Dry Etching of Ru Electrodes using O_2/Cl_2 Inductively Coupled Plasmas

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The characteristics of Ru etching using O_2/Cl_2 plasmas were investigated by employing inductively coupled plasma (ICP) etcher. The changes of Ru etch rate, Ru to SiO_2 etch selectivity and Ru electrode etching slope with the gas flow ratio, bias power, total gas flow rate, and source power were scrutinized. A high etching slope (~86°) and a smooth surface after etching was attained using O_2/Cl_2 inductively coupled plasma.

Keywords : *Ru, etching, ICP, plasma.*

1. Introduction

In recent years, high dielectric materials such as barium strontium titanate (BST) and tantallium pentoxide (Ta_2O_5), need to be used for the fabrication of capacitor structure.[1),2)]

Although platinum (Pt) has commonly been utilized as an electrode material, Pt has a difficulty in patterning and thus in forming a bottom electrode. Several research groups have reported that obtaining a sufficient etch selectivity of Pt to the mask material is extremely difficult.[3)-6)]

On the other hand, ruthenium (Ru) is expected to be patterned by chemical etching because the volatile etch product can be produced during the etching process.[7),8)] Previous researchers reported that volatile RuO_4 can be generated from the RuO_2 which is an intermediate phase of the Ru etching reaction.

However, there are not many systematic studies on the basic characteristics of Ru etching. In this study, we report the etching characteristics of Ru using O_2/Cl_2 inductively coupled plasma. We investigate the Ru etch rate, the Ru to SiO_2 mask etch selectivity, and the Ru etching slope with varied process conditions including $Cl_2/(O_2+Cl_2)$ gas flow ratio and bias power. We investigate the Ru surface after etching by employing Auger electron spectroscopy (AES), x-ray photoelectron spectroscopy (XPS), and transmission electron microscopy (TEM).

2. Experimental

The sample structure was substrate/ TiN 500 Å/ Ru 4000 Å/ TiN layer 600 Å/ SiO_2 mask 3000 Å. The SiO_2 mask, instead of photoresist mask, was used for patterning Ru, because oxygen gas was the main etchant in our experiments. The SiO_2 mask was patterned by $CF_4/N_2/Ar$ gas. The TiN layer was inserted between Ru and SiO_2 mask layer to prevent the contamination of etching chamber during SiO_2 mask etching due to Ru exposure. The TiN layer was patterned by Ar/Cl_2 gas. Since Ru cannot be etched by halogen gases only due to high boiling point of their etch products, we used O_2 and Cl_2 gases, expecting that the volatile RuO_4 is produced.[7),8)]

A DPS centura ICP tool commercially available from Applied Materials, Inc. has been used. During etching, the $Cl_2/(O_2+Cl_2)$ gas flow ratio was 0.1-0.3, the source power was 1000-1800 W, the bias power was 100-300 W, the pressure was 10-50 mTorr and the total gas flow rate was 100-400 sccm. The cathode temperature was set to 45 ℃ and the helium pressure was set to 15 Torr.

A scanning electron microscope (SEM) was used to measure the Ru etching slope and the Ru to SiO_2 etch selectivity. Ru surface after etching was analyzed by AES, XPS, and TEM.

3. Results and discussion

In order to investigate the characteristic of Ru etching, we have varied the $Cl_2/(O_2+Cl_2)$ gas flow ratio and bias power. Fig. 1 shows the change of Ru etch rate, Ru to SiO_2 mask etch selectivity and etching slope with varying $Cl_2/(O_2+Cl_2)$ gas flow ratio in the range of 0.1 to 0.3, using O_2/Cl_2 inductively coupled plasma. The source power, bias power, total gas flow rate and pressure are set to 1400

W, 2000 W, 100 sccm and 20 mTorr, respectively. We reveal that the maximum etch rate of about 670 Å/min is attained at the $Cl_2/(O_2+Cl_2)$ gas flow ratio of 0.2. The Ru etching slope increases with increasing $Cl_2/(O_2+Cl_2)$ gas flow ratio.

