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Perfect Selective, Highly Anisotropic, and High Rate ECR Plasma Etching for N⁺ Poly-Si and WSi_x/Poly-Si

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A new ECR plasma etching technology has been developed to realize simultaneously highly selective, high rate, and anisotropic etching for n⁺ poly-Si and WSix/poly-Si at a low ion energy. In this technology, a substrate is located at the ECR position in a ECR plasma. As a result of the ECR position etching, under the low pressure of 5×10^{-4} Torr a high etching rate and an infinite etching selectivity to SiO₂ etching are realized by using Cl₂/O₂ and Cl₂ /O₂/SF₆ etching gas.

I.Introduction

A very thin SiO₂ film will be used as the gate insulator in ultra large scale integrated (ULSI) circuits such as the 64-Mbit DRAM. The gate oxide film is estimated to be less than 100 A thick. When a gate electrode is fabricated by plasma etching, a high etching selectivity ratio to SiO₂ etching of more than 100 is required in order to prevent damage to the very thin SiO₂ film and to the SiO_2 /silicon interface layer. Since the gate electrode pattern widths determine the MOS channel length, minimizing critical dimension loss during dry etching is also necessary. Accordingly, highly anisotropic etching for the gate electrode while maintaining a high etch rate and extremely high selectivity over both an underlying SiO₂ film and a photoresist mask is required. However, it is recognized that it is quite difficult for conventional plasma etching to satisfy anisotropy, a high etch rate, and extremely high selectivity all at the same time.

This paper reports the ECR position etching accomplished by a newly developed ECR plasma etching system^{1, 2, 3} settles the above problems, and provides practical and accurate ECR plasma etching for n⁺ poly-Si and WSix/poly-Si.

II. Experimental

A schematic illustration of the ECR plasma etching system used in this study is shown in Fig. 1. The plasma chamber diameter is 260 mm. Silicon substrates of 6 or 8-inch diameters are automatically transported to the substrate holder. The main magnetic coils and the sub-magnetic coils are located around the periphery of the plasma chamber. The substrate position can be continuously changed to any position in the



Figure 1. A schematic illustration of the New ECR plasma etching system.

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sub-chamber and the plasma chamber. A substrate position of -50 mm, for instance, means that the substrate is located 50 mm from the boundary between the plasma chamber and sub-chamber in the plasma chamber.

In this experiment, a substrate is located at the ECR position (875 gauss position) in an ECR plasma, and the etching is carried out without RF bias power. The etching characteristics at the ECR position are investigated using a n⁺ poly-Si film and a WSix/poly-Si as the etching material. First, a thermal oxide film 1000 A thick is formed on a 6-inch-diameter silicon substrate. Next. a poly-Si (4000 A thick) film or a WSix (1100 A thick)/poly-Si (1600 A thick) film is deposited on the thermal oxide. The etching gases used for the n⁺ poly-Si and the WSix / poly-Si are Cl₂, Cl_2/O_2 and $Cl_2/O_2/SF_6$. The etching pressure is fixed at 5 $\times 10^{-4}$ Torr, microwave power is 1 kW, the main coil current is adjusted to 19 A, and the sub-magnetic coil current is fixed at 15 A. Then, the ECR position (875 gauss position for 2.45 GHz) corresponds to the substrate position of -40 mm in the plasma chamber.

III. Results and Discussion

A. Newly developed ECR plasma etching system

The dependence of ion current density on the substrate position is shown in Fig. 2. N2 gas plasma is used to measure ion current density with a Faraday cup. The results show that the ECR position has the maximum ion current density (15 mA/cm²) in the ECR plasma.^{2,3} Figure 3 shows the dependence of ion energy distribution on the substrate position. An energy analyzer with four to measure the ion energy grids is used distribution in the ECR plasma. The mean ion energy and the width of ion energy distribution decrease as they near the ECR position. Then, the mean ion energy near the ECR position is about 15 eV in the N₂ gas plasma. From these results, the ECR position in the ECR plasma has a high ion current density and low ion energy at the same time.

Figure 4 shows the ion current density distributions with the new ECR plasma etching



Figure 2. Ion current density as a function of the substrate position.



Figure 3. Ion energy distributions on the substrate position.

system and with the conventional ECR plasma etching system at the ECR position. The ion current denseness uniformity in the new ECR plasma etching system is $\pm 5\%$ in a 200 mm diameter area.³ The uniform ion current density is due to large quartz window for the microwave a introduction and a flat 875 equi-magnetic field position caused by the sub-magnetic field to the substrate holder.

