プラズマエッチングにおけるパーティクルの検出と発生機構に関する研究

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論文内容要約

Particle contamination in plasma etching equipment is one of the most serious problems in manufacture of large-scale integrated circuits (LSI). For example, particles often cause short circuits between the gate electrode and the source/drain in interconnecting process and lowered production yield of LSI. Overall equipment efficiency (OEE) also decreases because equipment must be stopped for maintenance and cleaning of the chambers. The development of particle-free processes and equipment in mass production of LSI requires studies on real contaminant particles in an actual manufacturing environment [1, 2]. During plasma etching process, the etching reaction products adhere to the inner walls of the process chamber, and gradually form films as wafers are processed. A few particles are constantly generated by flaking of the deposited films caused by electric field stress that acts at the boundary between the insulating inner wall and the film during plasma processing [3]. The electric field is formed between the inner wall surface at the floating potential and the chamber at the ground potential. On the other hand, many flaked particles are sometimes generated unpredictably during etching processes and result in a number of defective LSI devices. The particles seriously lower the production yield and OEE. In this study, to elucidate such an unpredictable particle generation, the mechanism is investigated under mass production condition and the practical detection method is developed.

The experimental apparatus used in this study is the mass production reactive ion etching (RIE) equipment which features a capacitive rf (13.56 MHz) discharge with a parallel plane geometry, as shown in Fig. 1. A wafer with a diameter of 200 mm is chucked on the powered electrode by an electrostatic chuck (ESC) with backside cooling using helium (He) gas. The etching process sequence and equipment parameters are the same as those used in actual manufacturing facilities. This study uses a tungsten etch back process that often causes significant particle contamination. The in situ particle monitoring system, a viewing port style plasma probe (VP-Probe), and an ESC wafer stage with a built-in acoustic emission (AE) sensor are employed in this study [4]. In the particle monitoring system, a sheet-shaped laser beam is

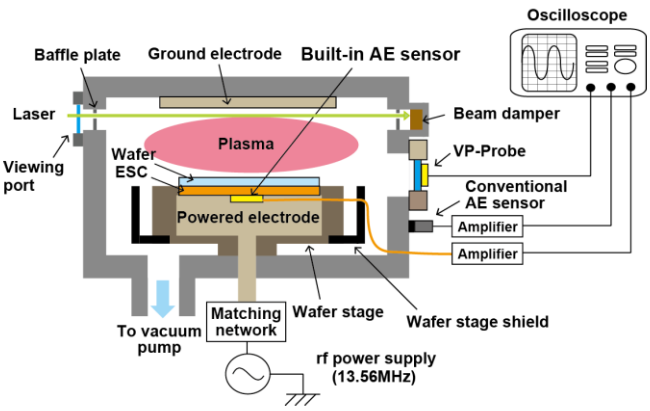

Fig. 1 Experimental setup

introduced in a plane parallel to the wafer in the processing chamber at a distance of 4 mm from the ground electrode. The light scattered by particles crossing the beam is measured using an image-intensified charge-coupled device (CCD) camera. The system can measure the generation of particles together with the status signals of the RIE equipment such as rf power. The VP-Probe can detect a transient change in the floating potential formed on the inner surface of the viewing port [5]. Because the deposited film formed on the inner wall is also at the floating potential and electric field stress is proportional to the square of the electric field generated by the potential [6], the probe can also detect the change in stress acting on the film. The AE sensor in the ESC wafer stage can detect unusual wafer movement [7]. The signals of VP-Probe and AE sensor are simultaneously monitored along with the status signals of the RIE equipment.

Particles appear after the etching of several hundred wafers. Their origin is, therefore, the flaking of etching reaction products from the film deposited on the ground electrode. Figure 2(a) shows the relationship between the number of particles and the operation of the etching equipment. In the etching process, at 53.3 s, the He flow rate increases unusually during the course of cooling due to the wafer movement and a large number of particles are observed at the same time. In Fig. 2(b), the unusual wafer movement is detected and confirmed by the built-in AE sensor. Figure 2(c) shows the response signal recorded by the VP-Probe. The amplitude of the probe suddenly and markedly increases simultaneously with the outbreak of particles in Fig. 2(a), and then fluctuates, maintaining its unstable condition for about 4 s. The result shows that the large and rapid change in floating potential on the deposited film occurs simultaneously with the sudden generation of many flaked particles from the deposited film; i.e., the films are strongly deformed and detached when the large and rapid changes in the floating potential occur. Then, the forced oscillation of a system under an external force due to such a potential change, which describes the displacement of the film, is analyzed [8]. The result reveals the instantaneous potential changes can lead to a sudden increase in electric field stress, which acts as an impulsive force. The films are seriously damaged by the impulsive force and then flake off in the form of a lot of particles. Such an instantaneous generation of particles is also observed when micro-arc discharge occurs [9]. Figure 3 shows an image of laser light scattered by particles, indicating many particles flaking off from the ground electrode although the micro-arc discharge occurs at the back of the wafer. The micro-arc discharge also gives rise to the instantaneous generation of numerous flaked particles because of the action of the impulsive force.

