Characteristic of a dielectric barrier discharges using capillary dielectric and its application to photoresist etching

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Abstract

In this study, atmospheric pressure plasmas were generated using a dielectric barrier discharge equipment using capillary dielectric materials and the characteristics of the plasmas and the surface cleaning rate were studied as a function of He/O₂ gas mixture and electrode material. The use of capillary dielectric instead of blank dielectric increased the plasma density by effectively using the voltage sustained in the dielectric for accelerating electrons at the capillary holes, therefore, by forming ion beam-like plasmas at the holes in addition to typical dielectric barrier discharges. The addition and increase of oxygen into He decreased the plasma density monotonically due to the increased charge neutralization; however, oxygen atoms increased initially and showed a maximum with the increase of oxygen. The etch trend of photoresist, therefore the cleaning rate of organic materials, was related to that of oxygen atoms in the plasma. As capillary dielectric materials, the use of ceramics instead of Teflon showed higher photoresist etch rate with higher radical and plasma densities due to the higher sustaining voltage at the air gap between the electrodes.

Keywords: Dielectric barrier discharge; Capillary dielectric materials; Plasma density

1. Introduction

Currently, electronic industries including semiconductor industry and flat panel display industry are using low pressure plasmas or wet chemicals for surface cleaning of the substrates. However, low pressure processing is very costly due to the use of vacuum and wet processing is environmentally undesirable due to the use of large amount of chemicals. If stable atmospheric plasmas could be realized, not only the decrease of processing cost by not using expensive vacuum equipment but also the increase of productivity due to the large amount of reaction species at the atmospheric pressure may be obtained in addition to the environmentally desirable characteristics [1–4]. Due to these potential benefits, many different types of atmospheric pressure plasmas such as dielectric barrier discharges [4–7], pulsed corona discharges, microwave plasma discharge, atmospheric pressure touch, etc. are currently under investigation and are applied to the cleaning of various substrates in addition to etching and thin film deposition [8–12].

Recently, capillary electrode discharge, a different type of dielectric barrier discharge having a number of parallel holes in the dielectric of the electrode, has been also used to generate atmospheric pressure plasmas and its characteristics have been investigated for the application to the removal of organic materials from the substrates. The high-aspect-ratio parallel holes, that is, capillaries in the dielectric of the electrode act as the current limiting resistor during the glow-to-arc transition, and also increase plasma density by accelerating electrons in the capillary through the electric field formed in the dielectric material during the AC voltage application to the electrode.

In this study, the effects of input AC voltage, helium flow rate, oxygen flow rate, and the dielectric material of the electrode on the He/O₂ discharges were investigated to obtain high etch rates of organic materials by optimizing these process parameters. Also, the mecha-
nism obtaining high etch rate of organic materials in the He/O₂ atmosphere. Capillary electrode discharges were investigated using a current probe and an optical emission spectroscopy.

2. Experiment

The experimental system used in this experiment is shown in Fig. 1. AC voltages with sine wave (20–30 kHz, 0–15 kV) were applied between the two electrodes of 150-mm diameter. The power electrode was covered with 8-mm-thick dielectric material with 700 parallel holes (the aspect ratio of the holes: 8) in it and the ground electrode was covered with 3-mm-thick blank quartz. The air gap between the two electrodes was maintained at 4 mm. To investigate the influence of dielectric material itself, two different dielectric materials such as Teflon and ceramic were used to the power electrode.

Different He/O₂ gas mixtures were used in this experiment and the flow rates of He and O₂ were varied independently. The flow rate of He was varied in the range from 4 to 14 sccm and that of oxygen was from 0 to 80 sccm. The gas mixtures were fed through the capillary holes of the power electrode using 0.6-mm diameter stainless tubing which is also used for power feeding. As the samples, 1.2-mm diameter stainless tubing which is also used for power electrode using 0.6-mm to 80 sccm. The gas mixtures were fed through the range from 4 to 14 slm and that of oxygen was from 0 to 80 sccm. The gas mixtures were fed through the capillary holes of the power electrode using 0.6-mm diameter stainless tubing which is also used for power feeding. As the samples, 1.2-mm diameter stainless tubing which is also used for power electrode using 0.6-mm to 80 sccm. The gas mixtures were fed through the range from 4 to 14 slm and that of oxygen was from 0 to 80 sccm. 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current, the current was saturated at above 8 slm of He flow after initial increase of the current with the increase of He flow rate. The saturation of current appears to be from the loss of charged particles by excessive gas flow to outside of the reactor without conducting. The initial increase of the photoresist etch rate with the increase of He flow rate appears to be from the increased transport of oxygen atoms or ions to the photoresist by the increased gas flow, however, the rapid decrease of photoresist etch rate with the further increase of He flow rate appears to be more related to the decrease of oxygen atoms or ions due to the decreased oxygen percentage in the chamber by the increased He gas flow to the chamber.

Fig. 4 shows the effect of oxygen flow rate and different capillary dielectric materials on (a) the photoresist etch rate and rms current and (b) the measured optical emission intensities of He*, O₂^+ and O* by optical emission spectroscopy. (6 slm of He, 9 kV of rms applied voltage and as dielectric materials ceramic and Teflon were used.)

