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Excellent Contact-Hole Etching with NH_3 Added C_5F_8 Pulse-Modulated Plasma

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1. Introduction

Perfluorocarbons (PFCs) such as CF_4 and cyclic (c-) C_4F_8, which have been used in the dry etching of SiO_2, have big global warming potentials and very long lifetimes as shown in Table 1 [1]. Recently the PFC alternative gases with small global warming potential and short lifetime are strongly required in order to protect the global environment

In this paper, excellent contact hole etching of sub-0.1 μm size in SiO_2 is achieved by adding NH_3 to c-C_5F_8 with small greenhouse effect, and Ar mixing gas in the pulse-modulated inductively coupled plasma (ICP).

2. Experiments

2.1 Etching system

The ICP etching system we used is schematically shown in Fig. 1. A source RF power of 13.56 MHz modulated using a function generator is introduced into the Cu ring electrode in order to control the plasma density and electron temperature independently. 400 kHz RF is used to generate substrate bias. The wafer is cooled to -11°C to suppress the etching of the resist mask. Pressure is 15 mTorr. Plasma source gas is a mixture of c-C_5F_8 (11 sccm) and Ar (60 sccm) added with NH_3 (1~5 sccm). For the comparison, the effect of other adding gas such as H_2 or O_2 was investigated.

2.2 Sample preparation

The (100) p-Si wafers with 900 nm thick phosphosilicate-glass (PSG) layer were used for the investigation of the etching profile. The photoresist (posi-type) was patterned using electron beam lithography to investigate the several size of contact hole pattern as shown in Fig. 2. After etching, photoresist and deposited polymer were removed by O_2-plasma and sulfuric acid/hydrogen peroxide/water mixture cleaning.

3. Results and Discussions

3.1 Effect of pulse modulation

The effect of pulse modulation was investigated by pulse-modulated plasma (the off time was fixed at 25μs, and on time was changed) using c-C_5F_8 (11 sccm)/Ar (60 sccm)/ O_2 (4 sccm) mixture gas. As shown in Fig. 3 a good etching selectivity (SiO_2/Si) is obtained for 25μsec on and 25 μsec off time. The effect of the pulse modulation is explained as follows [2]. After turning off the RF power, the electron temperature and the electron density decay. However, since their decay times are different, the average electron temperature and reactive species in the plasma can be controlled by the on/off time. For the pulse-modulated plasma, since the average electron temperature decreases and the number of generated ions is reduced, the CF_2 radicals, which are the main precursor of the deposition, increase and lead to the deposition of the C_xF_y polymer film [3]. It is known that the appropriately adjusted C_xF_y polymer deposition can improve the etching selectivity between SiO_2 and Si [3]. Therefore, we obtained a good etching selectivity using a pulse-modulated C_5F_8 plasma.

3.2 Effect of additional gases

Adding oxygen to C_5F_8/Ar plasma greatly influences the etching profiles and selectivity (Fig. 4(a)). The oxygen addition decreases the amount of excess deposition of C_xF_y polymer, leading to the suppression of etch stop, but it also decreases the selectivity[4].

Adding hydrogen to C_5F_8/Ar plasma greatly improves the selectivity (Fig. 4b). The hydrogen addition decreases the amount of fluorine radicals, which induces excess etching of Si, leading to the suppression of Si etching. However, the amount of C_xF_y molecules is maintained, and etch stop is still caused [5].

Adding NH_3 to C_5F_8/Ar plasma can realize contact hole of sub-0.1μm size with high aspect ratio and high selectivity (Figs. 4(c), 5). NH_3 in plasma generates hydrogen radicals which decrease the amount of fluorine radicals. And reaction of generated HCN and FCN may reduce the C_xF_y polymer [6].

4. Conclusions

By addition of NH_3 to C_5F_8/Ar pulse-modulated plasma, sub-0.1μm size and high aspect ratio (>10) contact hole etching with good vertically and excellent selectivity (SiO_2/Si≈80) is achieved.

This process could be used for the next generation ULSI devices (about 70 nm node MOSFET).

References

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Table .1 GWP and lifetime of some etching gases.

Gas	GWP_{100}	Lifetime (year)
CO_2	1	50-1200
CF_4	6500	50000
c-C_4F_8	8700	3200
c-C_5F_8	90	1

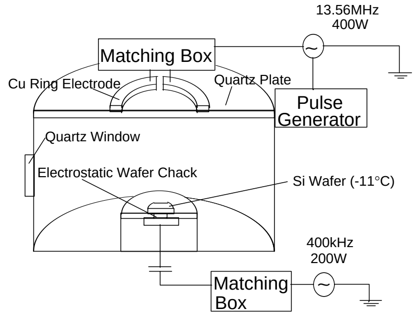

Fig. 1 Schematic diagram of ICP reactor.

