# Micro-fabrication of Hemispherical Poly-Silicon Shells Standing on Hemispherical Cavities

Cheng-Hsuan Lin[a], Yi-Chung Lo[b], Wensyang Hsu[*a]

[a]Department of Mechanical Engineering, National Chiao-Tung University, Hsinchu, Taiwan, R.O.C.
[b]Synchrotron Radiation Research Center, Research Division, Hsinchu, Taiwan, R.O.C.

## ABSTRACT

In the current paper, the fabrication process of a novel proposed hemispherical polysilicon shell standing on a hemispherical silicon cavity is demonstrated. This micro-fabrication process combines both bulk and surface micromachining, which include the isotropic wet etching, a novel mask design, the thick photo resist coating and exposure, and high-aspect-ratio curved sacrificial technique. In isotropic wet etching of a hemispherical cavity, the optimal concentration of etchant is experimentally determined along with adequate ultrasonic vibration during wet etching to produce the circle-like of hemispherical cavity. The conventional alignment mark, which will be destroyed during the rather long isotropic wet etching process, is replaced by a novel mask design with the second alignment mark. Also, for a deep hemispherical cavity larger than 100μm, the traditional photo resist can not be coated on the corner surface well. The thick photo resist, AZ4620, is found to be able to overcome this problem and be successfully exposed all through its bottom surface. Furthermore, the deposited sacrificial layer materials (PSG) on this cavity will usually result in thinner layer near the corner. In addition, the curved gap of PSG layer has the feature with high-aspect-ratio. These make the PSG etching difficult. Therefore, two steps etching process with two different hydrofluoric concentrations are used to release the PSG with 2μm thickness and 150μm arc length.

**Keywords:** Isotropic wet etching, hemispherical cavity, polysilicon shells, high-aspect-ratio

## 1. INTRODUCTION

The micromachining techniques of micro electronic mechanical system (MEMS) are based on IC fabrication, and divided mainly into the surface micromachining and the bulk micromachining. All shapes of the microstructure are limited by surface micromachining and anisotropic of techniques. These techniques can not fabricate the structure of circular shape which can reduce the stresses concentration. The isotropic wet etching is able to fabricate the circular shape and this technique is demonstrated to produce a hemispherical shell here, standing on silicon-cavity, by combining both bulk and surface micromachining. Furthermore, this shell stands on silicon-cavity is a curvilinear structure with three dimensional microstructure.

[*]whsu@cc.nctu.edu.tw; phone: +886-3-5782121ext55111; fax: +886-3-5720634



Device and Process Technologies for MEMS and Microelectronics II,
Jung-Chih Chiao, Lorenzo Faraone, H. Barry Harrison, Andrei M. Shkel, Editors,
Proceedings of SPIE Vol. 4592 (2001) © 2001 SPIE · 0277-786X/01/$15.00

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

Wise, et al. employed bulk micromachining techniques, including isotropic wet etching, deposition and oxidation, to fabricate free-standing hemispherical shells in 1981[1, 2]. However, the method proposed can make the shell itself only, and can not fabricate a shell standing on the substrate.

The hemispherical cavity of silicon was fabricated using isotropic wet etching and has been extensively investigated. Schwartz and Robbins reported a method to mix hydrofluoric (HF), nitric acids ($HNO_3$), and D.I. water/acetic acid ($CH_3COOH$) called HNA etchant and made an isotropic etchant in 1959[3]. The concentration of three chemical solutions was showed as a triangular form and was able to react with monocrystalline silicon non-directionally. Peterson was offered the different behavior between isotropic etching and anisotropic etching in 1982[4]. The adequate agitation to form an ideal isotropic etching otherwise the plate shape at the bottom of substrate has been demonstrated. In 1996, Schwesinger proposed there were three parameters, i.e. etching rate, activated energies, and surface profile may influence the results during isotropic wet etching[5, 6]. However, the detailed process parameters were not mentioned in their papers, which would need further investigation.

Here the fabrication process of a novel hemispherical shell standing on a hemispherical cavity is proposed and combine with isotropic wet etching, thick photo resist coating/exposure, and high-aspect-ratio curved sacrificial releasing techniques. The thickness of polysilicon shell, minimal diameter of silicon cavity, and the gap between shell and cavity are 2μm, 255μm, and 2μm, respectively. The error of diameter of silicon cavity is small than 2.0%.

