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A behavior of Xenon difluoride etching on poly-Silicon sacrificial layer for fabrication of MEMS device

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1. Introduction

Xenon difluoride(XeF_2) etching technology of silicon sacrificial layer is expected to be one of the key process for MEMS device fabrication, because of its extremely high etching selectivity against other materials (e.g. silicon dioxide, metal). Its selectivity makes it easy to fabricate 3-dimensional structures. However, it seems to be that the difficulty of treating XeF_2 crystal has disturbed its popularization for practical use [1]. In addition, the reaction mechanism has not been fully clarified yet. There are some models that have been proposed about the surface reaction between XeF_2 gas and Si surface [2].

In this paper, we evaluated the XeF_2 etching behavior under several practical conditions with some kinds of test patterns. The time evolution of etch front peripheral during the fabrication of cavities will be explained.

2. Experimental

We used Cluster-XeF_2 etching system made by Surface Technology Systems Ltd (UK). The system configuration is shown in Fig.1. The sublimation vessel contributes constant XeF_2 supply into the reaction chamber through each process run because of its enough volume. XeF_2 is solid and sublimates with 500 Pa vapor pressure under standard condition. The XeF_2 flow rates of each process condition relate to the balance of XeF_2 supplying pressure and chamber exhaust rate. We calibrated XeF_2 flow rates with Nitrogen by adjusting the system at the same conductance.

Figure 2 shows test structure. There is 100 nm poly silicon sacrificial layer entirely enclosed by silicon dioxide. The XeF_2 gas diffuses from the top opening (gas hole) to the etch front through the gap where sacrificial layer has already removed. Etch depth (x) is defined from the center of gas hole to the etch front peripheral. The radius of the gas holes is 1 μm.

3. Results and Discussions

Modeling the time evolution of etch front

The etch rates of the isolated gas hole sample at various conditions are shown in Fig.3. Etch rates are calculated with the result aimed 10 μm etch depth at each process run by observing the progress with optical microscope over a transparent lid of the reaction chamber. This indicates that the etch rate only depends on the chamber pressure under these experimental conditions. In addition, the etch rate increased proportionally as the pressure increased. It means that the diffusion of XeF_2 gas from gas hole to etch front peripheral is the determinant step of etch rate.

Based on this results, the number of incoming molecules consumed at etch front is proportional to the supplied ones from the gas hole. During the time Δt, the molecule balance is expressed as following equation,

$$h \cdot L_0 \cdot n_g \cdot v_g \cdot \Delta t = K \frac{\rho \cdot h \cdot L \cdot \Delta x}{M} \quad (1)$$

L_0: gas hole peripheral length, L: etch peripheral length,
n_g: number of molecules per unit at gas hole,
v_g : XeF_2 diffusion rate at gas hole, ρ : density of Si,
M: atomic mass of Si, h: thickness of Si layer
K: constant value related surface reaction,
Δx: displacement of etch peripheral during Δt.

Therefore, etch rate at the time t is inversely proportional to the etch front length L(t).

$$E/R = \frac{\Delta x}{\Delta t} = \frac{M \cdot n_g \cdot v_g}{K \cdot \rho} \cdot \frac{L_0}{L} = K' \frac{L_0}{L} \quad (2)$$

In the next section, we calculated the time evolution of the etch depth x(t) by integrating the progress Δx at each time step Δt.

Time evolution of etch front (etch depth)

When the process started, the shape of the etch front was expanding as concentric circle and its length was increasing until it intersects other etch front lines or SiO2 wall. Pattern-A in Fig.5 represents the case of the isolated gas hole configuration. As the circle peripheral L(t) increased, the etch rate decreased as in Eq.(2), showing the saturated profile of etch depth x(t).

Comparing Pattern-A and B, the junction of them means that etch front of pattern-B has reached the SiO2 side wall. The effect of sidewall relates with reduction of etch front length. The time that the etch front intersects each other depends on the interval of gas holes. Because the total etch front length decreases by merging, appeared etch rate increases when merging occurs. Significant increases after 6 minutes for Pattern-C and D reflect this phenomenon. All the case described above could be successfully explained by simple adsorption model described as Eq. (2).

It pointed out that it was necessary to shift the simulation result for 1.2 minutes as incubation time caused by oxidation of gas hole surface. The incubation time includes both breaking of natural oxide layer and removal of the internal portion of 2 μm gas hole circle.

Limitation of the model

The simulation result fits to the actual one in the range of less than 20 μm from the gas holes. When the range exceeds more than 20 μm, there is a different behavior observed. Fig.7 shows one of the examples that etch rate is not necessarily affected by the total amount of the exposed area of Si surface.

To explain these results, we need to consider the partial XeF_2 density, sticking effect etc.

The data observed by fundamental study such as molecular dynamics will assist to clarify the whole of reaction mechanism [3].

4. Summary

The observed etch depth of different gas hole configurations were well explained by etch front evolution model based on the adsorption reaction model. We believe these results accelerate the use of XeF_2 etching technology.

