Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 203-206

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Low Temperature Etching of Multi-Layer Resist by Side Wall Protection

Shingo Kadomura, Jun-ichi Satoh

Research and Development Div. Semiconductor Gp.
SONY Corp.
4-14-1, Asahi-cho, Atsugi-shi, Kanagawa,Japan 243

The temperature effect on the etching profile is investigated in dry etching of multi-layer resist using side wall protection by O_2/Cl_2 gas process.
O_2/Cl_2 process is a competitive reaction which involves the etching (by O_2) and the deposition of Cl_2 and CCl_x, a reactant of the resist. The undercut can be suppressed completely at -30°C if 20% Cl_2 is added to the etching gas.
Surface composition investigation by XPS shows that the reaction by-product is the same as the CCl_4 polymer.

1.Introduction

Delineation of sub-half micron feature sizes is required for future ULSI (e.g.16MSRAM) process.

One of the candidates for sub-half micron lithography is excimer laser lithography with multi-layer resist process.

Consequently, dry etching of multi- layer resist is the key technology in the realization of sub-half micron patterns.

It is well known that anisotropic etching of multi-layer resist using O_2 gas can be performed at low temperatures(below -100°C) (1) or low pressures (below 10^{-5}Torr) (2). But these conditions are considered to be impractical at mass-production levels.

In this paper,we report a more practical etching condition for anisotropic profiles. We found that when Cl_2 is added to O_2,the side wall of the resist is protected by a reaction by-product. This side wall protection allows multi-layer resist to be etched at a more practical temperature of -30°C.

2.Experimental

In this study, an ECR plasma etching system with RF biasing capability was used.

The frequency of RF power was 13.56MHz. For etching at low temperatures,the wafer susceptor electrode was cooled using an ethanol coolant system.(up to -100°C)

The sample wafer is mounted on the electrode by a ceramic clamp,and helium gas was introduced between the back side of wafer to ensure a good thermal contact.

The temperature of the wafer during etching was measured by an optical fiber thermometor contacted to the rear surface of the wafer.

A sample was prepared using a normal tri-level resist process with SOG as an intermediate layer.

The top and bottom layers were photoresist,whose thickness was both 1.0μm.

The intermediate layer was 0.15μm OCD type2 (Tokyo Ohka Corp.), and was baked at 200°C . The intermediate layer was etched using conventional SiO_2 RIE after the top resist patterning.

The etching gas mainly used in this study was O_2,O_2/Cl_2.

The etching profile and rate were investigated using SEM, and the surface composition during etching was investigated by XPS.

3.Result and Discussion

3-1.O_2/Cl_2 Process

Photo-1 shows an SEM cross- sectional view of the etching profile at room temperature. The etching gas was O_2 only, the RF power was 400W,and the etching pressure was 10mTorr.

Under these pressure and ambient conditions, undercut was observed, as expected.

Accordingly,we have developed an O_2/Cl_2 process for anisotropic etching$^{(3)}$.

The process is believed to be a competitive process which involves the deposition of CCl_x (a by-product of the photoresist) and Cl_2 and the etching of this deposited layer by O_2.

Hence,the CCl_x layer protects the side wall during the etch.

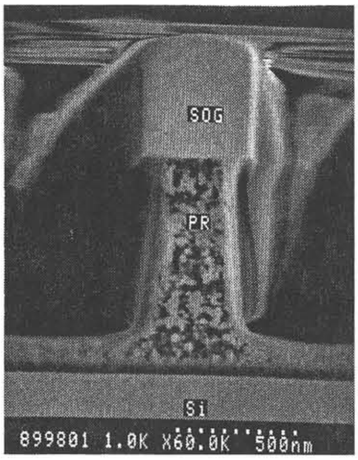

Photo.1. Cross sections of tri-level resist etched using O_2 gas.