## 2. PROCESSES

The following figures are the fabrication processes and make a hemispherical polysilicon shell standing on the hemispherical cavity using three masks.

The 4” silicon wafer using (100), P-type washed by RCA clean process. The 4000 Å thickness of $Si_3N_4$ layer as protecting material during isotropic wet etching had deposited using lower pressure chemical vapor deposition method (LPCVD) on double side of surface silicon wafer. The $Si_3N_4$ layer was fabricated as opening/compensating hole by Mask#1. During isotropic wet etching, the hemispherical cavity fabricated and showed in Figure 1(a). After dissolved the $Si_3N_4$ layer, the 3000Å thickness of the polysilicon had deposited on the cavity substrate by LPCVD method as a first structure layer, then the 2μm thickness of phospho-silicate glass (PSG) had deposited on polysilicon by atmospheric pressure chemical vapor deposition method (APCVD) as a sacrificial layer. The ratio of curved semi-length per thickness is larger then 70. The thick photo resist, AZ4620 placed with traditional thinner photo resist using to coat onto PSG. A Mask#2 patterns a hole shape on the bottom of PSG layer as the upholder connected first and second polysilicon layer and shown in Figure 1(b). Using LPCVD method, A 2μm thickness of polysilicon deposited on PSG and patterned by Mask#3. This polysilicon layer is a hemispherical shell structure, as shown in Figure 1(c). Finally, there have two steps using different concentration of HF etchant to react with PSG, which immersed in the two polysilicon layers and the gap is 2μm, as shown in Figure 1(d).



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

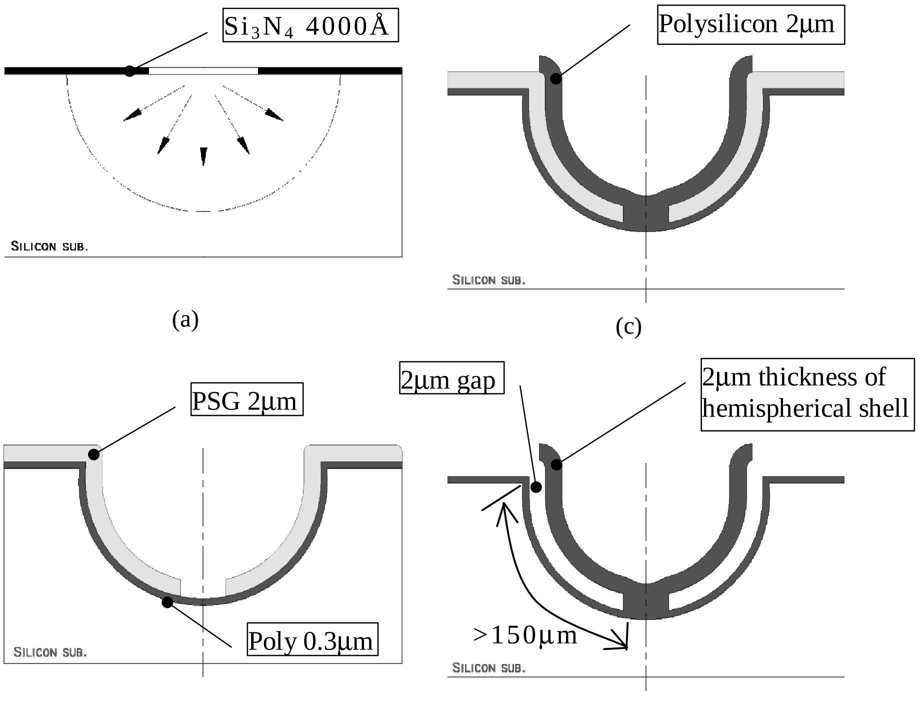



Figure 1. Sequence of steps illustrating formation of the hemispherical polysilicon shell is standing on silicon substrate. (a)A masking hole is fabricated using Mask#1; (b)A upholder in PSG is fabricated using Mask#2; (c)A structure is defined using Mask#3; (d)A hemispherical polysilicon shell is fabricated by PSG layer releasing.

Here the detailed processes are discussing how to fabricate the hemispherical polysilicon shell standing on the hemispherical cavity as follows.