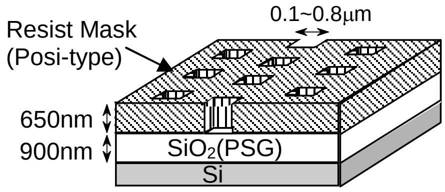

Fig. 2 Cross sectional structure of etching sample.

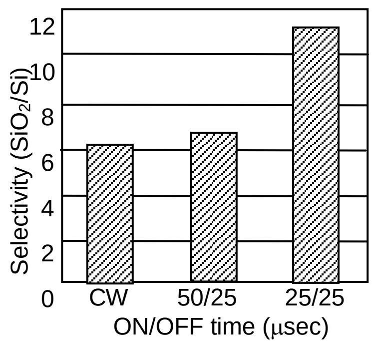

Fig. 3 Etching selectivity versus plasma on/off time.

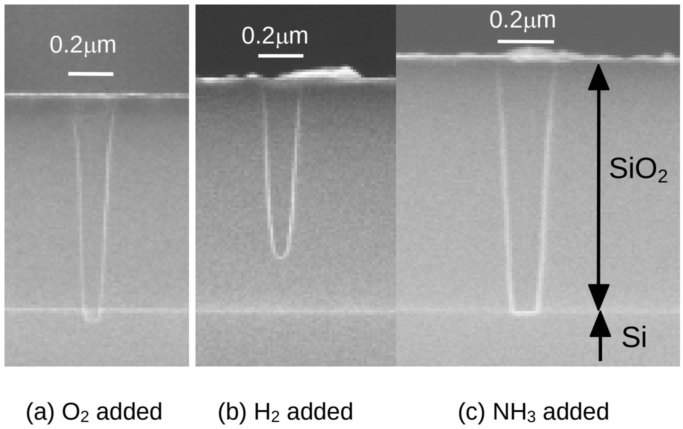

Fig. 4 SEM photograph of cross section of the 0.2μm contact hole etched with different additional gas.

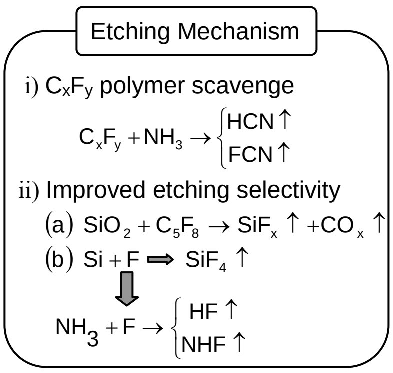

Fig. 5 Mechanism of NH_3 adding effect.

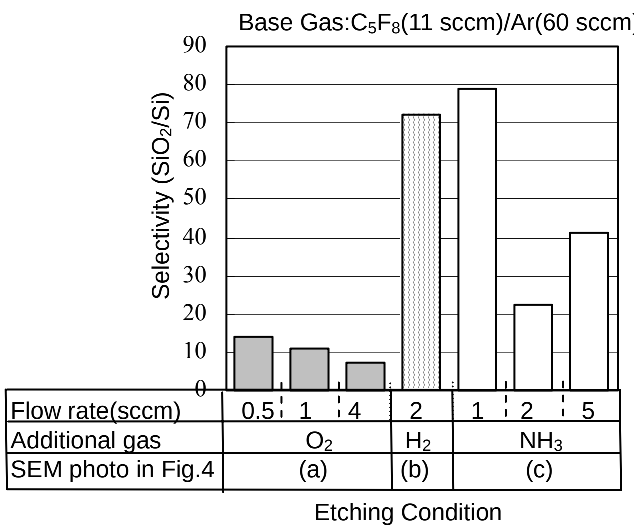

Fig. 6 SiO_2/Si etching selectivity for different additional gas and flow rate.

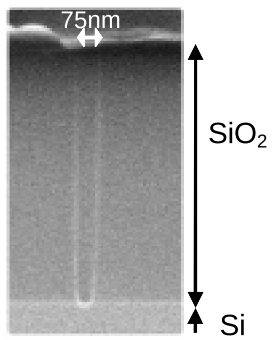

Fig. 7 SEM photograph of the cross section of the sub-0.1μm contact hole with high time: 50 μsec/25 μsec,70% over etch).