Fig. 2 shows the change of Ru etch rate, Ru to SiO_2 mask etch selectivity, and etching slope with varying bias power in the range of 150 to 300 W, using O_2/Cl_2 inductively coupled plasma. The source power, total gas flow rate and pressure are set to 1400 W, 100 sccm and 20 mTorr, respectively. The $Cl_2/(O_2+Cl_2)$ gas flow ratio is set to 0.2. Both the Ru etch rate and etching slope increases with increasing bias power. However, the Ru to SiO_2 mask etch selectivity decreases with increasing bias power due to the significant increase of SiO_2 mask etch rate. We assume that etching of SiO_2 mask with O_2/Cl_2 gas proceeds mostly by ion bombardment, because increasing the bias power helps to increase the ion bombardment energy.

In order to investigate the characteristics of Ru etching with varying the radical density, we varied the total gas flow rate and the source power using O_2/Cl_2 inductively coupled plasma. The pressure, bias power, and $Cl_2/(O_2+Cl_2)$ gas flow ratio are set to 20 mTorr, 200 W, and 0.2, respectively.

Fig. 3 (a) shows that Ru etch rate, Ru to SiO_2 mask etch selectivity, and etching slope increases with increasing total gas flow rate in the range of 100 to 400

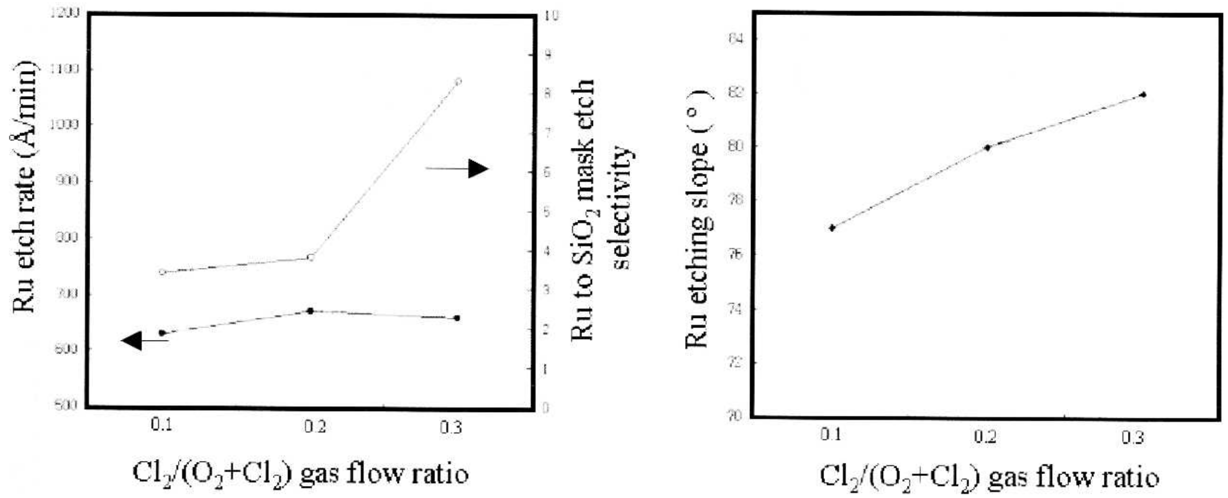


Fig. 1. Variation of Ru etch rate, Ru to SiO_2 mask etch selectivity and etching slope with varying $Cl_2/(O_2+Cl_2)$ gas flow ratio.

