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A New Side Wall Protection Technique in Microwave Plasma Etching Using a Chopping Method

K. Tsujimoto, S. Tachi, K. Ninomiya, K. Suzuki,
S. Okudaira and S. Nishimatsu

Central Research Laboratory, Hitachi Ltd.,
Kokubunji, Tokyo 185 Japan

A new anisotropic etching has been developed in microwave plasma etching using a chopping method. The presenting method prevents a side etching through exposing samples sequentially to separate gas discharges of etching and side wall film formation. Side etching of tungsten using SF_6 and NH_3 discharge chopping is found to be reduced less than one fifth that observed in conventional SF_6 etching. In-situ XPS spectra of the altered tungsten surface explain well those results on the side etching.

I. Introduction

Fine pattern transfer from a photoresist mask to an underlying layer by plasma assisted etching is one of the key technologies in the development of integrated devices.

In conventional plasma etching, gas mixing technique has been successfully used to control the etching profile.[1] However, some side etching has been observed in this type of etching. An etching of tungsten[2] indicates a typical side etching even when NH_3, N_2, O_2, CO_2, CCl_4 and CH_4 gasses are added to SF_6 gas. This is because gas phase reactions always resulted in a deficit of species which provides side wall protection films.

.This paper describes a new metod, gas and bias chopping, for anisotropic etching. The concept of this method is to generate sequentially and independently the discharges of the etching gas and the reactant gas for making the protective side wall film. Hence, film formation on the side wall is effectively carried out without disturbing the plasma of etching gas. Anisotropic tungsten and silicon etching in microwave plasma etching will be shown using this method.

II. Experimental

A. Experimental system

The experimental system was a microwave plasma etching apparatus with an ultra-high vacuum (UHV) chamber for XPS analysis.[3] The schematic diagram of the apparatus is shown in Fig. 1. Details are reported previously.[4] In short, plasma was generated by microwave of 2.45 GH_z and confined in a quartz tube by a mirror type magnetic field.

In order to achieve the gas chopping, two programmable gas flow lines were installed. Two kinds of the gasses were alternately introduced to the etching chamber. Duration of the each gas flow can be set independently at 1 ~ 60 seconds. It was found from plasma emission measurements

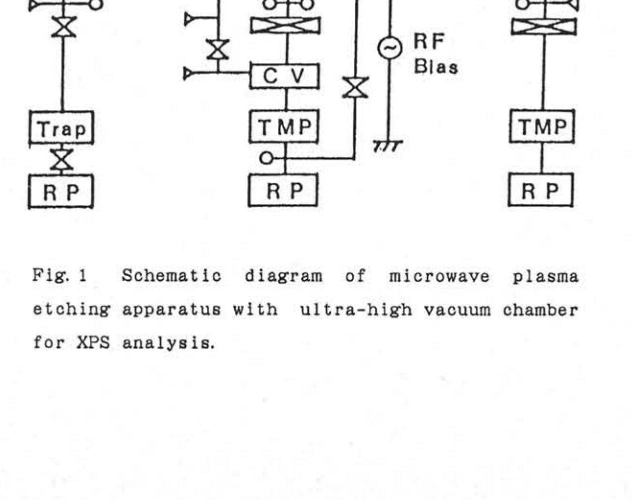

Fig. 1 Schematic diagram of microwave plasma etching apparatus with ultra-high vacuum chamber for XPS analysis.

that the time being necessary to change one to another gas is less than 1 second in the present system. Sample biasing was also programed to synchronize with the gas flow. A RF bias voltage (800 KH_Z) supplied directly to the sample stage was varied from -50 to -150 V (DC element).

The samples used were tungsten films about 350 nm thick deposited on oxidized silicon wafers by magnetron sputtering and Si(100) wafers. A PSG layer 60 nm thick was deposited on the tungsten film to prevent surface oxidation. The photoresist pattern was made on the PSG as an etching mask.