### 2.1. Isotropic wet etching

In order to check if the etched hemispherical cavity is ideal circle-like, it is best shown the top view and cross-section view of the cavity. Although the Schwesinger provided an opinion that it's difficult to make an ideal isotropic behavior etchant according to his experiments, but Wise had provided a very good-looking free-standing hemispherical shell in 1981. It's interesting to discuss with the method of isotropic wet etching in detail.

The behavior of isotropic wet etching is shown schematically in Figure 2. During the HNA etchant react with silicon, the $Si_3N_4$ layer is a protecting layer and the opening hole is an un-protecting pattern. The dash-lines are the profile corresponding to the etching time proceeds. When the first atoms layer reacted by HNA etchant in the instant time (t0), a dish formed under the $Si_3N_4$ hole. There have corners around a dish to become the quarter circular when the next time (t1) reached. In the same time, the bottom of the dish will be extended parallel to the original surface of the



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

silicon substrate according to the same chemical reaction regardless of the direction. Finally, the hemispherical-like profile will be fabricated for a long time (>t2) and the maximal length rate of the hemispherical profile are quarter arcs. Therefore, the diameter-size of opening hole in the $Si_3N_4$ layer will affect the profile of cavity and must be considered.

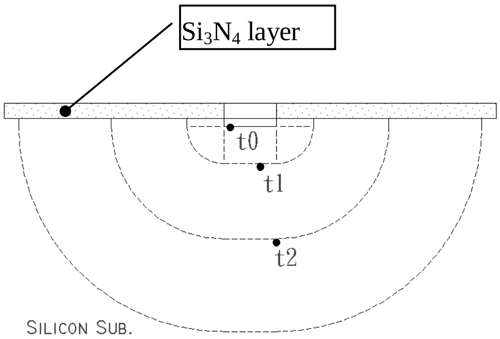



Figure 2. The behaviors of the schematic diagram in a hemispherical cavity of silicon substrate are formed using isotropic wet etching.

In experimental result, the reacting rate on horizontal direction is usually slow than vertical direction during isotropic wet etching but the opening hole also resolves this problem. Here the opening hole is also called compensating hole. Furthermore, the dish will be formed when the diameter-size of compensating hole is opened largely. Figure 3 illustrates the non-expecting result by the larger compensating hole for shorter time (3 min.) with isotropic wet etching.

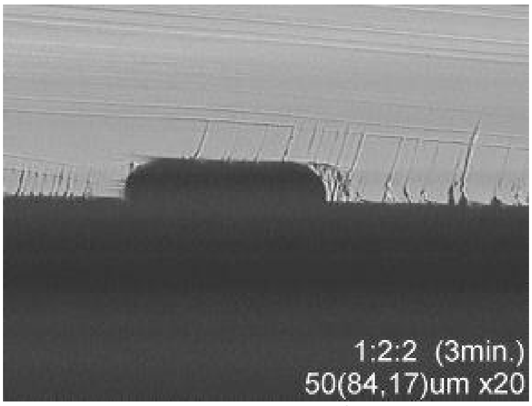



Figure 3. Cross-section view of dish, diameter: 84μm, depth: 17μm, opening hole: 50μm, etching time: 3 min., $HF:HNO_3:H_2O$ is 1:2:2.

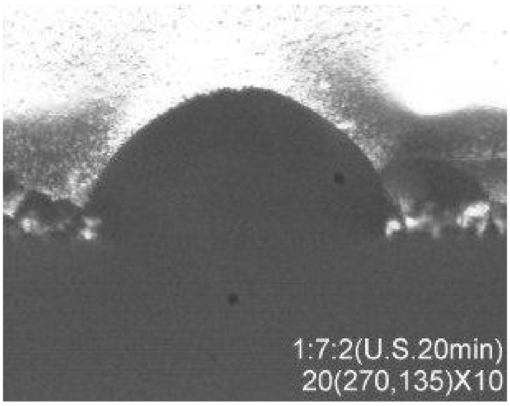



Figure 4. Cross-section view of cavity of (100) silicon wafer, diameter: 270μm, depth: 135μm, etching time: 20 min. Ultrasonic vibration added and $HF:HNO_3:H_2O$ is 1:7:2.

