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The large-area backside etching method by changing backside layout using loading effect and ARDE for foundry-based fabrication

Yuki Okamoto, Yukiya Tohyama, Naoto Usami, Yoshio Mita

Dept. of EEIS, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
Phone: +81-3-5841-6730 E-mail: mems@if.t.u-tokyo.ac.jp

Abstract

We propose a backside deep reactive-ion etching (DRIE) method to increase etching depth uniformity over a large area (>10 mm) by filling a compensated dummy mesh pattern. The mesh pattern is gradually changed in order to inversely compensate the global loading effect by local aspect ratio dependent etching (ARDE). It allows us to optimize the etching rate of a large opening even if the process tuning is impossible, such as with MEMS foundry process.

1. Introduction

To fabricate a large MEMS structure, DRIE of a large opening is essential. For instance, over 10 mm × 10 mm backside opening is needed for a MEMS mirror for HD720 resolution [1]. To process such a large opening, the difference of etching rate between the center and the edge of the opening is one of the largest issues. It causes the damage to the structure until all the backside substrate is etched out. Therefore, it is essential to uniformize etching depth distribution.

Such a DRIE distribution is caused by the two well-known effects: One is an opening-pattern-size dependent DRIE depth distribution, known as ARDE, or local loading effect, which is mainly caused by the absorption of radical species by vertical wall. The other is etching depth nonuniformity over a large (> 1 mm) area, known as global loading effect mainly caused by etching species exhausting. Because of these effects, backside etching of a large opening with a single pattern often fails as shown in Fig. 1b. To increase uniformity, the previous studies have focused on tuning DRIE condition [2] or process sequence [3]. However, such tuning is not always possible, e.g., in case of using foundry services. Therefore a design method that requires no process tuning is attractive for MEMS prototyping and seamless industrialization.

In this article, we propose a new method to uniformize the DRIE depth distribution by replacing a large opening with a mesh pattern as shown in Fig. 1c. Although such mesh pattern can reduce depth distribution to some extent, global loading effect still remains. We propose, therefore, filling the large opening with a "compensated mesh" pattern, whose density and gap are gradually changed from the center to the edge of the opening, to achieve the uniformity by inversely compensating the global loading by the local loading. Our method does not need tuning the etching conditions, and enables de-

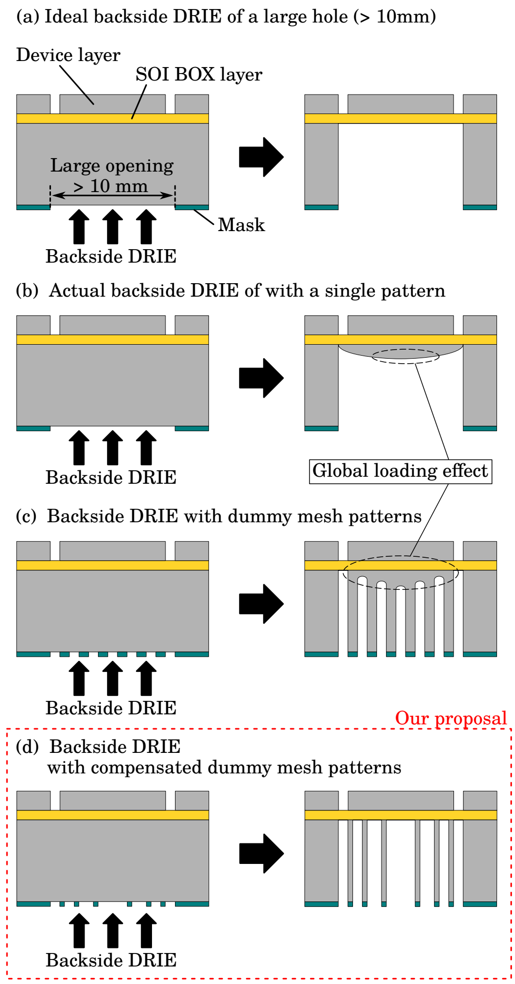
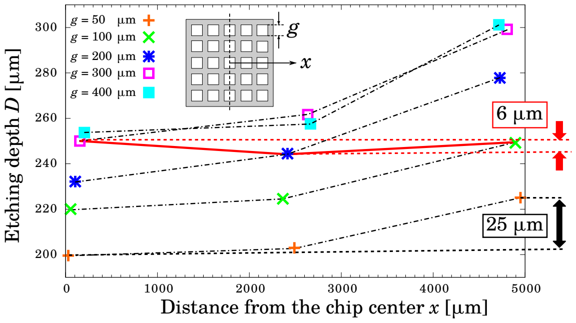


Fig. 1 (a) Ideal DRIE method of a large hole with one large pattern. (b) Real proceeding of DRIE with the large pattern shown in (a). (c) DRIE with a dummy mesh pattern. (d) Proposal large-hole DRIE method with a compensated dummy mesh pattern to increase uniformity.

