Reactive Ion Etching Selectivity of Si/SiO_2: Comparing of two fluorocarbon gases CHF_3 and CF_4

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(Dated: Received 15 January 2019; accepted 1 March 2019)

Two reactive ion etching (RIE) processes were studied to show the relative etch selectivity between SiO_2 and Si using two fluorocarbon gases, CF_4 and CHF_3. Results show that CHF_3 gives better selectivity (16:1) over CF_4 (1.2 :1). On the other hand, the etch rate of SiO_2 of CF_4 is approximately 52.8 nm/min, faster than CHF_3 (32.4 nm/min).

Key Words: Reactive ion etching, RIE, Si, SiO_2, CHF_3, CF_4, Selectivity

I. Introduction

In nanofabrication, etching a SiO_2 layer over a Si layer (or vice versa) is a common process. To make sure the target material is completely removed, a 10% over-etching is often included in process design. However, for most devices, as little over-etch as possible is preferred. In the reactive ion etching (RIE) process, etching happens primarily via chemical reaction. The plasma in reaction is formed by the high frequency electric field applied between two electrodes fixed on top and bottom. The electric field also defines the direction of plasma movement, which gives RIE process the merit of being high anisotropic. Fig. 1 shows the Oxford 80 Plus RIE, with a 220mm diameter platen, used in this study.

FIG. 1. Oxford 80Plus RIE

Fluorocarbon gases are commonly used for the dry etching of SiO_2 or Si. The mechanism of fluorine-based etching has been well studied[1]. Fluorine atoms are ionized and react with Si, resulting in gaseous products such as SiF_4, as is shown in Fig 2. Adding H_2 or O_2 in the gas flow will affect the reaction, resulting higher etching rate of SiO_2 or Si respectively. Meredith Metzler and co-workers studied etching behavior of Si, SiO_2 and Si_3N_4 in CF_4 or CHF_3/O_2 gases during RIE process with Oxford 80plus, and showed the etch rate and selectivity of substrates to organic resists[2–6]. This study aims at direct comparison of etch rate and selectivity between Si and SiO_2 with two fluorocarbon gases (CF_4 and CHF_3) in the RIE process. The results suggest different appli-

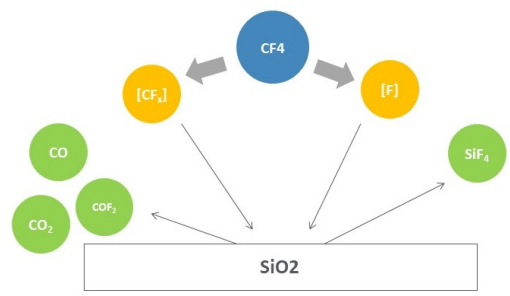

FIG. 2. Fluorocarbon gases etching process

FIG. 3. Cross-section view of the test structure

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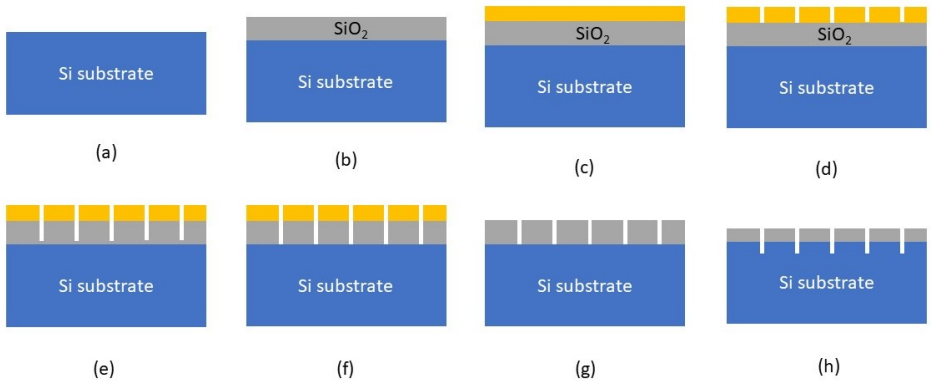

FIG. 4. (a) silicon substrate start, (b) deposit SiO_2, (c) spin coat photoresist, (d) lithography, (e) RIE to create trench, (f) HF surface clean (g) strip photoresist (h)RIE test.

cations of these two gases in practice.

II. Experiment

To investigate the etch selectivity (SiO_2: Si) of CF_4 or CHF_3, a trenched structure is created in photoresist. Fig 3 shows the top view and cross section of this structure. The width of each trench is identically 100 m. In the fabrication process of this structure, a layer of SiO_2 is deposited on top of a silicon substrate via plasma-enhanced chemical vapor deposition (PECVD). The measured thickness of the as-deposited oxide layer is 339 nm. After the lithography, the sample is etched with RIE to remove most of the SiO_2 in the trench. Then followed by hydrogen fluoride to clean the oxide residual in the exposed areas. With this process, SiO_2 trenches are made with Si completely exposed in those trenches. The key in this process flow is to keep the Si substrate untouched for further analysis. Figure 4 shows the process flow.

Then the RIE process is performed on a series of chips, each with the structure shown in Fig 4 (g). Both SiO_2 and Si can be etched by fluorocarbon gases. After etching, the change in thickness of SiO_2 is measured by reflectometry (Filmetrics F40), and the change in the trench depth is measured by 2D profilometry (P7 profilometer).

