Photo-resist ashing by atmospheric pressure glow discharge

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Abstract

Homogeneous glow plasma at atmospheric pressure without streamers and arcing was generated by making use of a radio-frequency (RF, 13.56 MHz) power supply. Oxygen gas was added to Ar/He gas as reactive agents for photo-resist (PR) ashing. The input power, flow rate, oxygen concentration, treatment time, substrate temperature are controlled for high ashing rate and uniform ashing. Thickness of PR film was measured by NANOSPEC (AFT200) and a Step (P-10). An unstable discharge occurs destroying the uniformity, when the input power exceeds a threshold value determined from the distance between the substrate and plasma source. An increase of oxygen quantity or temperature increase makes high ashing rate, but the ashing surface is rugged. The PR ashing rate was related to oxygen atom in plasma. The number of treatment may not be important in PR ashing at the atmospheric pressure.

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1. Introduction

Low-pressure plasma requires an expensive and complicated vacuum system to operate, thereby making the process slow and difficult. Atmospheric plasma without vacuum equipments makes the PR process simple, easy and inexpensive. However it is not easy to generate stable and uniform glow plasma at the atmospheric pressure. Therefore, there have been many researches on generation of non-equilibrium atmospheric plasma called cold plasma [1–3]. A low temperature RF plasma source at the atmospheric pressure, which exhibits many characteristics of a low-pressure glow discharge, has been developed [4–7].

Recently, plasma technologies have been used in electronic devices like LCD or semiconductor industry. There are many processes in the electronics industry. Lithography as a process of electronics industry is the basic technique for miniaturization of the electronic devices. PR removal is an indispensable technique in lithography. Photo-resistance material must be removed completely without making any damage to the substrate. Two types of process were used in the PR removal in industry, PR strip in wet process and PR ashing in dry process. PR ashing has used a vacuum system typical in vacuum plasma processing. This vacuum system is bulky, heavy and expensive. The atmospheric plasma may be very useful tool of PR ashing to replace the vacuum device. We therefore developed a uniform glow plasma source at the atmospheric pressure, which exhibits many useful characteristics for surface treatment [5]. The PR ashing test has been carried out by this plasma source.

2. Experiment

The experimental apparatus for PR ashing is shown in Fig. 1. The glow plasma generated at the atmospheric pressure is free from filaments, streamers and arcing. The glow plasma device consists of a powered electrode and two grounded electrodes. One grounded electrode is placed...
near the powered electrode for low breakdown voltage preventing the glow-to-arc transition in main plasma. The distance between powered electrode and the other grounded electrode controls stability of main plasma and plasma uniformity. Powered electrode is covered with dielectric material for stable glow and for prevention of arc transition. The radio-frequency (RF) power system used for plasma generation has frequency of 13.56 MHz and has maximum power of 300 W. A matching box has been used. The plasma area is $20 \times 100$ mm and the distance between the powered electrode and grounded electrode is 0–4.5 mm for argon gas and 0–9 mm for helium gas. The power in our experiment ranges from 150 W to 250 W, which ensures stable and uniform plasma.

Argon or helium is used as a feeding gas because of low breakdown voltage at the atmospheric pressure. A small amount of oxygen gas is added to feeding gas as reactive agents for PR ashing. Flow rate of each gas was controlled by MFC. The flow rate of feeding gas varied from 1 to 10 lpm and oxygen concentration has been also varied from zero to 100 sccm. The gases were fed through a narrow gap into the main plasma area. The system was operated in the environment open to ambient air.

The heating system was made of a nichrome wire and 4 mm brass plate covering it. The temperature of the heating system ranges from the room temperature to 470 °K. We varied the substrate temperature from 320 °K to 420 °K near the hard baking temperature. Samples of 24000-A˚-thick PR covered wafer were used. PR ashing rate were measured as a removal rate from surface. All ashing rates were measured in minutes. We calculate the uniformity as $100 \times \frac{\text{maximum ashing rate} - \text{minimum ashing rate}}{2 \times \text{average ashing rate}}$, which is often used in semiconductor industry. Three methods were used to measure thickness of the PR film for accuracy. Nanospec (AFT200) was used as a main measuring device. Nanospec is a tool to measure depth of thin films on silicon. Nanospec measures the resist film depth on silicon in the range of 500–40,000 Å. The $\alpha$-Step (P-10) measures roughness of the substrate surface. The measurements are repeated many times to improve accuracy.

An on-line moving system is used for continuous process of the substrate. All the system parameters were controlled by a computer.