Figure 4 illustrates the isotropic wet etching rate of <111> and <100> planes is not the same value in the (100) silicon wafer. The etching rate of <111> plane is slower than <100>. Using agitation by stirring or ultrasonic method



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

can reduce the different etching rate between those planes, especially the ultrasonic method for a small time etching. Figure 5 and 6 illustrated the different size of perfect hemispherical cavity in cross-sectional profile. A minima diameter-size of cavity is 25μm for 13 min. etching time under ultrasonic method.

Figure 5. Cross-sectional view of cavity, diameter: 25μm, etching time: 13 min.. $HF:HNO_3:H_2O$ = 1:2:2. Ultrasonic vibration added.

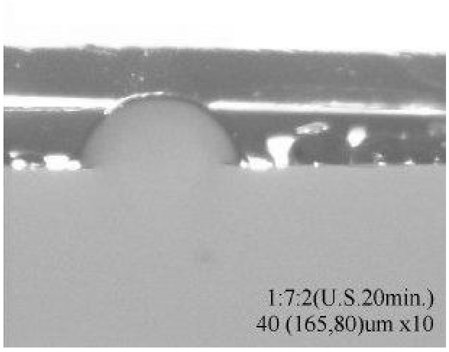



Figure 6. Cross-section view of cavity, diameter: 165μm, depth: 80μm, etching time: 20 min., $HF:HNO_3:H_2O$＝1:7:2.

The experimental results also show that the etching rate of the perpendicular to the surface of substrate is usually larger than the parallel to one but the compensating hole of protection layer will also to resolve this problem. Assume the etching rate fixed in all the wet etching process and Figure 7 illustrates a schematic diagram when the HNA etchant react with silicon substrate. The size D has two functions to fabricate circle-like of hemispherical cavity. One is the opening hole and the fresh etchant through it to work. Another is a compensator that enables to balance the different value between u and v, usually u is small than v. According to geometrical method, if ϕ is the final diameter of cavity, the time $\phi \Big/ \frac{2}{v}$ is needed and the diameter D of cavity can be get:

$$D=\phi\left(1-\frac{u}{v}\right), \quad (1)$$

where u and v represent the etching rate of horizontal and vertical direction, μm/min., D the diameter of mask hole, μm, and ϕ the final diameter of hemispherical cavity after etching, μm.

The ϕ and v/u are assumed as known, the value of D can be got from equation (1). In the experimental result, the value of u/v is 0.75 using $HF:HNO_3:H_2O$ =1:2:1 as an isotropic solution. The value of D is 25μm which is needed by equation (1) if the 100μm diameter of hemispherical cavity is got. Figure 8 illustrates the relationship of three parameters, which D, ϕ, and v/u from equation (1).

In Figure 8 shows that if value of ϕ is fixed and u/v is decreased, the value of D will be increase and if the value



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

of u/v is increased or ϕ is decreased, the value of D will be decrease. The larger value of D has a limitation to avoid forming a dish shape, as shown in Figure 3. Moreover, a lot of bubbles surround the masking hole when the D is small enough. Those bubbles will cover the masking hole and resist the fresh chemical etchant to react from the outer hole to silicon substrate. The ultrasonic method can improve it. The experimental result shows that the etching rate of v is larger when the size of D is larger during the same isotropic etchant.

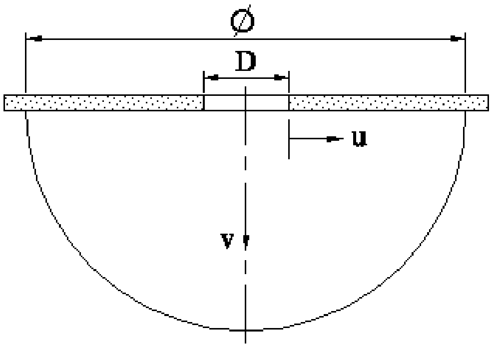



Figure 7. The schematic diagram illustrates the relation of etching rate and diameter.

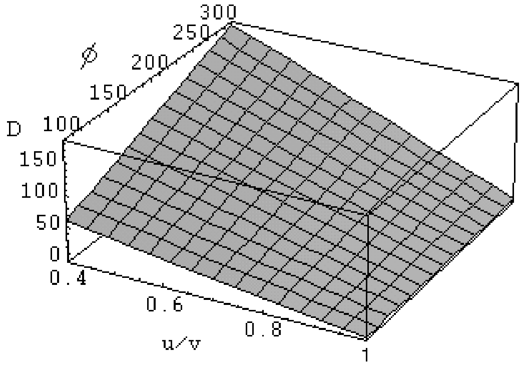



Figure 8. The relationship of three parameters, the diameter of mask hole (D), the final diameter of cavity (ϕ), and the velocity rate (u/v).

