Dual Jet Ionizer for Manufacturing Semiconductor Devices

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The corona discharge air ionizer is one of the most important equipment for controlling electrostatic charges in the manufacture of semiconductor devices. However, the conventional air ionizer generates various kinds of contaminations, including particles. The dual jet ionizer that has a jet emitter in a nozzle has been proposed for reducing contamination from an emitter. Ions are generated in a nitrogen atmosphere in the dual jet ionizer because of nitrogen gas flow in both the emitter and the nozzle. The characteristics of ion generation and ozone generation were investigated for both the dual jet ionizer and the non-jet ionizer. The characteristics of the dual jet ionizer depended strongly on the flow rates of nitrogen gas in the emitter and the nozzle. The number of particles generated by the dual jet ionizer under the optimum operating conditions was approximately four times smaller than that by the non-jet air ionizer.

Keywords: electrostatic discharge, ionizer, semiconductor manufacturing, static control

1. Introduction

Several phenomena related to electrostatic charge events, such as electrostatic discharge (ESD) and electrostatic attraction (ESA), cause serious yield reduction in the production of semiconductor devices. ESD destroys semiconductor devices and ESA attracts particulate contaminants to the surface of silicon wafers and photo-masks used in lithography. Corona discharge air ionizers have been widely used for preventing the yield reduction in the production of semiconductor devices. However, the conventional corona discharge air ionizer generates contamination during operation\(^3\). The contamination is classified into three categories. The first is the generation of ozone from the ionizer. Highly concentrated ozone assists in the growth of an oxide film on the silicon wafer. The second is the generation of particles from the emitter tip. The sputtering phenomenon generates particles from the emitter tip because the ionizer is operated at a high voltage. In addition, an oxide film tends to grow on the emitter tip because of the plasma around the tip, and its breakdown generates particulate contaminants. The third is the cluster-like material growth on the emitter tip. Freely drifting particles are attracted to the emitter tip because of the strong electric field near it. These cluster-like materials are scattered by the emitter.

We have proposed a dual jet ionizer for controlling the contamination generated by an air ionizer\(^2\). The dual jet ionizer is composed of nozzles and jet emitters located at the center of the nozzles, and both the jet emitters and the nozzles can spray nitrogen gas. The nitrogen gas sprayed by the jet emitters (inner jet) carries the ions generated at the emitter tip. On the other hand, the nitrogen gas sprayed by the nozzles (outer jet) keeps the emitter in a clean nitrogen atmosphere in order to reduce ozone generation, oxide film growth on the emitter tip, and the cluster-like material growth.

In this report, the ion generation characteristics, the ozone generation, the particle generation and the cluster-like material growth on the emitter tips of the dual jet ionizer were investigated as a function of flow rate, and the results were compared with those of a non-jet air ionizer.

2. Structure of Dual Jet Ionizer

The jet emitter was made of silicon because particle generation by a silicon emitter was much less than that by a conventional tungsten emitter\(^4\). Figure 1 shows the dimensions of the jet emitter. The schematic of the dual jet ionizer is shown in Figure 2. The ionizer can spray nitrogen gas through both the inside (inner jet) and outside (outer jet) of the emitter. A grounded electrode was placed on the same plane as that of the emitter edge in order to stabilize the electric field around the emitter edge. The nozzle length was 30.0 mm, and its diameter was 10.0 mm. The flow rates of the inner jet and the outer jet were 0 – 2.0 L/min and are 0 – 5.0 L/min, respectively.

In this study, the non-jet air ionizer was used for comparison, of which the nozzle was removed and the flow rates of both the inner jet and the outer jet were 0 L/min.

\[ Figure 1. \text{ Dimensions of the jet emitter} \]
3. Discharge Characteristics

The discharge characteristics of the ionizers were measured in a clean room with laminar air flow of 0.35 m/s. Figure 3 shows the schematic of the setup for measuring the discharge current, which is the current produced by the flow of ions generated by the ionizer. The ionizers were set 0.5 m above a large grounded metal table and were operated at 0 ~ 10 kV. The charge plate monitor (Hugle Electronics Model 700A) was used for measuring the discharge characteristics and was set on the table. The metal plate as an upper electrode of the charge plate monitor had an electrical capacitance of 20 pF. The metal plate was placed on top of the charge plate monitor and its upper surface was located 50 mm above the metal table. A voltage of +1000 V or -1000 V could be applied to the metal plate.