B. Principle of a Chopping Method

As we reported previously[5], there are basically two groups in etching gas-substrate combinations to achieve an anisotropic etching. One is the group which is anisotropically etched by an ion assisted reaction. The etching proceed only normal to the substrate surface by ion bombardment. Neutral species have very low reactivity in this type of the combination, e.g. silicon etching with chlorine containing gas plasma.

The other is the combination which needs to form the side wall protecting films during bottom surface etching. Neutrals in the plasma react with surface atoms with a high reactivity in this case. Tungsten and silicon etching with fluorine containing gas are typical examples. The presenting chopping method is applicable to this type of combination to perform an anisotropic etching.

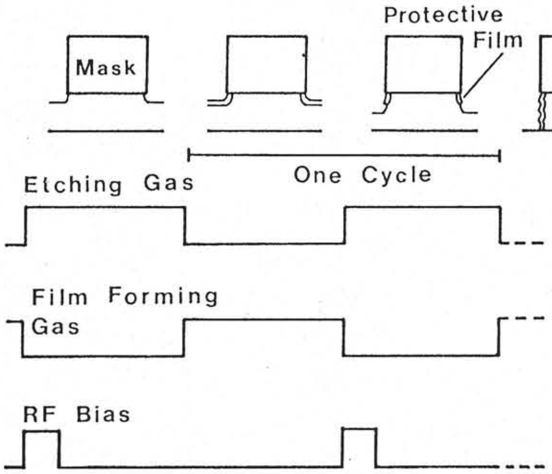

Fig. 2 Procedure of the chopping method.

The basic procedure of the chopping method is shown in Fig. 2. The method is composed of three steps: Protecting film formation, removal of the protecting film from bottom surface by biasing, and etching of the bottom surface. In order to form effectively protective side wall films, the separate discharge step for film formation was set prior to etching gas discharge. The system switched from a film forming condition to an etching condition in a short period and repeated this sequence several times.

At the start of the etching gas discharge, samples were biased so as to remove the altered bottom surface rapidly by energetic ion bombardment, without etching the side wall surface. After finishing the biasing, only bottom surface etching proceeded during the etching discharge, since the protecting film remained on the side wall. Thus, an anisotropic etching can be performed by repeating these three steps.

III. Results and Discussion

Tungsten etching was carried out with SF_6 and NH_3 gasses using the chopping method . The SF_6 discharge period was set at 10 sec. while that for NH_3 was varied 0 ~ 10 sec. Bias voltage was applied to samples for 5 sec. just after finishing NH_3 period. The resulting etching profiles in the tungsten samples are shown in Fig. 3. Side etching of tungsten was

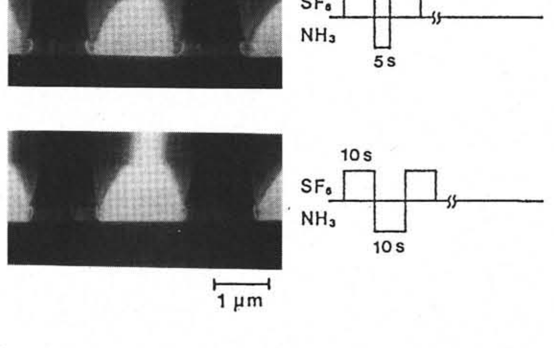

Fig. 3 Cross sections of tungsten etched using SF_6/NH_3 chopping.

found to be reduced to 0.1 μm in contrast to 0.5 μm in conventional SF_6 etching.