Fig. 4. Effect of O₂ flow rate and different capillary dielectric materials on (a) the photoresist etch rate and rms current and (b) the measured optical emission intensities of He*, O₂^+ and O* by optical emission spectroscopy. (6 slm of He, 9 kV of rms applied voltage and as dielectric materials ceramic and Teflon were used.)

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Fig. 4 shows the effect of oxygen flow rate and dielectric materials on (a) the photoresist etch rate and rms current and (b) the measured optical emission intensities of He*, O₂^+ and O* by optical emission spectroscopy. He, 6 sml and, as the dielectric material, ceramic and Teflon were used. The oxygen flow rate was varied from 0 to 80 sccm. As shown in Fig. 4a, the addition and increase of O₂ up to approximately 40
sccm increased photoresist etch rate and the further increase of oxygen decreased the photoresist etch rate. In the case of the measured current, the addition and increase of oxygen decreased the current monotonically. The decrease of current with the increase of oxygen in He/O2 appears to be related to the removal of electrons by the formation of oxygen negative ions because atoms or molecules with high electronegativity such as F and O tend to form electronegative ions by the recombination of electrons and the radicals at low energies. However, the formation of O− has not been confirmed yet, therefore, more study is required.

Also, due to the high collision probability between molecules at the atmospheric pressure, charge neutralization probability between electropositive ions such as He+ and O2+ and electronegative ions such as O− will be also very high. Therefore, the decrease of measured current with the increase of oxygen appears to be related to the decrease of plasma density due to the increase of charge neutralization in the plasma. Even though, plasma density is decreased with the increase of oxygen, radicals such as oxygen atom can increase with increase of oxygen percentage in He/O2.

Fig. 4b shows the measured optical emission intensities of O, O2+ and He with the increase of oxygen in He. He optical emission lines were observed at 447.1, 501.6, 587.6, 667.8, 706.5 and 728.3 nm while the emission lines from oxygen atom were observed at 436.8, 533.1, 615.8, 645.6, 777.2, 794.8, 822.2 and 844.6 nm. Optical emissions from molecular oxygen ion (O2+) were also observed in the range from 580 to 640 nm. As shown in the figure, the increase of oxygen in He/O2 increased optical emission intensities from oxygen atom until 40 sccm of O2 was reached similar to the change of photoresist etch rate with oxygen. In the case of He and O2+, the increase of oxygen decreased the optical emission intensities from He and O2+ monotonically similar to the change of current with oxygen. Therefore, the photoresist etch rate in our atmospheric He/O2 plasmas is believed to be dependent on the density of oxygen atoms in the plasmas. Ozone generated by the addition and increase of oxygen may also affect the photoresist etch rate, however, the effect of ozone was not investigated and currently under study using an ozone detector.

Fig. 4 also shows the effect of dielectric materials of the same thickness to power electrode on photoresist etch rate, the measured current and optical emission intensities from O, He and O2+ as a function of oxygen flow rate in He/O2. As shown in Fig. 4a, the use of ceramic showed higher photoresist etch rate and higher measured current compared to that of Teflon. Also, optical emission intensities from O+, O2+ and He were generally higher for ceramic. Therefore, the use of ceramic appears to increase the photoresist etch rate due to the increase of oxygen atoms by the increase of plasma density. When applied voltage between the two electrodes is kept same, higher voltage is sustained at the air gap between the electrodes when the dielectric constant of the dielectric is higher. Therefore, the increase of plasma density by using ceramic instead of Teflon appears to be related to the increased voltage at the air gap due to the higher dielectric constant of ceramic. The difference of secondary electron emission from the dielectric surface might be also important, however, when the effect of different coatings on the same dielectric material was investigated, no significant differences were observed (not shown). Therefore, the effect of different dielectric material in our experimental conditions was mostly related to the difference of voltage sustained at the air gap between the electrodes.

4. Conclusions

In this study, the effect of input voltage, He/O2 gas mixture and the capillary dielectric materials of the power electrode on the photoresist etch rate was studied as a measure of organic material cleaning rate using capillary electrode atmospheric discharges and its etch mechanism was investigated using a current probe and optical emission spectroscopy.

The use of capillary dielectric instead of blank dielectric to power electrode in dielectric barrier discharge increased the plasma density by effectively using the voltage sustained in the dielectric for accelerating electrons at the capillary holes, therefore, increasing plasma density. The addition and increase of oxygen into He decreased the plasma density monotonically by the increased charge neutralization, however, in the case of oxygen atoms, there was initial increase of oxygen atoms with the increase of oxygen. The amount of oxygen atoms in the plasma appears to be related to the photoresist etch rate, therefore, the cleaning rate of organic materials. The uses of ceramics as the capillary dielectric material instead of Teflon showed higher photoresist etch rates with the increase of radical and plasma densities. The increase of photoresist etch rates with ceramic instead of Teflon appears to be related to the increase of oxygen atoms by the increased sustaining voltage at the air gap between the electrodes due to the higher dielectric constant of ceramics compared to Teflon for our experimental conditions.

Acknowledgments

This work was partially supported by National Research Laboratory program by Ministry of Science
and Technology and Clean Technology program by Ministry of Commerce, Industry and Energy.

References