The discharge current from the positive polarity ionizer was measured using the charge plate monitor as follows. The metal plate was charged with a voltage of -1000 V. The decay of the plate voltage was measured in order to observe the charge elimination characteristic by the positive ion current. The time for the voltage decay from -1000 V to -100 V was defined as the charge eliminating time by the positive ions, and the discharge current \( I_{dp} \) was expressed as

\[
I_{dp} = \frac{(\Delta V_p / \Delta t_p)}{C_p} \tag{1}
\]

where \( C_p \) is the capacitance of the metal plate on the charge plate monitor. Then, the discharge current \( I_{dn} \) for the negative polarity ionizer was measured by the same method using the charge plate monitor charged with a voltage of -1000 V, and was expressed as

\[
I_{dn} = \frac{(\Delta V_n / \Delta t_n)}{C_p} \tag{2}
\]

The discharge current was measured as a function of the applied voltage for the dual jet ionizer at the inner jet flow rate of 1.0 L/min and the outer jet flow rate of 1.0 L/min. Figure 4 shows the relationship between the discharge current and the emitter voltage, that is, the I-V characteristic of the dual jet ionizer. The positive and negative polarity dual jet ionizers showed threshold voltages at +5.6 kV and -4.9 kV, and discharge currents of \( \pm 10 \) nA at \( \pm 7.6 \) kV and \( \pm 8.5 \) kV, respectively. The negative polarity dual jet ionizer require higher voltage than the positive one to obtain the discharge current of 10 nA; on the other hand the threshold voltages of the negative polarity dual jet ionizer shows lower value than that of the positive one. This anomalous could be explained as follows. The majority charged particles are the positively charged nitrogen ions and the electrons in the nozzle flowing nitrogen gas. The electrons that could be generated easily by emitter could be easily absorbed in the grounded electrode because the mobility of the electrons is much higher than that of the nitrogen ions.

The dependence of the discharge currents on the flow rates was investigated for the dual jet ionizers. The voltages applied to the positive polarity and negative polarity ionizers were fixed at \( \pm 7.6 \) kV and \( \pm 8.5 \) kV, respectively. Figures 5 and 6 show the discharge currents as a function of the inner jet and outer jet flow rates. In both figures, the discharge currents were increased with increasing inner jet and outer jet flow rates. These results indicated that the
ions generated at the emitter tip were carried by the nitrogen gas flow.

4. Ozone Generation Characteristics

Figure 7 shows the setup for measuring the density of ozone generated by the dual jet ionizer. The ionizers were set in a chamber (500 mm × 500 mm × 500 mm) that was made of acrylic resin. The positive polarity and negative polarity jet ionizers were operated at fixed voltages of +7.6 kV and -8.5 kV, respectively. Air at 10.0 L/min was injected into the chamber to maintain the oxygen density inside the chamber, because a reduction of the oxygen density leads to a reduction of the ozone density. The ozone densities in the chamber were measured with the ozone monitor (Dylec Model 1200) with a ozone density detection limit of 0.001 ppm for both the positive polarity ionizer and the negative polarity ionizer, as a function of the flow rates. The measurements of the ozone densities for the non-jet air ionizers were carried out for both the positive polarity ionizer and the negative polarity ionizer as well. The operating voltages of the non-jet air ionizers were adjusted so that the discharge currents were ±10 nA.

Figures 8 and 9 show the ozone densities in the chamber as a function of the flow rates. In these figures, an ozone density of 0 ppm means a density below 0.005 ppm, because the background of the ozone density was 0.005 ppm. The ozone densities for the positive polarity dual jet ionizer \( D_{\text{p}} \), and the negative one \( D_{\text{n}} \) depended strongly on the flow rates. On the other hand, the ozone densities for the non-jet air ionizer, \( D_{\text{p}} \), and \( D_{\text{n}} \), were 0.014 ppm and 0.343 ppm, respectively. The reason why the ozone densities were reduced for the dual jet ionizers may be the reduction of the oxygen densities in the nozzle.

The ratio of the discharge current to the ozone density, \( I / D \), is an important parameter for determining the optimum operating conditions. Therefore, the characteristics of the dual jet ionizer were evaluated by proposing the normalized ratios \( R_{\text{p}} \) and \( R_{\text{n}} \):

\[
R_{\text{p}} = \left( \frac{I_{\text{p}}}{D_{\text{p}}} \right) / \left( \frac{I_{\text{n}}}{D_{\text{n}}} \right) \quad \text{(3)}
\]

\[
R_{\text{n}} = \left( \frac{I_{\text{n}}}{D_{\text{n}}} \right) / \left( \frac{I_{\text{p}}}{D_{\text{p}}} \right) \quad \text{(4)}
\]

respectively, where \( I_{\text{p}} \) and \( I_{\text{n}} \) are the discharge currents for the positive polarity and negative polarity dual jet ionizers, and \( I_{\text{p}} \) and \( I_{\text{n}} \), are those for the positive polarity and negative polarity non-jet air ionizers.