The CF_4 etching process starts by pumping the chamber pressure to 5.5×10^{-5} Torr. Then CF_4 flows at 20.0 sccm and the chamber is maintained at 6.5×10^{-2} Torr. The CHF_3 etching process starts by pumping to 4.5×10^{-4} Torr, CHF_3 then flows at 12.0 sccm and Ar at 38.0 sccm, the chamber pressure is kept at 3.0×10^{-2} Torr.

III. Results and Discussion

In fluorocarbon gases, the fluorine atoms are responsible for the etching of Si. In the etching process, the CF_3 radicals generated are absorbed on the Si substrate and form a thin film that resists the etching of Si, while the etching of SiO_2 continues because of those radicals. Addition of H_2 reduces the etch rate of Si by forming HF[7].

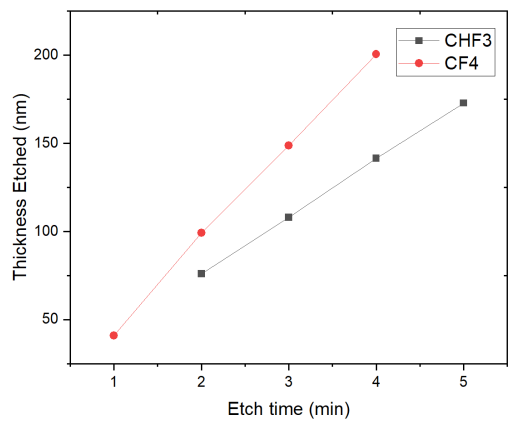

FIG. 5. Etch depth of SiO_2 vs time for the CF_4 and CHF_3 processes

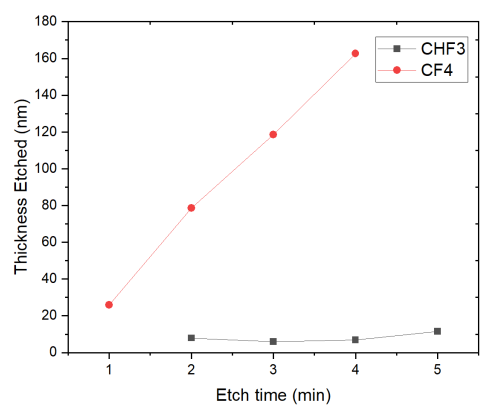

FIG. 6. Etch depth of Si vs time for the CF_4 and CHF_3 processes

Hence using CHF_3 should increase the etch rate of SiO_2.

Fig 5 and 6 depicts the etch curve of each gas with respect to etching SiO_2 and Si. Fig 5 shows that the etch rate of SiO_2 of CF_4 is approximately 52.8 nm/min, faster than CHF_3 (32.4 nm/min). On the other hand, the etch rate of silicon is comparable of CF_4 and CHF_3, while CHF_3 etches much less of SiO_2 than CF_4 as shown in Fig 6. The measured data are listed in Table I and II with a schematic image of labels in Fig 7. Based on those measurements, the etch rate and selectivity were calculated as listed in Table III. CHF_3 gives better selectivity (16:1) over CF_4 (1.2 :1). Taken as a whole, a better etch selectivity (SiO_2: Si) of CHF_3 and a faster etch rate of SiO_2 by CF_4 were observed.

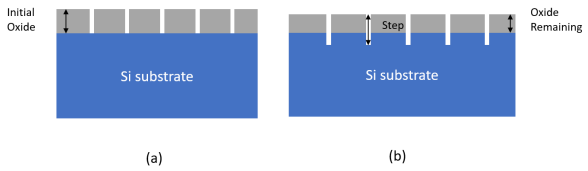

FIG. 7. Schematic images for measurement (a) before RIE (b) after RIE

IV. Summary

According to the result, CHF_3 gives better selectivity of SiO_2 to Si (16:1) versus CF_4 (1.2 :1). The etch rate of SiO_2 of CF_4 is approximately 52.8 nm/min, faster than CHF_3 (32.4 nm/min). For applications, CHF_3 fits for where SiO_2 needs to be etched while Si remained untouched, CF_4 fits for when a single type of material gets exposed to etch and it gives better etch rate.It should be noted that this study did not specify the effect of gas pressure and different mixture of gas components. This is a qualitative comparison of CF_4 and CHF_3 in the RIE process.

V. Acknowledgements

This work was performed at the Singh Center for Nanotechnology at the University of Pennsylvania, a member of the National Nanotechnology Coordinated Infrastructure (NNCI) network, which is supported by the National Science Foundation (Grant NNCI-1542153).

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TABLE I. Measurement of oxide thickness and step height before and after CHF4 etch

Initial oxide (nm)	Etch time (min)	Oxide remaining (nm)	Step (nm)	Oxide etched (nm)	Silicon etched (nm)
339	1	298.1	324	40.9	25.9
339	2	239.7	318.4	99.3	78.7
339	3	190.3	308.9	148.7	118.6
339	4	138.5	301.2	200.5	162.7

TABLE II. Measurement of oxide thickness and step height before and after CHF_3 etch

Initial oxide (nm)	Etch time (min)	Oxide remaining (nm)	Step (nm)	Oxide etched (nm)	Silicon etched (nm)
339	2	263	270.9	76	7.9
339	3	231	237	108	6
339	4	197.6	204.5	141.4	6.9
339	5	166.2	177.7	172.8	11.5

TABLE III. Etch rate and selectivity (SiO_2:Si)

Etch rate (nm/min)	SiO_2	Si	Selectivity
CHF_3	32.4	2	16:1
CF_4	52.8	45	1.2:1