Formation Mechanism of Micro Defect in Anisotropic Etching Analyzed by using Quasi-defect Pattern

Junji Miyazaki and Akira Kawai

*Department of Electric Engineering, Nagaoka University of Technology
1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan*

Anisotropic wet etching for Si substrate is a key technology for manufacturing three dimensional structures for MEMS. It is important to understand a printability of defect during this etching process to create a complete design of MEMS structure. In this paper, an impact of quasi-defects on an etched structure is investigated. It is demonstrated that a minimum defect size which is not affect on the final structure is around a half of total etching depth.

Keywords: Anisotropic etching, defect, photo lithography, MEMS, Si wafer

1. Introduction

Micro Electro Mechanical Systems (MEMS) is a key technology to integrate machine, sensor, actuator or electric circuit into one device. It is already applied to such as gyroscope, acceleration sensor or digital mirror device^[1,2]. One method to fabricate MEMS device is to apply a process technology which has been already developed for LSI manufacturing. A single crystalline of silicon which is used for this process has an anisotropic etching property for strong alkaline wet etching process. This property easily enables to fabricate a three dimensional structure into a Si substrate. It is not a new technology, but useful technology because it is simple and low cost process, but it enables to construct a complex three dimensional structure.

Photolithography is used to create an etching mask. Defect control is one of key technology for photolithography. It is important to know a printability of defect during this etching process. However it is difficult to predict an impact of defect during anisotropic etching.

In this paper, an impact of quasi-defect on an etched Si substrate is studied. Etched window shape using anisotropic wet etching on Si substrate is shown in Fig.1. Preparing quasi-defect on oxide

mask, we investigated defects printability and demonstrated minimum defect size which is not affect on the final structure.

(a) Shape of anisotropic etched window

(b) 0 ° rotated pattern

(c) 45 ° rotated pattern

Fig. 1 Schematic diagram of Quasi-defect pattern.

2. Experiment

Several quasi-defects were prepared in a thermal oxide film as a etching mask to evaluate a printability of these defects by using EPW anisotropic etching into Si substrate.

2.1. Thermal oxide film

A Si substrate was oxidized by using an electric furnace after removing native oxide layer by HF treatment. Temperature profile was shown in Fig.2. The substrates of 12mm x 12mm size were used. SiO₂ thickness measured by Elipsometry was also shown in Fig.2.

Fig.2 Temperature profile for thermal oxidation.

2.2 Photomask with quasi-defects

Several design of quasi-defects of which width is from 10 μm to 50 μm were employed on a photo mask. Lithography conditions and a top view of the photomask were summarized in Table 1.

Table 1 Conditions for photo mask preparation.

F value	22
Focus	50
Shutter	Open
Exposure time	2 min
Developer	5min
Rinse	20sec
Fixer	2min
Water washing	15min

2.3 Substrate etching

Figure 3 showed a process flow of anisotropic etching. Resist film was coated on a Si substrate with oxide layer. (2): Quasi-defects on the photomask were printed into resist film on oxide layer by using photolithography. Lithographic conditions were shown in Table 2. (3): Defect

Fig.3 Flow chart of anisotropic etching.

patterns were etched into the silicon dioxide layer by HF wet etching. The substrates were inserted into 5% of HF solution for 3 min. Etching rate measured was 0.54nm/sec. The SiO₂ mask with defects was created into the oxide layer during wet etching. After removing the resist film, anisotropic etching with SiO₂ mask was treated by using the EPW solution. The EPW etching conditions were summarized in Table 3.

Table 2 Lithographic conditions.

HMDS	Vapor	1hr
HMDS-Bake	120	5min
Resist coating	500rpm	5sec
	3000rpm	30sec
Pre-bake	90	5min
Exposure	2.5sec	
Development	TMAH 2.38%	22sec
Rinse	DI-Water	10sec
Hard-bake	150	5min

Table 3 EPW etching conditions.

Etching Solution (EPW)	Ethylendiamine	NH ₂ (CH ₂) ₂ NH ₂	46.4 mol%
	Pyrocatechol	C ₆ H ₄ (OH) ₂	4.0 mol%
	DI-water	H ₂ O	49.6 mol%
Temperature	85 ± 5		
Process time	60 min		

Etching rate was calculated from window size before and after etching as shown in Fig.4. It was observed that a diagonal shape of window became an octagonal shape because of a different etching rate of Si(100) from Si(110). The mask window of 531 μm became 712 μm after 150 min EPW etching. Etching rate is 0.6 $\mu\text{m}/\text{min}$ for Si[110] direction.

Fig. 4 Mask window width before and after anisotropic etching.

3. Results and Discussion

Figures 5a and 5b show top view of samples before and after EPW etching respectively. Mask direction was parallel to Si (110). It was found that defects were remained when the defect was larger than 16.3 μm . It was also investigated using 45 degree rotated mask. Results were show in Fig.6a and 6b. It is clearly demonstrated that defects were remained when the defect was larger than 10.9 μm .

Figure 7 shows etching time dependency of defect formation. It was observed that 30 μm of the defect was remained until 60 min and removed after 90 min.

It is estimated that the defects are removed in the following step. The etching rate at the edge of a defect is assumed a half of that at flat plane, since

Fig.5 Etched defect shape for non-rotated mask.

Fig.6 Etched defect shape for 45 degree rotated mask.

the area that the etching species can attack the Si surface. When the defect is lifting off, the etching rate becomes two times as fast as that of the flat plane since the top of defect has two times wider area which the etching species can attack. The main part of defect will disappear after a half of total etching time. This estimation means the defect of which size is smaller than the half of total etching depth cannot be printed. It can be predicted that a limit of printable defect size is 18 μm for 60 min etching and 27 μm for 90 min etching.

Fig. 7 Time dependency for defect formation.
Defect width = 30 μm , no-rotated mask

4. Conclusion

An impact of defects during anisotropic etching for Si substrate is investigated. A defect printability is observed using quasi-defect on an oxide mask. It is found that a defect of around 10 μm width is not printed into Si substrate in case of 60 min of EPW wet etching. It is demonstrated that a minimum defect size which couldn't affect on the final structure is determined as around a half of total etching depth.

Acknowledgement

The present work was partially supported by Grant-In-Aid Scientific Research from Japan Society for the Promotion of Science (Scientific Research (B) 19360157).

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