For the practical method to detect sudden generation of many particles, a high-speed and practical load impedance monitoring system is developed. The load impedance changes with the change in inner wall potential, so that the particle generation can be detected by the detection of the rapid change in the impedance. The impedance monitoring system employs a directional coupler connected in series between the rf power supply and the matching circuit; i.e., the sensor part is installed in the 50 Ω transmission line [10, 11]. The attenuated forward and reflected rf powers containing phase information are measured using the directional coupler and the Cross Domain Analyzer™ (ADVANTEST) in a wide measurement range from µW to kW without time delay. The load impedance, $Z_L = R_L + jX_L$, is the impedance of the load side seen from the output port of the matching circuit, where R_L and X_L are the real and imaginary parts of the load impedance, respectively, and j is the imaginary unit. Impedance monitoring software can be used to calculate the characteristic impedance, which involves not only the load impedance but also the impedance of the matching circuit including variable capacitors C_1 and C_2, hence the system simultaneously monitors these capacitances to separate the load impedance from the characteristic impedance by calculating the circuit equation. In other words, our monitoring system can directly measure the load impedance. The forward and reflected powers are recorded, and the load impedance is calculated at a rate of 10 MS/s for up to 100 µs. The time interval for the data acquisition is approximately 200 ms, which is the time needed for computing and displaying the results. The trigger system starts recording the forward and reflected rf powers only when a small reflected power caused by the arcing above an arbitrary threshold is detected. Figures 4(a)–4(d) are the results in the experiment of micro-arc discharge detection. The rf power is turned

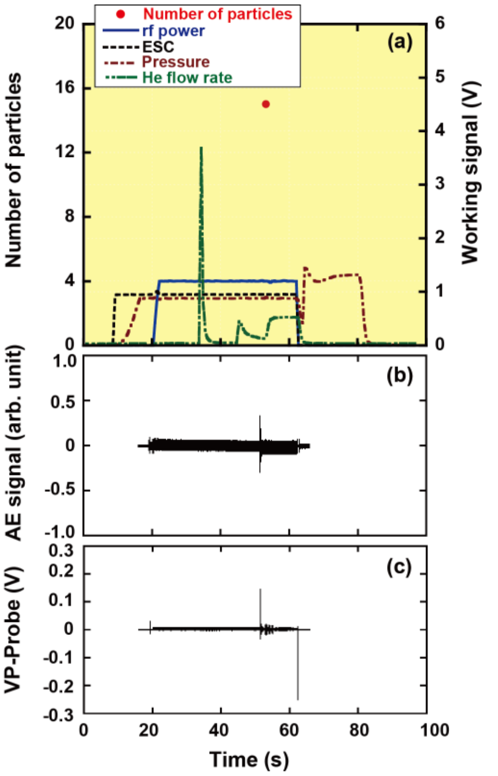

Fig. 2 (a) Relationship between the number of particles and the operation of etching equipment, (b) signal of AE sensor, and (c) signal of VP-Probe.

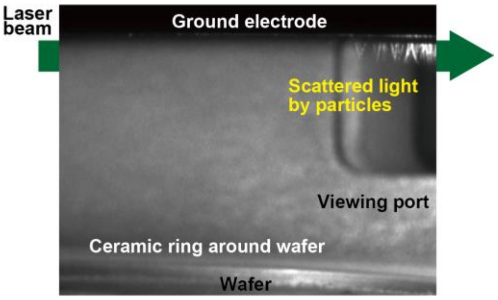

Fig. 3 Image of laser light scattered by particles.

on at 0 s and shut down at 22.2 s, and the system is triggered 7 times during etching. After the plasma is stably generated, the values of C_1 and C_2 become stable, and R_L and X_L also become stable at approximately in the matching position. At 5.8 s, the system is triggered by the reflected power caused by the arcing. In Fig. 4(a), R_L suddenly and markedly changes from the matching value. At the same time, X_L also largely changes from the matching value as shown in Fig. 4(b). In contrast, the capacitance values in Figs. 4(c) and 4(d) do not respond to the arcing at all. The variable capacitors cannot be used for detecting the sudden changes in the impedance caused by micro-arc discharge because the capacitors are subject to the rotation rate of the stepper motors. Therefore, the results demonstrate that the system successfully detects micro-arc discharge from the 50 Ω transmission line.

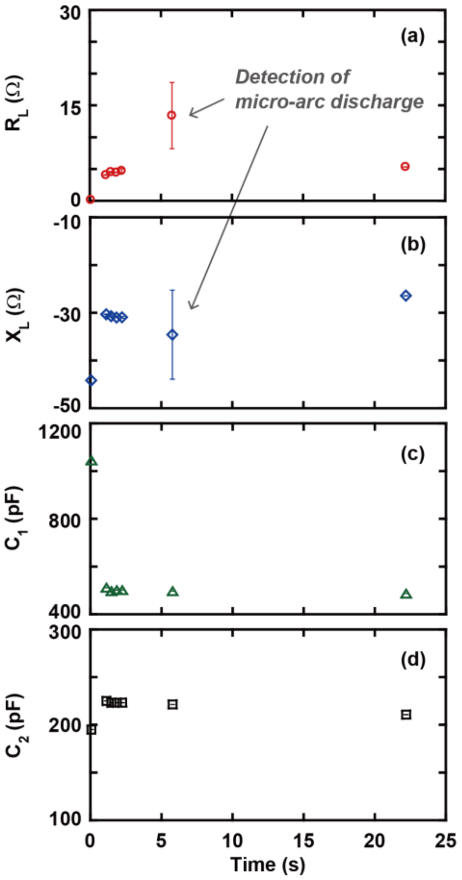

Fig. 4 Time variations of (a) real part of load impedance R_L, (b) imaginary part of load impedance X_L, (c) capacitance of variable capacitor C_1, (d) capacitance of variable capacitor C_2.

The mechanism of the instantaneous generation of many flaked particles is investigated under mass production condition. The results of this study reveal that the particles are generated by electric field stress acting as an impulsive force. The effectiveness of the novel load impedance monitoring system for the detection of the particle generation is demonstrated. This practical method can directly monitor the load impedance at high speed, and contribute to improving production yield and OEE.

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