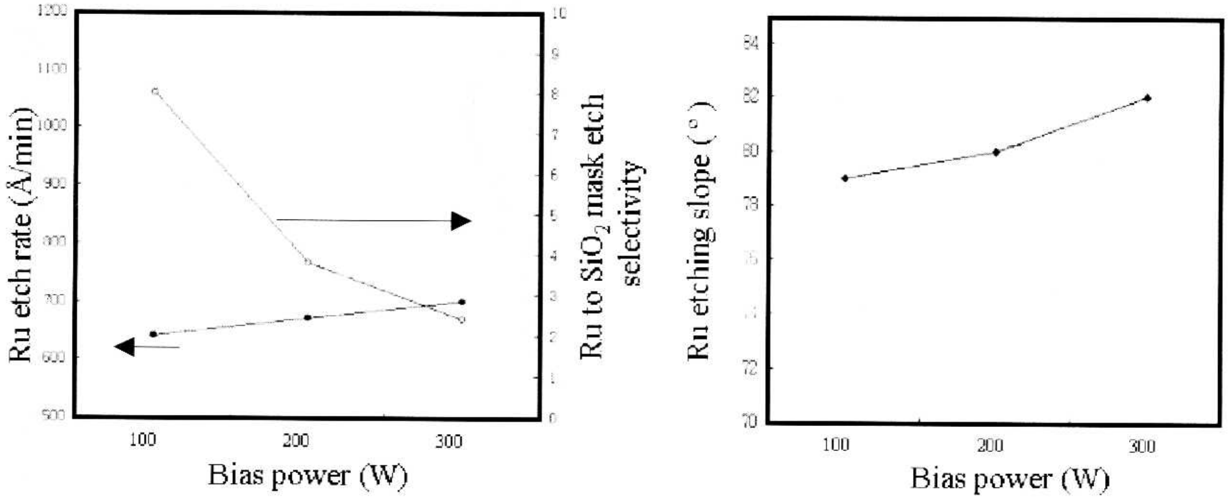


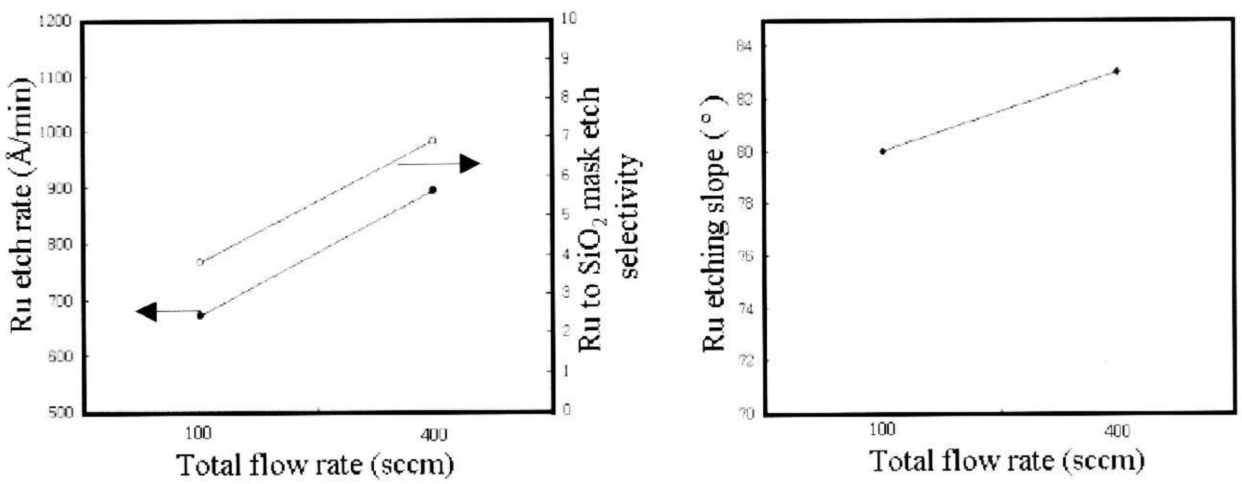
Fig. 2. Variation of Ru etch rate, Ru to SiO_2 mask etch selectivity, and etching slope with varying bias power.

sccm. Fig. 3 (b) shows that Ru etch rate, Ru to SiO_2 mask etch selectivity, and etching slope increases with increasing source power in the range of 1000 to 1800 W. We surmise that the amount of radical flux per unit time may increase and thus the Ru etching reaction may be enhanced with increasing gas flow rates and source power. Accordingly, the radical plays an important role in Ru etching process.