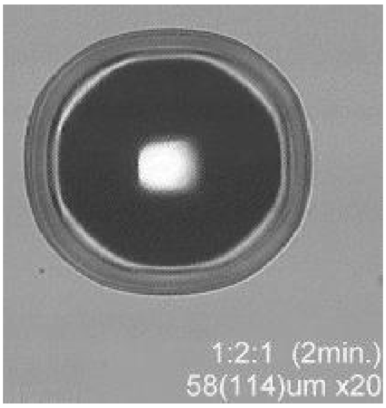



Figure 9. The top of cavity, etching time: 2 min., diameter: 114μm, $HF:HNO_3:H_2O = 1:2:1$.

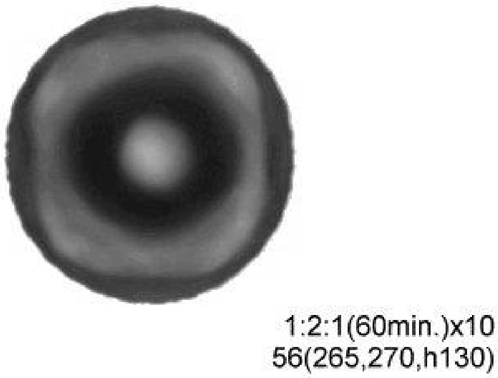



Figure 10. The top of cavity, etching time: 60 min., $HF:HNO_3:CH_3COOH = 1:2:1$, diameter of 0, 45 degrees line and depth of cavity are 265, 270, and 130μm, respectively.

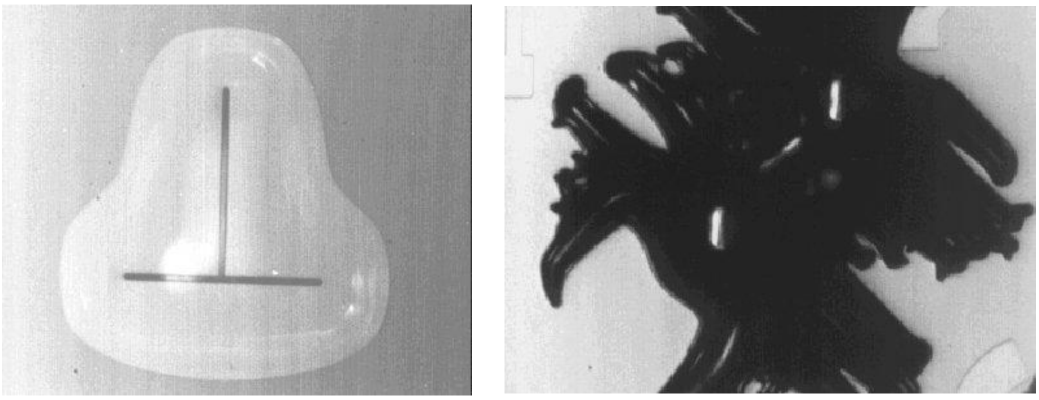
Figure 9 illustrates the deformed shape of top side according to the difference of the etching rate on <100> and <110> directions. To cause this result is the density of atomic structure and the interface between resist layer and substrate. The ultrasonic method and the suitable HNA etchant can also reduce this but a long etching time is the key process. To compare with Figure 9 and 10, the same HNA etchant ($HF:HNO_3:CH_3COOH = 1:2:1$) reacts with silicon



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

substrate for 60 min. using the almost same size of mask. The diameters of 0, 45 degrees line and the depth of cavity are 265, 270, and 130mm, respectively. The error of circular is small than 2.0% but the deformed circular shape illustrated in Figure 9 during 2min. without ultrasonic method.

The chromium/gold, thermally grown Oxide, and the LPCVD Nitride layers are able to use a protecting layer when the HNA etchant react with the silicon substrate. Because the limitation of our equipments, it’s difficult to deposit the Cr/Au layers as a protecting mask. In fact, the anti-reacting rate of the nitride layer is better than oxide, especially the rich nitride layer in the experimental result. Unfortunately, the thickness is another consideration during isotropic wet etching because the nitride layer is reacted, too. The ultrasonic vibration will reduce the strength of anti-reaction rate.