3. Results

It may not be easy to get stable glow plasma at the atmospheric pressure because of its requirement of a high breakdown voltage and its narrow range of glow region. Arc transition occurs easily due to excessive current flow at high voltage at the atmospheric pressure. We used dielectric material such as quartz to prevent arc transition. It prevents arc transition and helps generation of glow plasma at atmosphere. Corona discharge generated between powered electrode and closer grounded electrode provides a seed for the main discharge breakdown. Therefore we can get stable plasma by a reduced breakdown voltage. But, the unstable discharge to destroy uniformity of discharge may easily occurred if the input power exceeds

Fig. 1. Schematic diagram of atmospheric discharge system used in experiment.
a threshold value determined from the distance between the ground electrode and powered electrode or if oxygen concentration is too high. Oxygen concentration in the experiments was up to 3.5% for argon as feeding gas and was up to 10% for helium as feeding gas. We obtained a stable plasma for PR ashing at that oxygen concentration. We can add more oxygen or we can low the power to sustain stable plasma, if the substrate temperature increases. But high temperature destroys uniformity of glow plasma.

Fig. 2 shows effect of the number of treatment on PR ashing rate. The number of treatment does not impose significant influence on the ashing rate or uniformity. PR ashing rate increases from 1700 Å/min to 2000 Å/min as the number of treatment increases from 1 to 10. The uniformity showed fixed value when there was an increase in the number of the treatments. There is no overall improvement of uniformity by increase of the number of treatment. A slight increase of ashing rate by increase of the number of treatment may be caused by increase of substrate temperature, which increases roughly from 300 °K to 320 °K by exposing it to the plasma for 10 min. The number of treatment may not change the ashing rate substantially, but the total amount of ashing increases with ashing time.

PR ashing may be carried out by oxygen atoms in plasma. Previous literatures [8,9] of the PR ashing carried out under the vacuum condition claims that the ashing is a reaction between oxygen radicals in the plasma and organic material of PR. Oxygen radicals react with carbon or hydrogen in the PR. More oxygen radicals are needed for high PR ashing rate to react with PR. The increase of input power generates more oxygen atoms and radicals in the plasma. Therefore, high ashing rate may be achieved by increase of input power. Fig. 3 shows effect of input power on PR ashing rate and Fig. 4 shows effect of power on uniformity of PR ashing. PR ashing rate increases continuously according to increase of input power. But the ashing uniformity done by argon plasma deteriorates drastically if the power exceeds a threshold value, which is 250 W for 3 mm distance between the powered electrode and grounded electrode in argon or in helium without oxygen. Coronas and streamers between the powered electrode and closer grounded electrode may cause the uniformity deterioration. We may eliminate the non-uniformity by controlling power, oxygen concentration and flow rate. Coronas or streamers can easily be generated in argon gas in comparison with helium gas. However, higher ashing rate can be achieved in argon as feeding gas than that in helium as feeding gas. But, uniformity is better in helium than that in argon. Fig. 5 shows effect of oxygen concentration on PR ashing rate and uniformity. Higher oxygen concentration makes more oxygen radicals. But, high oxygen concentration makes more difficult for maintenance of stable plasma. PR ashing rate increases continuously as oxygen concentration increases. The PR activation is one of the ways of high ashing rate. Our PR activation is the wafer
heated by heating plate. The ashing rate increases dramatically by heating the PR substrate. Fig. 6 shows effect of substrate heating on PR ashing rate and uniformity. The ashing rate increases substantially by temperature increase, but the uniformity deteriorates considerably. The uniformity deteriorates drastically over the temperature of 370 °C (100 °C). Fig. 7 shows effect of flow rate on PR ashing. PR ashing rate increases as the flow rate increases. But the ashing rate saturates over the 5 lpm. Generally, there is a certain critical value of increasing PR ashing rate by the flow rate, which is 5 lpm in our case. An increase of a flow rate over the threshold value may not make high ashing rate. Instead the flow rate increase over the threshold value deteriorates the ashing uniformity.

4. Conclusions

Atmospheric glow plasma was generated by use of two grounded electrodes. The outer grounded-electrode wrapping around the powered electrode generates corona discharge, which in turn initiates the main plasma over the grounded plane electrode. Stable plasma was generated by controlling distance between the powered electrode and the plan electrode. System parameters were varied for high ashing rate. The unstable discharge occurs readily destroying the uniform discharge and making rugged surface of substrate, if the input power exceeds a threshold value determined from the distance between the substrate and plasma source. The ashing rate improved as the substrate temperature rises. Meanwhile, the treatment uniformity deteriorates. The ashing rate increases with input power increase, with oxygen concentration increase, with higher substrate temperature and with high flow rate. We found the optimum physical parameters for uniform surface and high ashing rate, getting 3000 Å/min ashing and 5% uniformity at the room temperature by making use of argon plasma. These optimum parameters are input power with 200 W, oxygen concentration with 1%, flow rate with 3 lpm and the gap distance with 3 mm.

References