Figures 10 and 11 show the normalized ratios \( R_{\text{p}} \) and \( R_{\text{n}} \) as a function of the flow rates. The normalized ratios were much higher than 1.0, when both the inner jet flow rate and the outer jet flow rate exceeded 1.0 L/min. These results suggest that the characteristics of the dual jet ionizer were improved by the nitrogen gas flow, because \( R_{\text{p}} = 1.0 \) and \( R_{\text{n}} = 1.0 \) are the normalized rates for the non-jet air ionizer.
5. Particle generation Characteristics and Cluster-Like material Growth Characteristics

The numbers of particles generated by the emitter were measured for both the dual jet ionizer and the non-jet air ionizer for each polarity. The voltages applied to the emitters were adjusted so that the discharge currents were ±10 nA. The measurement was carried out at the inner jet flow rate of 1.0 L/min and the outer jet flow rate of 1.0 L/min. Particles generated by the ionizers were collected by funnels with a diameter of 50 mm, placed 40 mm below the emitter tips. The cumulative number of particles was counted using the particle counter (TSI Model 3025A) with a particle size detection limit of 0.03 μm. The measurement was performed every minute for 24 hours.

Figure 12 shows the cumulative number of particles generated by the dual jet ionizer and the non-jet air ionizer as a function of time. The cumulative number of particles generated by the dual jet ionizer was approximately four times smaller than that generated by the non-jet air ionizer.

The mechanisms of the particle generation are classified into two 4889. One is the sputtering phenomenon of an emitter and the other is the breakdown of an insulating thin film formed at the emitter surface. The former occurs at the emitter tip independent of the atmosphere, whereas the latter depends on the atmosphere because the creation of an insulating thin film depends on the atmosphere.

In this study, the emitters of the non-jet air ionizer were operated in air atmosphere that had a high concentration of oxygen. Therefore, the insulating thin oxide film that was formed on the emitter tip broke down, generating particles. On the other hand, the emitters of the dual jet ionizer were operated in the nitrogen atmosphere. Thus, no insulating thin film was formed on the silicon emitter because nitrogen is more stable than oxygen.

That particle generation by the positive polarity emitter was greater than that by the negative polarity emitter in the case of the non-jet air ionizer could be explained as follows. Ozone molecules and oxygen molecules tend to be negative ions and act as oxidizers. These molecules are attracted to the positive polarity emitter, thereby forming an oxide film on the emitter.

The cluster-like material growth on the emitter tips was investigated by an acceleration test. Air ionizers were placed in a box the size of a 0.5 m cube. An acrylic board coated with silicone resin was placed 0.1 m below the emitter tips. Siloxane (H₂SiO₃SiH₃SiOH₃) generated from the silicone resin was grown on the emitter tip. The emitter tip was observed by microscopy to check for adhesion and growth of the siloxane before and after the
ionizer was operated for 48 hours. These experiments were carried out for the dual jet ionizer with the inner jet flow rate of 1.0 L/min and the outer jet flow rate of 1.0 L/min and the non-jet air ionizer.

Figure 13 shows photographs of the cluster-like material growth on the emitter tips. (A), (B), (C), and (D) show the initial states of the emitters. (E) and (F) show the positive and negative polarity emitters of the non-jet air ionizer after operation for 48 hours, respectively. Significant cluster-like material growth was observed on the emitter tips. On the other hand, (G) and (H) show the positive and negative polarity emitters of the dual jet ionizer after operation for 48 hours, respectively. No cluster-like material growth was observed.

As mentioned above, the growth of the cluster-like material on the emitter tips was prevented by the dual jet ionizer, which is considered to prevent the re-scattering of the cluster-like material.

6. Conclusions

The dual jet ionizer was proposed as a means to reduce the contamination generated by the non-jet air ionizer. The results of the evaluation are summarized as follows:

1) The ozone density around the emitters of the dual jet ionizer depended strongly on the flow rates, and was much lower than that of the non-jet air ionizer.

2) The number of particles generated by the dual jet ionizer was approximately four times smaller than that generated by the non-jet air ionizer.

3) The cluster-like material growth on the emitter tip was not observed in the dual jet ionizer, whereas it was marked in the non-jet air ionizer.

(Manuscript received Sept. 15, 2004, revised March 28, 2005)

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