(a) (b)

Figure 11. The destroyed mask during the rather long isotropic wet etching process. (a)A un-like mask using rich nitride layer; (b)A destroyed mask using oxide layer as protecting layer.

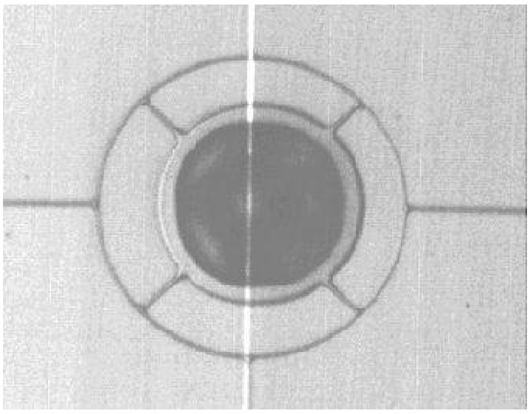


Figure 12. A novel mask design aligned with a circular shape of cavity and patterned to photo resist.

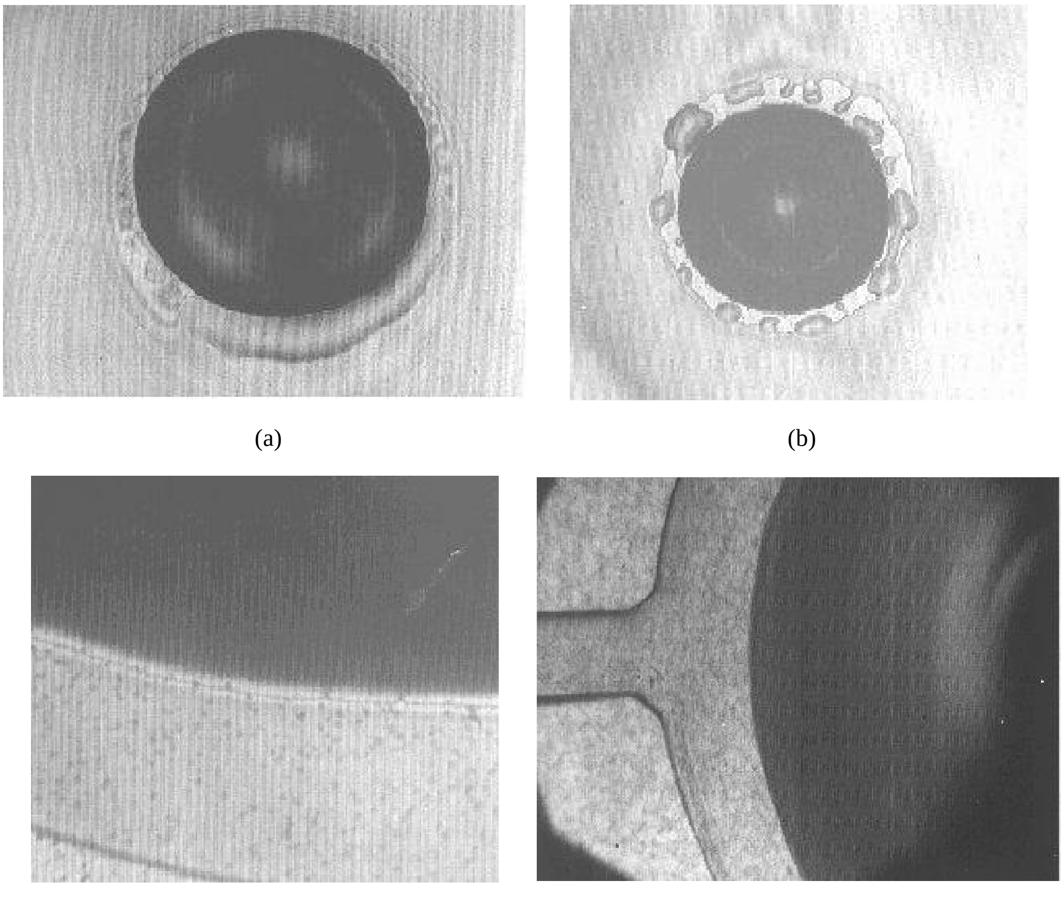


Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

### 2.2. Thick photo-resist coating and exposure

The depth of hemispherical cavity is larger than 100μm, which fabricated by isotropic wet etching for 60 min. long. Therefore the profile of surface is not a plate and two problem needed to be resolved. One is the photo resist coating and it's difficult to use the conventional photo resist (FH6400L) to coat onto the profile of hemispherical cavity. The exposure with larger gap (depth: 100μm) using contact printing is another one.

