of Advanced Materials Engineering, Sungkyunkwan Univ, Suwon, Kyunggi-do 440-746, South Korea**

Keywords: atmospheric pressure plasma, DBD, ashing, PR, plasma discharge

Abstract

In this paper, we studied about atmospheric pressure remote plasma ashing of photoresist(PR), by using a modified dielectric barrier discharge(DBD). The effect of various gas combinations such as N_2/O_2, N_2/O_2+SF_6 on the changes PR ashing rate was investigated as a function of power. The maximum PR ashing rate of 1850 nm/min was achieved at N_2 (70 slm)/ O_2 (200 sccm) + SF_6 (3 slm). We found that as the oxygen and fluorine radical peaks were increased, the ashing rate is increased, too.

1. Introduction

Currently, the most of the plasma processing for FPD materials is mainly performed using low pressure plasma. However, the increasing substrate area and the advent of flexible displays as the next generation FPDs demands the processing equipments with low cost, no vacuum processing, easier scalability, etc. Atmospheric pressure plasma equipment might be one solution. One of the candidates for FPD in-line processing is atmospheric pressure plasma processing. Many atmospheric pressure plasmas such as DBD[1], capillary electrode discharge[2], microwave discharge[3], plasma jet[4], and hollow cathode discharge[5], have been investigated.

Among the various atmospheric pressure plasmas discharge sources, the DBD which is consisted of two parallel electrodes covered by dielectric plates has been studied most widely due to the easier generation of stable glow discharges. That's why direct plasma-type DBD is generally used in FPD processing because it is a glow discharge-type that can provide a uniform plasma over the large substrate area [6]. But, filamentary and arc discharge frequently occurred between two electrodes during the operation of the DBD and the substrate is easily damaged during the processing. In addition, low processing rate due to low plasma density of the conventional DBD source is another problem. These disadvantages can be overcome by using a remote plasma-type. Because remote plasma does not contact the substrate directly, the substrate can avoid from any kind of radiation damage from the plasma. And, one may also have more control over radical flux[7]. In this paper, dry ashing process for photoresist (PR) has been studied using a remote-type modified DBD. And the effect of gas combination of $N_2/O_2/SF_6$ on the PR ashing characteristics and the discharge characteristics was investigated.

2. Experimental

In this study, a pin-to-plate DBD consisting of a multi-pin power electrode instead of a planar power electrode was used to generate high-density plasma at low breakdown voltages[8]. Therefore, the pin-to-plate type appeared to be more efficient compared to the conventional DBD-type. Fig. 1 shows the schematic diagram of the system used in the experiment. The discharge system was composed of a power electrode having multi-pins and a blank ground electrode.

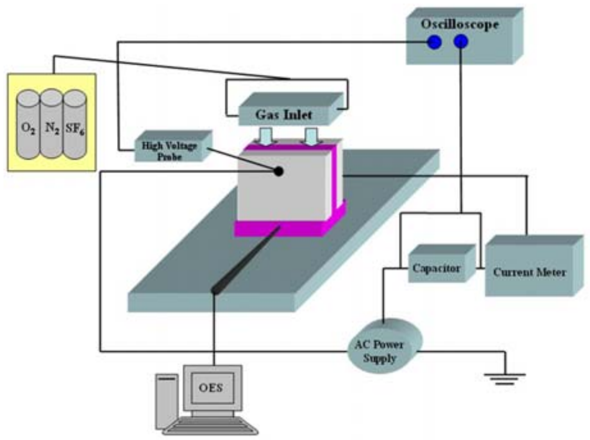
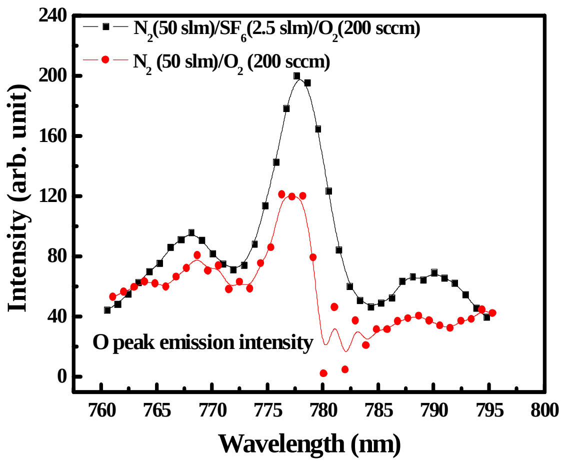


Fig. 1. Schematic diagram of the remote-type atmospheric pressure discharge system.