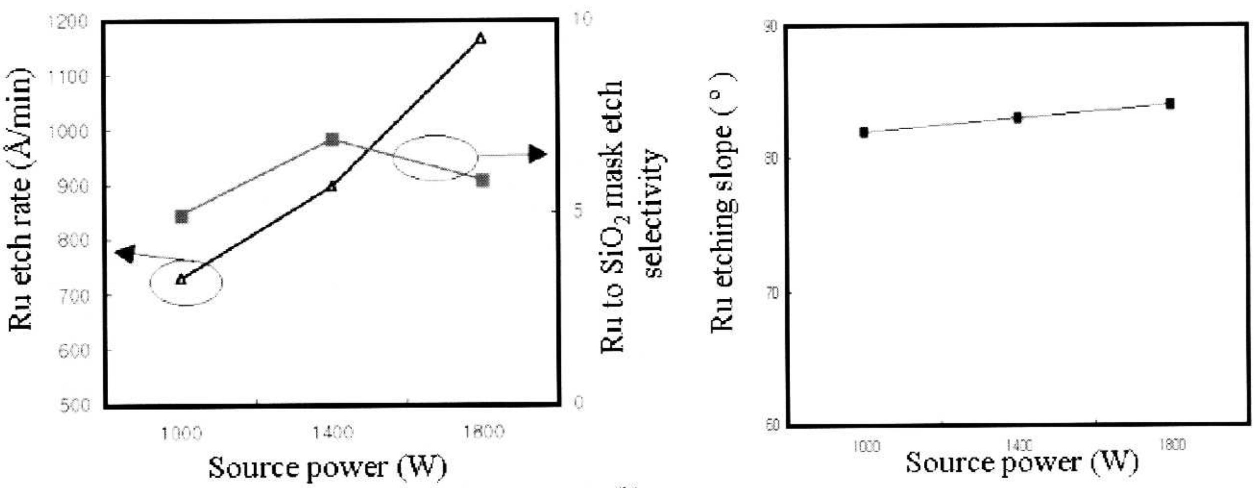
We demonstrate the pattering of Ru electrode with a CD of 0.15 μm using O_2/Cl_2 inductively coupled plasma. Fig. 4 shows that the Ru etching slope at the optimized etching condition is measured to be 86°.

Fig. 5 shows a TEM image of a sample etched using O_2/Cl_2 inductively coupled plasma, revealing that no additional layer is formed on top of the Ru surface. The distance between 2 adjacent crystalline plane of the material both at position "A" and "B" is identical and measured to be about 2.4 Å, corresponding to the lattice parameter of Ru(100). In order to understand the Ru etching process, we investigated the etched Ru surface using O_2 and O_2/Cl_2 plasma.

We performed an XPS analysis and measured the relative amounts of Ru, O, and Cl elements on the etched Ru surface below the depth of 100 Å. The amount of O and Cl is about 36.8 % and 13. 4%, respectively, in case of O_2/Cl_2 plasma ($O_2/(O_2+Cl_2)=0.8$). The amount of O and Cl is about 55.1 % and 1. 9%, respectively, in case of O_2 plasma ($O_2/(O_2+Cl_2)=1.0$).The relative amount of O element on the Ru surface etched using O_2 plasma is greater than that using O_2/Cl_2 plasma. Also, the relative



(a)



(b)

Fig. 3. Variation of Ru etch rate, Ru to SiO_2 mask etch selectivity, and etching slope (a) with varying total gas flow rate in the range of 100 to 400 sccm. (b) with varying source power in the range of 1000 to 1800 W.

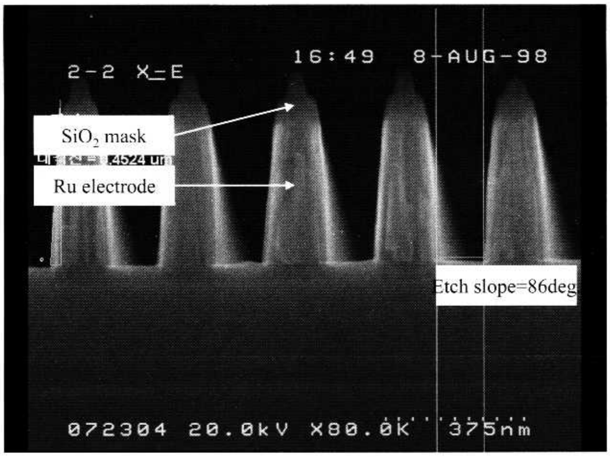


Fig. 4. SEM image of Ru etching profile.

