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다구치 방법을 이용한 비정질 수정 건식 식각 최적화

송은석[*], 정형균[*], 황영석[*], 현익재[**], 김용권[*], 백창욱[**]
서울대학교[*], 중앙대학교[**]

Optimization for Fused Quartz DRIE using Taguchi Method

Eun-Seok Song[*], Hyung-Kyun Jung[*], Young-Seok Hwang[*], Ik-Jae Hyun[**], Yong-Kwon Kim[*], Chang-Wook Beak[**]
Seoul National University[*], Chung Ang University[**]

Abstract - In this paper, optimal DRIE process conditions for fused quartz are experimentally determined by Taguchi method to develop high-performance inertial sensors based on the fused quartz material, which is known to have high Q-factors. Using Si layer as an etch mask, which was formed by previously developed bonding process of the fused quartz and Si wafer, fused quartz DRIE process was performed. Different 9 flow rate conditions of C_4F_8, O_2, He gas have been tested and the optimum combination of these factors was estimated. By this work, the ability to fabricate high aspect ratio fused quartz structure was confirmed.

1. Introduction

Quartz has a good mechanical property and thermal stability. So it has been prominently used for essential elements of precision control systems like inertial measurement units (IMU) or time keeping oscillators, although it is inferior to silicon material in terms of precise processing and compatibility with electronic circuits[1]. Generally quartz etch process, especially for single crystal quartz, uses wet etch process. So it is not only hard to achieve accurate patterned profile but limited to make structures freely owing to its crystal direction [2]. For these reasons, quartz material has not been prevailing in MEMS technology. However, DRIE process for glass or quartz becomes available thanks to the development of dry etch process equipment [3].

In this paper, optimum quartz DRIE conditions have been experimentally estabilished using Taguchi method. To obtain high aspect ratio etch profile, we used Si-fused quartz bonding process for Si mask of fused quartz wafer [4]. We could extract the optimal conditions to minimize side etch rate by changing flow rate of etch gases.

2. Experimental plan using Taguchi method and experiment procedure

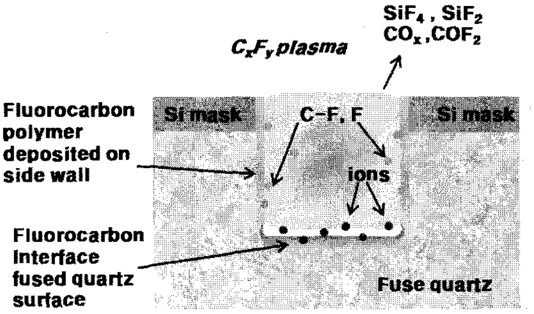
2.1 Fused quartz DRIE mechanism

Fused quartz DRIE process is different from Si DRIE process. As for Si DRIE process, generally called Bosch Process, it is composed of 3 steps: clothing polymer layer with C_4F_8 - bottom polymer layer etching by SF_6 - Si layer etching by SF_6. But in quartz (SiO_2) DRIE process, polymer layer deposition is done simultaneously with physical and chemical etching by heavy ions, as shown in Fig. 1.

DRIE process gas(C_4F_8) is decomposed into radicals such as F, CF2, CF and heavy ions like CF^+, CF_2^+, CF_3^-. It is generally known that the fluorocarbon layer which is deposited on the surface of quartz wafer is made by CF_x radicals when deposition is more dominant than etch. Meanwhile, etch process is performed with fluorine atom and CF_3^+ which physically bombard SiO_2 layer, then become SiF_4 CO_x by chemical reaction[4].

O_2 gas plays a role of eliminating C_xF_y polymer layer for better etch rate of quartz layer. However, O_2 gas that brings much fluorine which etches Si layer, would make selectivity lower. Moreover, large flow rate of O_2 gas which could make SiO_2 layer on the surface of quartz wafer might have the opposite effect.

He gas is used for cooling the surface of wafer to make high selectivity. And large amount of He gas that decreases residual time of C_4F_8 gas improves perpendicularity of high aspect ratio structure[4]. By changing these three gases flow rate conditions, we are able to set experimental plans as follows.



<Figure 1> Mechanism of quartz(SiO_2) DRIE

2.2 Experimental design and orthogonal array

To investigate the optimal quartz DRIE condition, three process parameters which have three-levels each, i.e. flow rates of C4F8, O2, He are considered. The process parameters and their selected levels are presented in Table 1. For three parameters at three levels each, the trial and error method would require 3^3 experiments. However, by Taguchi method (L9 orthogonal array), the required experiments are only nine [5].

The experimental design for optimizing quartz DRIE condition process parameters using L9 orthogonal array is shown in Table 2. This design involves nine particular combinations of parameters and levels to achieve experimental efficiency under the condition that all three parameters do not effect each other. This condition guarantees quantitative calculation of each parameter's effectiveness [5].