The tungsten surfaces treated by plasma are transfered to the UHV chamber for XPS analysis. The spectrum for the bottom surface exposed to NH_3 plasma for 20 sec. is shown as a solid line in Fig. 4(a). Then the surface was treated in

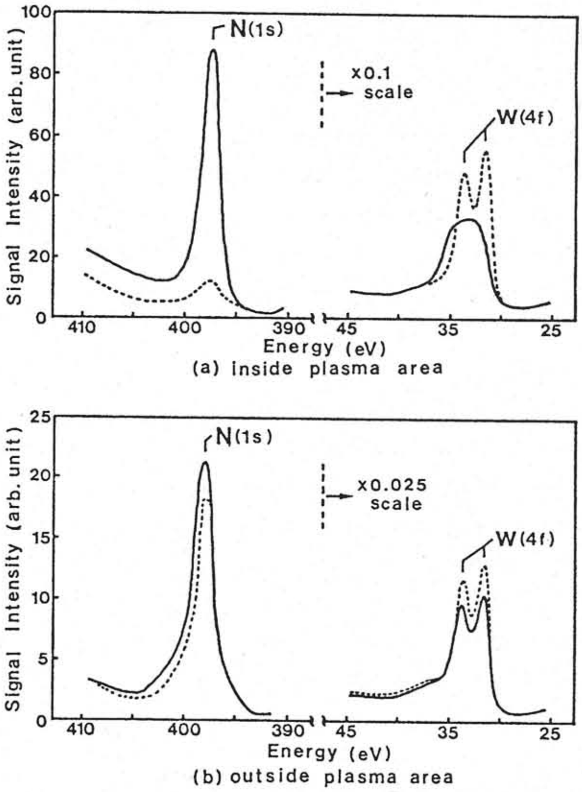

Fig. 4 XPS spectra of tungsten surfaces which are exposed to NH_3 plasma of 2.0×10^{-1} Pa for 20 sec. (solid line) and those exposed to SF_6 plasma of 1.3×10^{-1} Pa for 5 ~ 20 sec. with sample biasing after NH_3 plasma exposure (broken line). Samples are set inside(a) and outside(b) plasma area.

SF_6 plasma for 5 sec. with an initial biasing. The spectrum is shown as a broken line. These results indicate that (1) the energy shift of W(4f) and N(1s) signals can be attributed to tungsten nitride formation on the surface by NH_3 plasma treatment[7], (2) nitride films can be removed by SF_6 plasma with the sample biasing for 5 sec. Therefore the remaining SF_6 discharge period is used effectively to etch the bottom surface.

The same experiments were carried out using samples processed outside plasma area. In this condition, the tungsten surface was still struck by neutrals from the plasma but not by ions. Hence, the surface is thought to be same condition to the side wall in the chopping method. The results are shown in Fig. 4(b). The surface was weakly nitrided by a exposure in NH_3 plasma for 20 sec. It is clear that the tungsten nitride remains on this surface even during the SF_6 plasma treatment for at least 20 sec. from these two spectra. Therefore it is obvious that tungsten etching using a chopping method with NH_3 plasma provides protective films on the side wall, while the altered bottom tungsten surfaces are quickly etched by the SF_6 plasma when the samples are biased. The etching profiles in Fig. 3 can be well explained by these results.

Further investigations were performed by varying the combination of process parameters such as the pressure and discharge time of the etching gas and film formation gas, and the bias voltage and bias duration on each cycle. It was found that the side etching depends on NH_3 discharge time as shown in Fig. 5. The side etching is reduced with increasing NH_3 discharge time and this effect saturates after the NH_3 discharge time reached 10 sec.

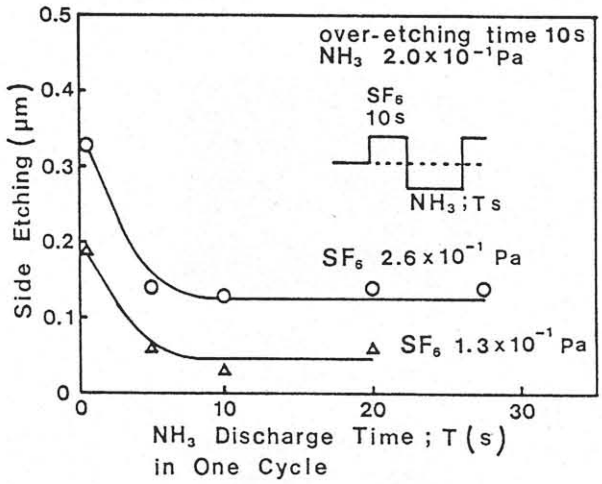

Fig. 5 Side etching of tungsten as a function of NH_3 discharge time.