B. N⁺ poly-Si etching characteristics





The n⁺ poly-Si etching characteristics at the ECR position are investigated using pure Cl₂ gas. The Cl₂ flow rate is 20 sccm. Etching pressure is 5 $\times 10^{-4}$ Torr. At the ECR position, the n⁺ poly-Si etching rate is 3000 A/min and the etching selectivity ratio to SiO₂ is about 100. The etching selectivity ratio to the photoresist is more than 20. Etching rate uniformity is ±5 % across a 6-inch-diameter substrate. ECR position etching can satisfy a high etching selectivity ratio to SiO₂, a high etching rate, and excellent etching uniformity corresponding to the ion current density and ion energy at the ECR position.^{2,3} In addition. as ECR position etching leads to higher selectivity ratios to photoresist, extremely precise control of pattern transfer is possible.

Figure 5 shows the effects of a small amount of O_2 for further improving the selectivity ratio and accuracy at the ECR position. The total gas flow rate of Cl_2 / O_2 is 20 sccm. The existence of O_2 lowers the etching rate of SiO_2 . As a result, the n⁺ poly-Si/SiO₂ etching selectivity ratio is increased infinitely. It is supposed that the extremely high selectivity ratio to SiO_2 is achieved by the low ion energy at the ECR position and the film formation by the oxidized oxychloride on the SiO_2 surface.⁴ A cross-sectional SEM image of the anisotropically etched n⁺ poly-Si etching profile with a Cl_2 / O_2 gas mixture at the ECR position is shown in Fig. 6.



Figure 5. The effects of adding a small amount of O_2 gas to Cl_2 .



Figure 6. A cross-sectional SEM imagé of an anisotropically etched n⁺poly-Si pattern with a Cl_2/O_2 gas mixture.

C. WSix/poly-Si etching characteristics

Since the deposition of etching products is generated in simply Cl₂ gas plasma because of the relatively low vapor pressure of WClx. SF6 is added to remove the deposition. The total gas flow rate is 20 sccm. Addition of a small amount of SF_6 to Cl_2 is effective in preventing the deposition. When the SF6 flow rate is 1 sccm, the deposition suppressed, completely. is Then. WSix/poly-Si etching rate 2200 is A/min. Furthermore. highly accurate etching without undercutting is accomplished and etching stability is ensured in a certain amount of SF6 to Cl2. However, as the ECR position has a high ion current density, the SiO₂ etching rate increases rapidly. When the SF6 mixing ratio is 5%. the

SiO₂ etching rate increases to 150 A/min. Then, the etching selectivity to SiO₂ decreases to 15. To improve the poor selectivity of the WSix/poly-Si to the SiO₂ in Cl₂ /SF₆ discharge plasma, O₂ gas is added to the Cl₂/SF₆ gas mixture. Addition of a small amount of O_2 to the Cl_2 /SF₆ gas mixture is efficient for improving selectivity at the ECR position as shown in Fig. 7. The Cl₂ gas flow and the SF6 gas flow rates are fixed at 19 and 1 sccm, respectively. The WSix/poly-Si etching rate of 2200 A/min is not changed even if 02 gas of 2 sccm is injected. On the other the existence of O₂ reduces only the SiO₂ hand, supposed that the SiO₂ rate. It is etching surface is covered by the oxychloride oxydized with oxygen atoms.⁴ As a result, WSix /poly-Si etching selectivity to SiO₂ is infinite. This is caused by the low ion energy at the ECR position and the addition of O2 gas. A cross-sectional SEM image of an anisotropically etched WSix/poly-Si profile with a Cl₂ /SF₆ /O₂ gas mixture at the ECR position is shown in Fig. 8.

IV. Conclusion

Perfectly selective, highly anisotropic and high-rate ECR plasma etching for n^+ poly-Si and WSix/poly-Si at the ECR position has been achieved in the new ECR plasma etching system. The perfect selectivity is considered to be due to the addition of O_2 gas and to low ion energy at the ECR position. The high etching rate is obtained by high ion current density at the ECR position. We are sure that this technology is a promising candidate for future etching technology in ULSI.

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VI. References

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Figure 8. A cross-sectional SEM image of an anisotropically etched WSix/poly-Si pattern with a Cl₂/SF₆ /O₂ gas mixture.