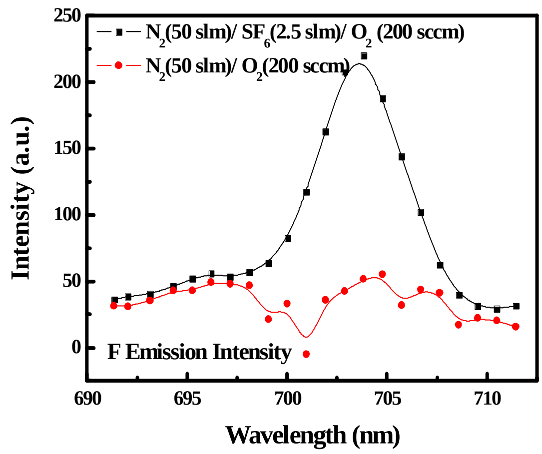
Both electrodes were deposited with 300 µm dielectric materials. The top electrode was connected to AC (Alternating Current) power supply while the bottom electrode was grounded. The AC power system was used for plasma generation has maximum frequency of 30 KHz and maximum power of 4 kW. The input voltage in our study was varied from 6.5 kV to 8 kV(rms voltage), which ensures stable and uniform plasma, and the frequency was fixed at 30 kHz, processing time was 30 sec. N_2 gas was used as a feeding gas while SF_6 and O_2 were used for reactive gas. The sodalime glass was used as the substrate. The PR, AZ 1512 was etched in this study. In this atmospheric plasma discharge system, Electrical values such as peak to peak voltage, discharge current, are recorded on the oscilloscope (Tektronix TDS 340A). The PR ashing rate was estimated by measuring the ashing depth using a step profilometer (TENCOR, alpha-step 500). Optical emission intensity of the atmospheric pressure plasma was measured using an OES (Optical Emission Spectroscopy, PCM 420 SC-Technology) in order to detect radicals or activated species in the plasma.

3. Results and Discussion

Fig. 2 a) and b) show the O and F atomic emission spectra for N_2 (50 slm)/O_2 (200 sccm) and N_2 (50 slm)/O_2 (200 scccm)/ SF_6 (2.5 slm). As shown in Fig. 2, the addition of SF_6 gas to N_2 (50 slm)/O_2 (200 sccm) gas composition showed F emission optical emission spectra clearly at 700 ~ 705 nm. Also the O emission intensity was increased after SF_6 gas addition to N_2/O_2 gas composition[9].



(a)



(b)

Fig. 2 Optical emission intensities of a) O peak and b) F peak[9] measured for the discharges of N_2 (50 slm)/O_2 (200 sccm) and N_2 (50 slm)/O_2 (200 sccm)/SF_6 (2.5 slm).

These results by adding a SF_6 gas were believed to be caused by penning ionization/ dissociation induced during the atmospheric pressure plasma discharge. The addition of SF_6 causes the ionization/dissociation of O_2 further by the collision of metastable F with O_2 as studied by Massinesa et al.[10].

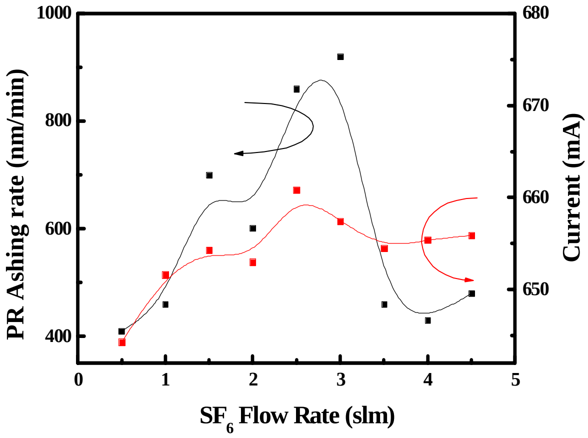


Fig. 3. PR ashing rate and discharge current measured as a function of the SF_6 flow rate at N_2(50 slm)/O_2(200 sccm)[9].

The discharge current and PR ashing rate were measured as a function of SF_6 flow rate and the result is shown in Fig. 3. Input voltage was fixed at 8 kV(AC). PR ashing rate and discharge current showed the similar trend, so the highest discharge current and PR ashing rate were obtained at 3 slm of SF_6. The maximum PR ashing rate of about 920 nm/min was obtained at N_2 (50 slm)/O_2 (200 sccm)/SF_6 (3 slm). Also highest discharge current value of about 660.8 mA was obtained at the same conditions. But as SF_6 gas was increased more than 3 slm, PR asing rate was decreased to 430 nm/min. Also, the discharge current was saturated or slightly decreased when the SF_6 flow rate was higher than 3 slm. The increase of PR ashing rate with the addition of SF_6 up to 3 slm, is believed to be related to the increase of etchant. Not only oxygen related atom or radical, F related radical also good PR etchant, so by adding SF_6 gas in N_2/O_2 gas composition, more PR etchants participate in the PR ashing process. Also, more F atom or radicals are induced by the enhanced ionization/dissociation with the SF_6 gas addition to the gas composition. The addition of SF_6 to N_2/O_2 higher than a certain amount decreases electron density in the plasma by forming electronegative ions due to the high electronegativity of O(3.5) and F(4.0) and tends to change from glow discharge to arc or filamentary discharge. The change of a glow discharge to a filamentary discharge could be also observed by the decrease of the discharge current and process efficiency.