Characteristics of a side etching during over-etching was observed because some degree of over-etching was always necessary to remove the residues on the underlying films at substrate steps. The side etching is shown in Fig. 6 as a

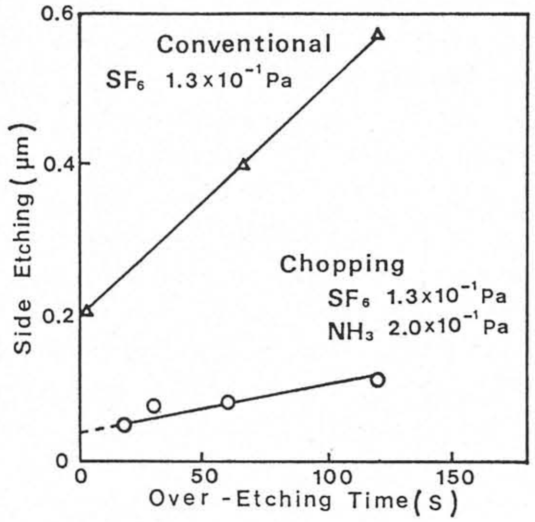

Fig. 6 Side etching of tungsten as a function of over-etching time.

function of over-etching time. Here, the over-etching time in the chopping method is defined by the total time of SF_6 discharge after a end point. It was found that the side etching can be reduced to less than one fifth that in conventional SF_6 etching. Over-etching for 120 sec. in the chopping method corresponds to about 70 % in over-etching ratio to the end point time.

The chopping method was applied to obtain anisotropic silicon etching with fluorine containing gas plasma. Using NH_3 and SF_6 gas

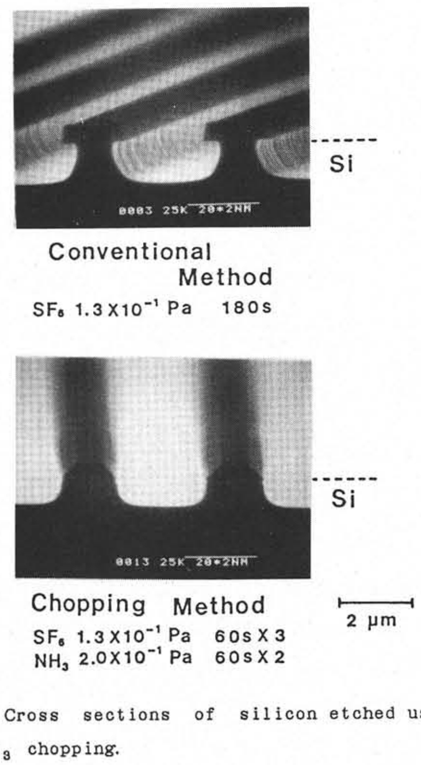

Fig. 7 Cross sections of silicon etched using SF_6/NH_3 chopping.

plasma chopping, the side etching could be reduced to less than 0.1 μm as shown in Fig. 7. Hence, it was concluded that the presenting method has a great potential for achieving anisotropic etching of other materials without reducing selectivity and is applicable to both microwave plasma etching and reactive ion etching.

IV. Conclusion

A new anisotropic etching was performed using a chopping method. For the presenting method, a sample surface is sequentially and independently exposed to a film forming gas and an etching gas. Hence, the side wall was covered with a protective film during the bottom surface etching.

The side etching of tungsten was reduced to less than one fifth that observed in conventional SF_6 etching. Anisotropic silicon etching was also carried out with small side etching less than 0.1 μm. The results of in-situ XPS analysis on surfaces treated with etching gas and film formation gas are good agreement with the etching profiles obtained by the presenting chopping method.

Acknowledgments

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