<Table 1> Selected process parameters and their levels

Parameters	Level 1	Level 2	Level 3
C_4F_8 (sccm)	20	40	60
O_2 (sccm)	0	20	40
He (sccm)	25	75	125

<Table 2> L9 orthogonal array design

Experiment	C_4F_8 (sccm)	O_2 (sccm)	He (sccm)
1	60	40	75
2	60	20	25
3	60	0	125
4	40	40	25
5	40	20	125
6	40	0	75
7	20	40	125
8	20	20	75
9	20	0	25

2.3 Experiment procedure

Samples for quartz DRIE was prepared as follows. For bonding of fused quartz wafer with Si wafer (DSP), which will be used for quartz DRIE mask, each wafer was cleaned by RCA1 process and treated by O_2 plasma process. These processes make the surface of each wafer hydrophilic, and improve the surface activity. After contacting wafers each other at an atmospheric pressure, annealing process was performed at 300 °C to reinforce bonding strength [4]. Making samples is completed with Si DRIE process for patterning Si mask, which was made by lapping Si surface down to 30 ㎛ thickness. As fixed conditions, RF power and frequency were set to 1300 W and 13.56 MHz, respectively. Pressure and temperature of chamber are kept at 4 mTorr and 60 °C. Etching process time was set to make 20 ㎛ deep trenches on the surface of the fused quartz wafer.

3 Result and analysis

3.1 Experimental result and S/N noise ratio

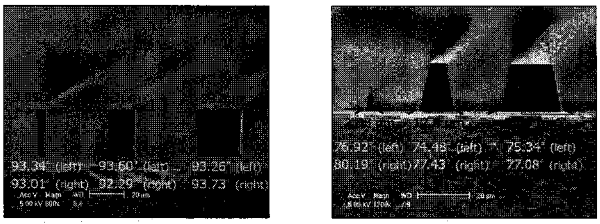
At each experimental level 24 samples were prepared to minimize the noise factor. Each data of experiment, as shown in Fig. 2, was measured and calculated from difference of width between Si mask pattern which was made before quartz DRIE process, and fused quartz pattern that was obtained after quartz DRIE process. And the data representing results for each set of experimental conditions were mean values of these 24 samples and summarized in Table 3.

Fig. 2(a) and (b) shows the profile of structures that was formed by the 9th and 8th experiment, respectively. These two figures show the largest and the smallest deviation from the designed mask pattern width.

In addition to these results, S/N noise ratio value which was considered for smaller-the-better characteristics could be also calculated. In Taguchi method, the signal to noise ratio is used to determine the deviation of the quality characteristics from the desired value [5]. The S/N ratio n_j(smaller-the-better) in the jth experiment can be expressed as :

$$n_j = -10\log\left\{\left(\sum_{i=1}^{N} Y_{ij}^2\right)/N\right\} \tag{1}$$

where N is the number of samples and Y_{ij} is the experimental value of the ith quality characteristic in the jth experiment[5].



<Figure 2> measured pattern width afters fused quartz etch : (a) the smallest side etch result (b) the largest side etch result

<Table 3> Summarized results and S/N ratio

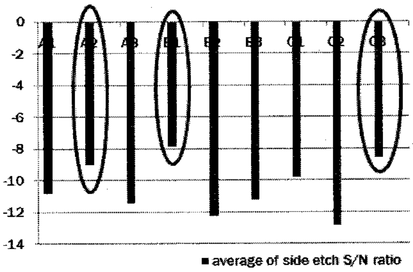
Experiment	Deviation of width (μm)	S/N ratio (dB)
1	2.039	-12.643
2	2.074	-12.677
3	1.917	-9.017
4	2.401	-11.158
5	1.069	-6.964
6	1.310	-8.931
7	1.561	-9.807
8	3.531	-17.003
9	0.902	-5.635

3.2 S/N noise ratio analysis

Summation of S/N ratio values at specific level for one process parameter can be considered as the effect of each parameter's level on side etch. Additionally, the variance of summation of S/N ratio at different levels can be used to calculate each parameter's contribution[5]. This analysis is summarized in Table 4. And Fig. 3 shows S/N graphs for the deviation of the pattern width, where capital A, B and C represent C_4F_8, O_2, He gas, respectively. The processing condition for attaining optimal side etch rate is C_4F_8 (A)? at level 2, O_2 at level 1, He at level 3. Calculated contributions for each parameters are about 13.7 %, 44.8 %, 41.5 % respectively.

<Table 4> L9 orthogonal array design

Parameters		C_4F_8 (A)	O_2 (B)	He (C)
Summation of S/N ratio of parameter level	level 1	-10.815	-7.861	-9.823
	level 2	-9.018	-12.215	-12.859
	level 3	-11.446	-11.203	-8.596
	Sum	-31.278	-31.278	31.278
Variance of summation of S/N ratio		3.229	18.954	9.214
		5.895	1.024	18.170
		0.398	11.168	1.506
	Sum	9.522	31.146	28.890
Contribution (%)		13.691	44.776	41.533



<Figure 3> Optimal condition for fused quartz DRIE

4. Conclusion

From this study, the optimum process condition for fused quartz DRIE using Taguchi method is determined. To achieve the most desired conditions for fused quartz DRIE process, flow rates of C4F8, O2, He gas, which are regarded as the most considerable factors, were differently leveled by L9 orthogonal array. Each result data of 9 experiments were converted to S/N noise ratio to estimate the most proper conditions and contribution rate of each parameter. From this established DRIE process conditions, one would be able to fabricate accurate, high aspect ratio structures of fused quartz.

[Reference]

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