N_2 gas in the gas mixture composed of N_2/O_2 (200 sccm)/SF_6 (3 slm) was varied and the effect of N_2 flow rate on the PR ashing rate and the optical emission intensities of O and F were investigated and the results are shown in Fig. 4[9]. The input voltage was fixed at 8 kV. The increase of N_2 flow rate increased the PR ashing rate until 70 slm is reached. The maximum PR ashing rate was about 1850 nm/min at the gas mixture of N_2 (70 slm)/O_2 (200 sccm)/SF_6 (3 slm). The optical emission intensities of O and F were also increased with the increase of N_2 flow rate up to 70 slm. In the case of remote plasma sources, active species are transported from the plasma source to the substrate. In this experiment, the optical emission intensities were measured at the location between the source and the substrate.

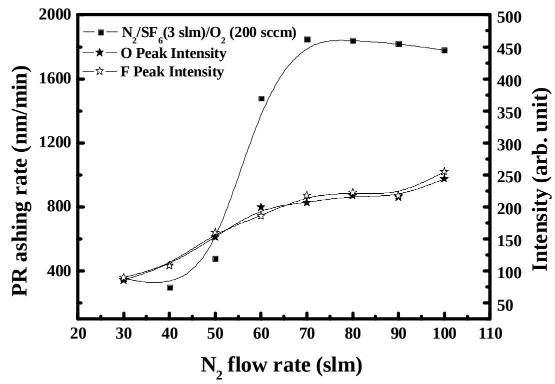


Fig. 4. The PR ashing rate and O and F optical emission intensities as a function of N_2 flow rate (30~100 slm) with O_2 (200 sccm)/SF_6 (3 slm)[9].

Therefore, the increase of optical emission intensities from O and F atoms is related to the increased transport of the species to the substrate before recombination. But as the N_2 flow rate was increased higher than 70 slm, the residual time of O_2/SF_6 was shrunk down. Consequently, the ionization and dissociation process of O_2/SF_6 gases were decreased, and PR ashing rate was decreased due to the decrease of O and F related radical species.

4. Summary

In this study, atmospheric pressure remote plasmas were generated by using a modified DBD called pin-to-plate DBD and the effect of gas combinations of $N_2/O_2/SF_6$ on the effect of PR ashing rate and its plasma characteristics were investigated. The addition of SF_6 (3 slm) to N_2 (50 slm)/O_2 (200 sccm) increased the PR ashing rate due to the increase of PR etchant and enhanced dissociation by the penning ionization. However, the further increase of O_2 and SF_6 decreased the PR ashing rate due to the decrease in the PR etchant by the transition of the discharge from a glow discharge to a filamentary or arc discharge. By optimizing $N_2/O_2/SF_6$ gas mixtures, the highest PR ashing rate of 1850 nm/min could be achieved at N_2 (70 slm)/O_2 (200 sccm)/SF_6 (3 slm).

Acknowledgement

This work was carried out for the Direct Nano Patterning Project supported by the Ministry of Knowledge Economy under the National Strategic Technology Program.

5. References

1. Q. Y. Nie, C. S. Ren, D. Z. Wang, S. Z. Li, J. L. Zhang, and M. G. Kong, *Appl. Phys. Lett.*, **90**, p.221504 (2007).
2. S. J. Kyung, Y. H. Lee, C. W. Kim, J. H. Lee, and G. Y. Yeom, *Carbon*, **44**, p.1530 (2006).
3. J. T. Krile, A. Neuber, H. G. Krompholz, and T. L. Gibson, *Appl. Phys.Lett*,. **89**, p201501 (2006).
4. Y. Sakurai, T. Kobayashi, Y. Hasegawa, and H. Shirai, *Jpn. J. Appl. Phys.*, **44(1)**, p749 (2005).
5 T. I. Lee, K. W. Park, H. K. Baik, and S. M. Lee, *Appl. Phys. Le.*, **87**, p261502 (2005).
6. C.H. Yi, Y.H. Lee, G.Y. Yeom, *Surf. Coat. Technol.*, **171**, p237 (2003).
7 M. J. Kushner, *J. Appl. Phys.*, **71**, p4173 (1992).
8 Y.H. Lee, S.J. Kyung, C.H. Jeong, G.Y. Yeom, *Jpn. J. Appl. Phys.*, **44(2)**, p78 (2005).
9 J. B. Park, S. J. Kyoung, G. Y. Yeom, *Jpn. Jour. Appl. Lett.*, **46(38)** pL942 (2007)
10 F. Massinesa, P. Se ´ gurb, N. Gherardi, C. Khamphan, and A. Ricard, *Surf. Coat. Technol.*, **174-175,** p8 (2003)