Figure 13(a) illustrates the resist, which is stacked and surrounded the cavity, and it's look non-uniformly to cover in the profile near the corner. Although, the cavity coating uniformly when the FH6400L added thinner solution and the viscosity of it reduced to cause a broken area near the corner of cavity, as shown in Figure 13(b). Even the optimal coating parameter used, it still has sheet broken near the corner of cavity, as shown in Figure 13(c). Because the limitation with equipments, using the other material to replace FH6400L is the suitable method. The thick photo resist, AZ4620, has a 7-8μm high after spin coated on the surface of substrate and the viscosity of it is larger than FH6400L in experimental result. Figure 13(d) illustrates the polysilicon coated, exposed, and developed by AZ4620 well.



(a) (b) (c) (d)

Figure 13. The top view using photo resist to coat, expose, develop, and pattern. (a)FH6400L stacked around the hole of cavity, (b)FH6400L+thinner broke near the corner of cavity, (c)A sheet broken near the corner of cavity, (d)AZ4620 coated, exposed, and developed very well.



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

### 2.3. A novel alignment mark design

During the reaction of HNA etchant, the non-circular of first masking pattern is became a circular shape or even broken. These masks can not be aligned in the next step and shown in Figure 11(a) and (b). Here is a method to solve this problem that pattern a first alignment mark before the photo resist layer coating and one extra mask needed. A novel mask design of alignment mark used to replace the conventional alignment mark, the second mask aligned with circular shape of cavity. The target-like shape aligned with the circular shape of cavity and patterned, as shown in Figure 12.

Another problem is the exposure with a higher depth of hemispherical cavity. The thick photo resist is stacked on the bottom of cavity and has a larger gap between light source and photo resist. This is a limitation of the contact printing equipment. The three methods of exposure during lithography process are projecting printing, proximate printing, and contact printing. The first of two methods are suitability for the larger gap exposure, which is larger than 100μm. Furthermore, the method of contact printing is the only one choice in our laboratory and is used to expose photo resist with larger gap, 100μm. There have no quantification data of experiment to explain the process of exposure with larger gap but the energy of light source, wavelength, distant of gap, the diameter of mask hole, and repeatedly expose must be considerate. Figure 14 illustrates the upholder of PSG under the cavity hole after developed.

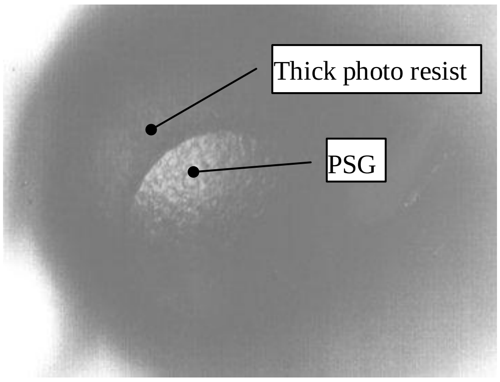



Figure 14. A photo resist on the bottom of hemispherical cavity was exposed and developed successfully.

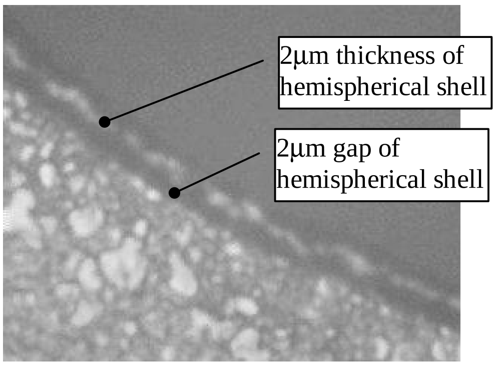



Figure 15. 2μm suspending gap and 2μm thickness of polysilicon hemispherical shell.