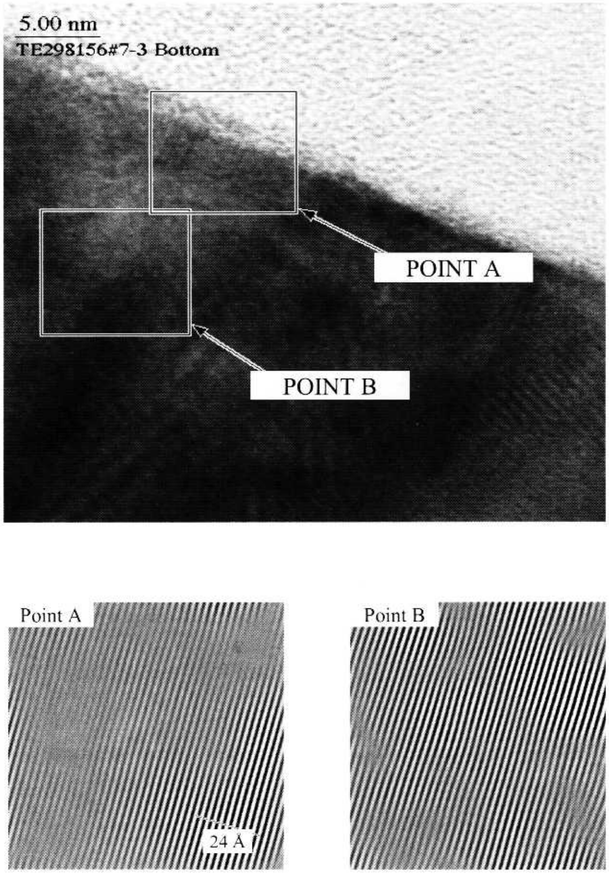
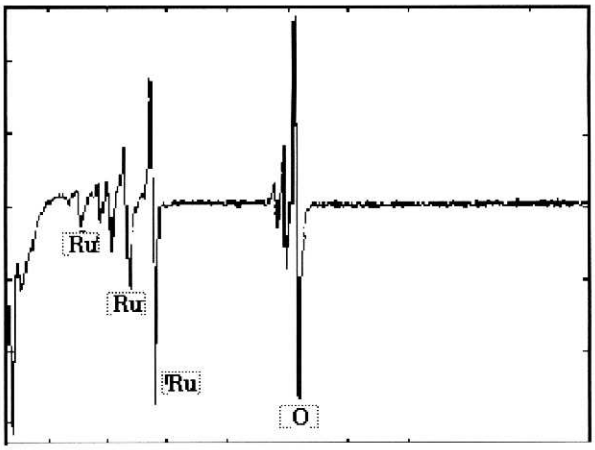


Fig. 5. TEM image of Ru etching profile.

amount of Cl_2 elements on the Ru surface etched using O_2 plasma is smaller than that using O_2/Cl_2 plasma.

Fig. 6 shows the AES spectrum of etched Ru surface. The relative signal of O element compared to Ru element



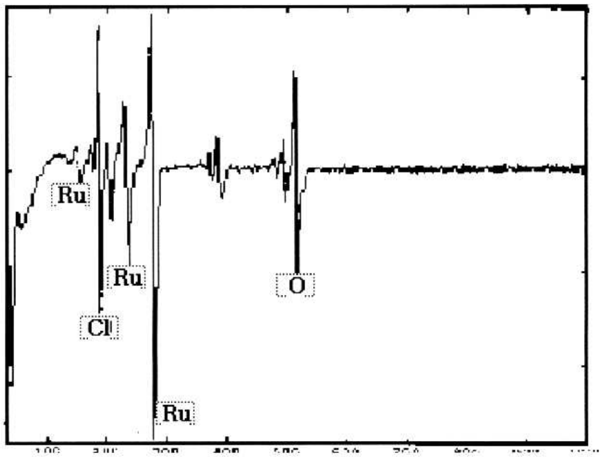


Fig. 6. AES spectrum of etched Ru surface (a) using O_2 plasma and (b) using O_2/Cl_2 plasma.

is greater when etched using O_2 plasma than when etched using O_2/Cl_2 plasma. AES spectra agree with an XPS measurement. We surmise that Ru etching proceeds by generation of RuO_2 from Ru, and subsequent generation of volatile RuO_4 from RuO_2. Further study is necessary to reveal the detailed etching mechanism.

4. Conclusions

The characteristics of Ru electrode etching by inductively coupled O_2/Cl_2 discharges is studied. The variation of Ru etch rate and Ru etching slope by varying process parameters such as $Cl_2/(O_2+Cl_2)$ gas flow ratio, bias power, source power and total gas flow rate have been investigated. A high etching slope of Ru electrode was attained using the ICP plasma. We reveal that the Ru surface after etching using ICP plasma contains no RuO_x layer. The Ru etched surface using O_2 plasma has a greater amount of O element than that using O_2/Cl_2 plasma.

Acknowledgment

This work was supported by Samsung Electronics. We thank to Dr. Chang Jin Kang and Dr. Tae Hyuk Ahn for helpful discussions.

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