References

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[2] P. B. Chu et.al., TRANSDUCERS 1997 pp665-668
[3] M. J. M. Vugts, et. al., J. Vac. Sci. Technol. A 14(1996) pp2766-2774

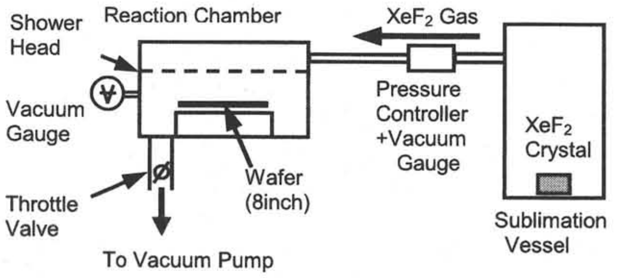

Fig.1 Schematic diagram of XeF_2 Etching System

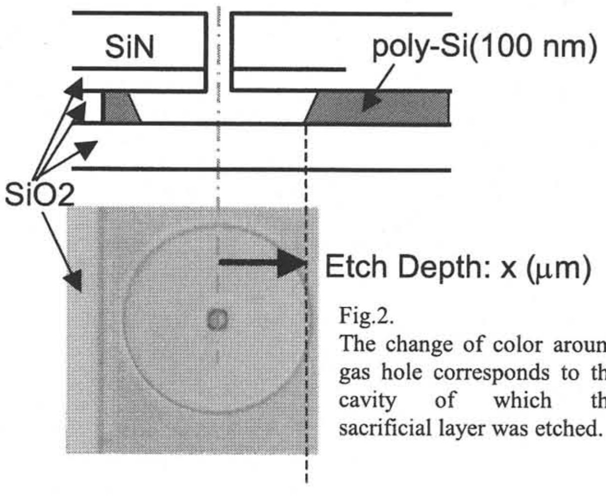

Fig.2.
The change of color around gas hole corresponds to the cavity of which the sacrificial layer was etched.

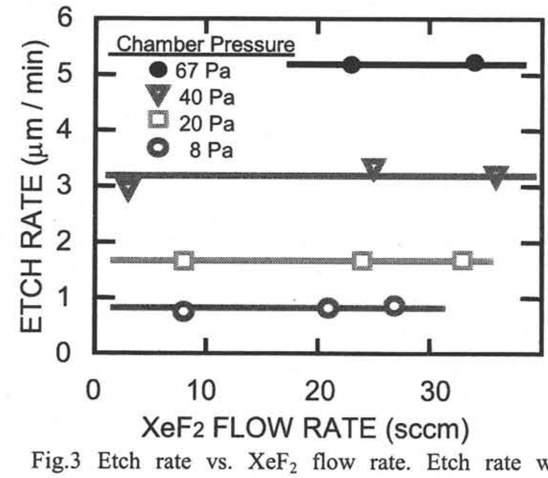

Fig.3 Etch rate vs. XeF_2 flow rate. Etch rate was measured using test pattern A (isolated gas pattern) as shown in Fig. 2, but no SiO2 sidewall nearby.

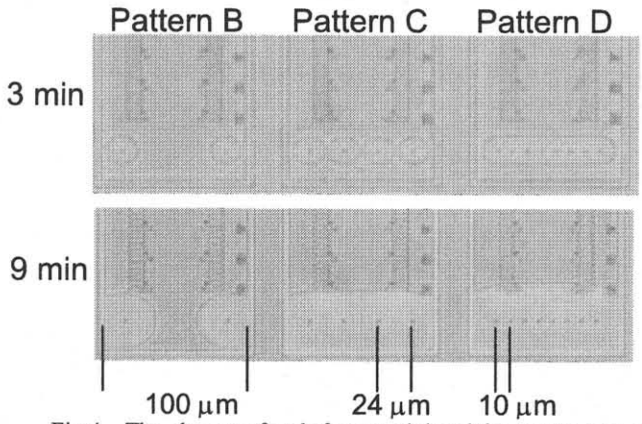

Fig.4 The change of etch front peripheral for Patterns B, C, and D after 3 and 9 minutes etching, respectively.

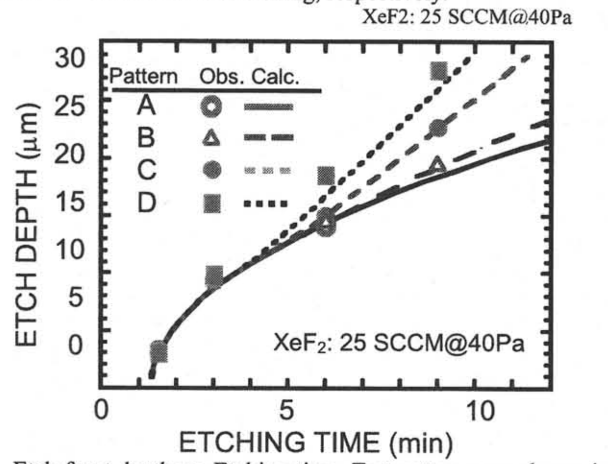

Fig.5 Etch front depth vs. Etching time. Test patterns are shown in Figs. 2 and 4. Solid and dots lines are calculated using Eq. (2).

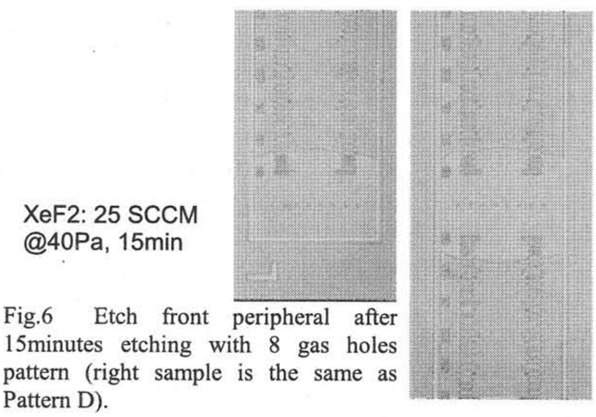

Fig.6 Etch front peripheral after 15minutes etching with 8 gas holes pattern (right sample is the same as Pattern D).