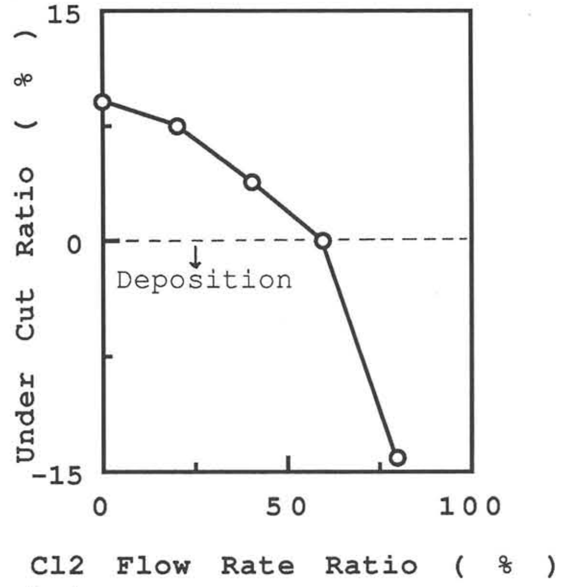

Fig.1. Undercut ratio as a function of Cl_2 flow rate ratio.

Fig.1. shows the undercut ratio of the resist as a function of Cl_2 flow rate ratio at room temperature.

The undercut ratio is calculated from undercut length/etch depth, as shown in Fig.1.

We found that the undercut becomes smaller as the Cl_2 flow ratio increases, and, when the Cl_2 ratio exceeds 60%, the undercut is completely suppressed.

Moreover, as Cl_2 flow rate ratio increases,the etching profile changes to a tapered shape.

This result indicates that the etching mechanism is realized by a competitive reaction, as stated earlier.

However,etching with excess Cl_2 and high RF power, which is essential for anisotropic etch profiles as room temperature. Therefore,we attempted to lower the RF bias and the Cl_2 flow by etching at lower temperatures.

3-2.Low temperature etching

Fig.2 shows the under cut ratio of the resist as a function of wafer temperature (pressure was 10mT,RF power was 200W).

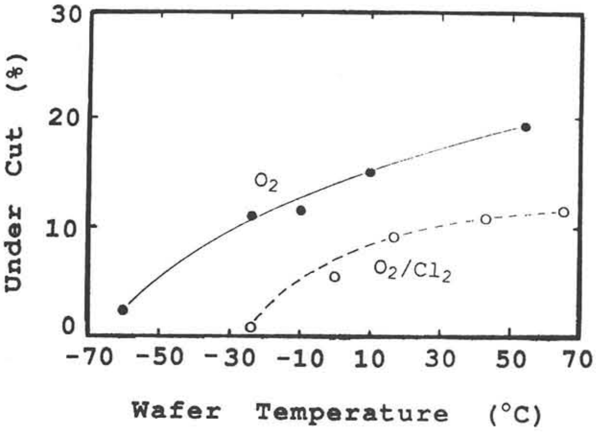

Fig.2. Undercut ratio as a function of wafer temperature.

As the temperature of the wafer is lowered, the under cut is suppressed. The undercut is suppressed completely at -60°C. In contrast, when 20% Cl_2 is added, the undercut could be suppressed even at -30°C. Therefore, by using this process, low temperature anisotropic etching is possible at more practical temperatures. For anisotropic etching at -30°C, the quantity of Cl_2 can be reduced to 20%, from 60% for anisotropic etching at for room temperature, and the RF power can be reduced to 200W, from 400W for etching at room temperature. Because a lower RF power is required, the process has a higher etch selectivity to SOG.

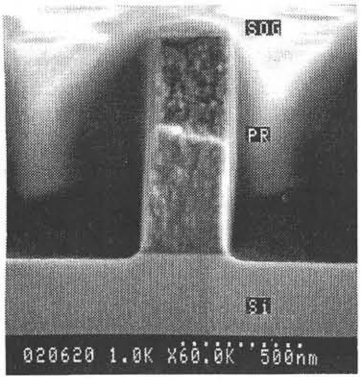

Photo.2. Cross sections of tri level resist etched using O_2/Cl_2 at low temperature.

Photo.2 shows an SEM cross-sectional view of the etching profile at -30°C, when 20% Cl_2 added. It is found that very good anisotropy can be achieved by this process. Therefore, we believe that by lowering the temperature, radical reaction is suppressed and reactant deposition is promoted. These effects contribute to the achievement of anisotropic etching.

Next experiment was done to confirm above hypothesis. The deposition rate of CCl_x polymer was investigated at various temperatures. The result is shown in Fig.3.

As the temperature of the wafer is lowered, CCl_x polymer deposition rate is increased.