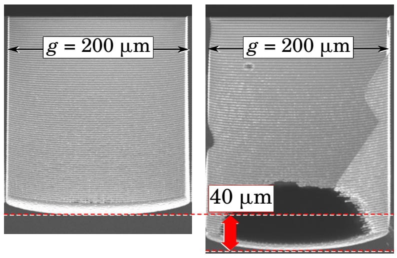
vice engineer to obtain a large opening with a standard process. The gap of the mesh pattern filling a large opening hole area in the backside is defined by the test structure measurement. As a result, the gap size gradually changes from the largest at the center to smallest at the edge. Backside etching of the device is performed with the same DRIE condition used for the test structure. The sacrificial BOX layer etching with hydrofluoric acid releases the frontside MEMS movable part and the backside dummy mesh simultaneously.



(a)

Gap [µm]	50	100	200	300	400
Max distribution [µm]	25	28	40	50	50

(b)



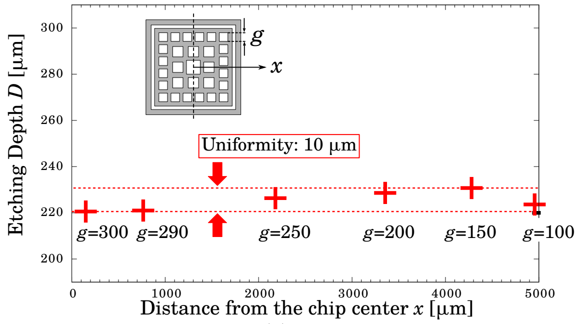
(c)

Fig. 2 (a) Results of the measurement of etching depth distribution using test structures. If the gap is compensated, the gap can be recuded to 6 µm. (b) The maximum distribution with uniform gap, the distribution was at least 25 µm. (c) Side view of the $g = 200$ µm mesh pattern in the center and the edge.

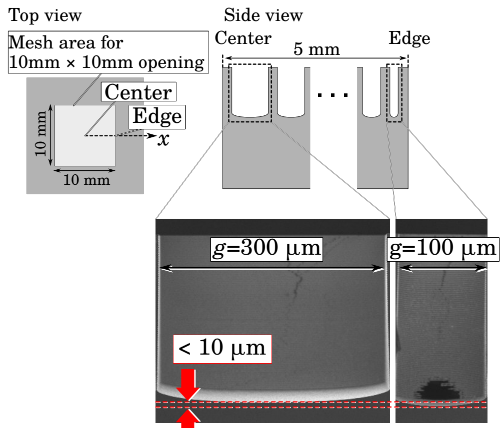
2. Fabrication and Measurements

For the measurement of etching distribution, we prepared five types of the test structures on silicon wafers. The pattern was a square hole and five different gaps were designed: The gaps were 50 µm, 100 µm, 200 µm, 300 µm, and 400 µm, respectively. Fig. 2 shows the result of etching of the test structures. In the structure with constant mesh gap, the etching depth at the center of the device is at least 25 µm shallower than at the edge of the sample. Fig. 2 also indicates that if the gap is optimally chosen, that is, 300 µm in the center and 100 µm in the edge, the difference of etched depth can be reduced to 6 µm.

Then, a proposed mesh pattern was fabricated on a silicon wafer. The gap was 300 µm in the center of the mesh patten, and gradually decreased to 100 µm in the edge of the pattern. Fig. 3 shows the result of etching distribution using the compensated mesh pattern. The process condition was the same as that in the test structure measurement, and the variation was reduced to 10 µm. It indicates that the DRIE distribution was successfully uniformized not by tuning the process condition but by optimizing the backside layout.



(a)



(b)

Fig. 3 (a) Results of etching depth distribution using the compensated mesh pattern. The gap of the mesh was firstly 300 µm at the center and gradually decreased to 100 µm at the edge. The etching distribution was reduced to 10 µm. (b) Side view of the mesh pattern at the center and the edge.

3. Conclusions

We proposed a method to uniformize the etching depth distribution by filling the compensated dummy mesh pattern in the backside. In our method, the density and the size of the mesh pattern is gradually changed from the center to the edge of a large opening. The two (local and global) loading effects can thereby be compensated, enabling a uniform etching with a standard DRIE condition.

Acknowledgments

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References

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