This result indicates that the deposition of the reaction by-product is promoted at low temperature.

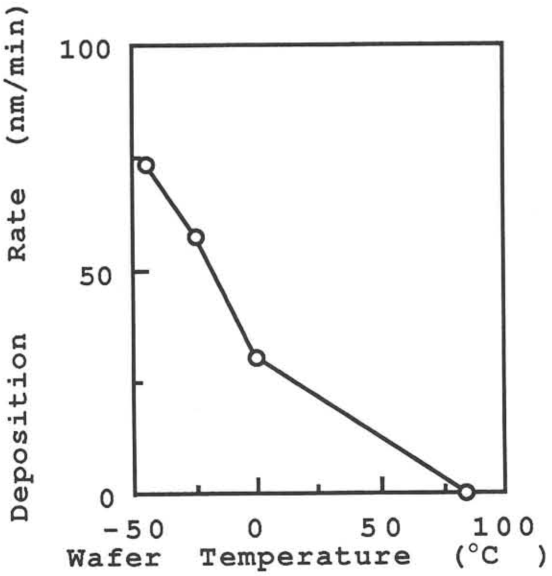

Fig.3. Deposition rate as a function of wafer temperature in CCl_4 plasma.

3-3 The surface analysis after etching

The surface composition during etching was investigated by XPS.

The result is shown in Fig.4.

The spectrum for the bottom surface of the photo-resist before etching is shown as a solid line in Fig.4(a).

The spectrum for the bottom surface of the photo-resist exposed to O_2/Cl_2 plasma is shown as a solid line in Fig.4(b). The spectrum for the surface of polymer deposited in CCl_4 plasma at low temperature is shown as a solid line in Fig.4(c).

In contrast with results (a) and (b), the energy shift of $C_{(1s)}$ signals is different. In the case of O_2/Cl_2 plasma exposed sample, $C_{(1s)}$ signals make an appearance at 287 288eV.

These signals are comparable to that for polymer deposition in CCl_4 plasma at low temperature of Fig.4(c).

Hence,in the case of O_2/Cl_2 plasma exposed,$C_{(1s)}$ signals can be attributed to C-Cl bonds.

This result shows that when Cl_2 is added to O_2 at low temperature,the surface of the resist is covered with a layer of CCl_x which is a by-product of the resist and Cl_2. It is believed that the side wall of the resist is also protected by this reaction by-product.

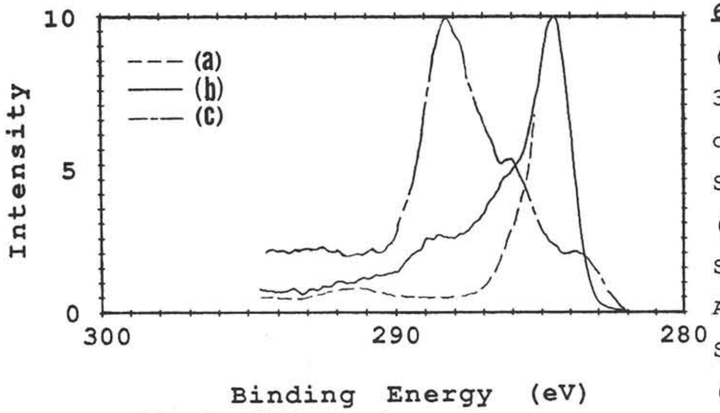

Fig.4. XPS spectra of
(a) the bottom surface of the PR before etching
(b) the bottom surface of the PR exposed to O_2/Cl_2 plasma
(c) the surface of polymer deposited in CCl_4 plasma

4.Conclusion

The effect of low temperature on the dry etching of multi layer resists in O_2/Cl_2 gas process has been investigated.

The undercut can be suppressed completely at -30°C if 20% Cl_2 is added to the etching gas. Therefore,by using this process, low temperature anisotropic etching is possible at a practical temperature. The quantity of Cl_2 that is required for anisotropic etching decreases from 60% for room temperature etching to 20% for -30°C etching.

XPS investigation of the surface composition during etching indicates that the surface of the resist is covered with a reaction by-product of resist and Cl_2.

5.Acknowledgement

The authors wish to express their appreciation to T.Shimada for his support of the project and K.Shinohara for his helpful suggestions.

6.References

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