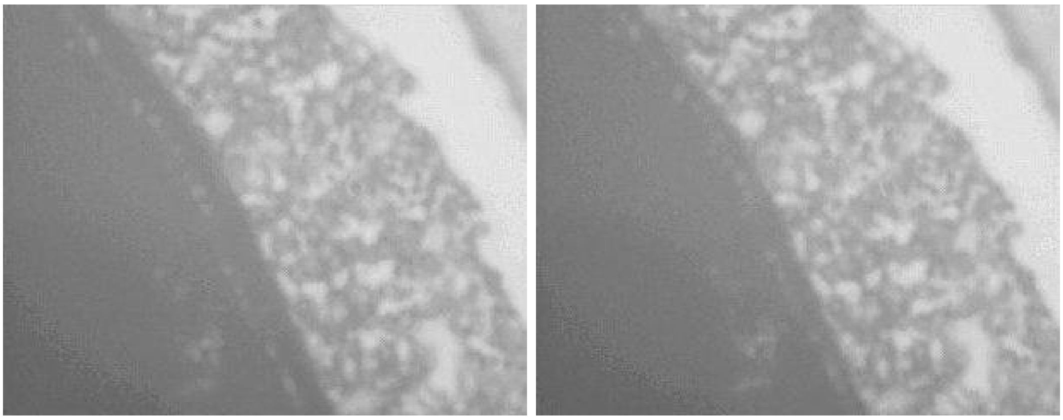
### 2.4. High-aspect-ratio curved sacrificial layer etching

It's difficult to release PSG by hydrofluoric etchant. Furthermore, the deposition of PSG will usually be the thin layer surrounding the corner and initial PSG released on the corner difficultly. Another is the curved aspect ratio of PSG larger than 75:1, which 2μm thickness and larger than 150μm arc length. Here are the two steps to solve. The first step uses concentrated HF etchant to react with the thinner PSG and the second step uses dilute HF etchant to react with PSG until it released.



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

After releasing sacrificial layer, the hemispherical shell will stand on the bottom of cavity, as shown in Figure 15. It's difficult to take a side-picture viewpoint and the top of shell is no swung and moved when needle is force it. Figure 16 illustrates the demonstration and the hemispherical shell stands on the silicon cavity, finally.



(a) (b)

Figure 16. The top of shell swung and no moved by needle. (a)Before a needle push with shell; (b)After a needle push with shell and the shell contact with the first polysilicon.

## 3. CONCLUSION

The experimental results show the hemispherical shell of polysilicon is fabricated successfully and is standing on the hemispherical cavity, where the diameters of cavities ranged from 255 to 320mm with the deviations of 1.5 to 1.9%. The suspending gap and the thickness of hemispherical shell of polysilicon are both 2μm. In the fabrication processes, there are some factors to make great improvement of forming the hemispherical shell well. For the isotropic wet etching, the larger diameter of masking hole will reduce the hemispherical profile for short time of wet etching but the ultrasonic method can improve it. After long time of wet etching, all the factors affecting the results of hemispherical cavity will be reduced. The conventional alignment mark, which will be destroyed during the rather long isotropic wet etching process, is replaced by a novel mask design with the second alignment mark.

The thick photo resist, AZ4620, can cover in the larger profile completely although the precision reduced. During the repeatable process of the exposure and development, the upholder has fabricated. After patterning the second polysilicon layer, two steps with different concentration of HF etchant are used to release the high-aspect-ratio curved sacrificial layer. Finally, the hemispherical shell stands on cavity successfully.

The proposed processing techniques are particularly useful to make microstructures for hemispherical or other new geometrical shapes.



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms

## 4. ACKNOWLEDGEMENTS

Authors deeply appreciate Professor Liwei Lin of UC Berkeley, Professor Y.F. Chou of National Taiwan University for providing valuable comments on the design of fabrication processes.

## REFERENCES

1. Wise, K.D., Jackson, T.N., Masnari, N.A., and Robinson, M.G., “Fabrication of Hemispherical Structures Using Semiconductor Technology for use in thermonuclear Fusion Research”, *American Vacuum Society*, pp. 936-939, 1979.
2. Wise, K.D., Robinson, M.G., and hillegas, W.J., “Solid-State Process to Produce Hemispherical Components for Internal Fusion Targets”, *Journal of Vacuum Science Technology*, Vol 16, pp. 1179, 1981.
3. Schwartz, B., Robbins, H., *J. Electrochem. Soc.*, vol.106, p.505, 1959.
4. Peterson, K.E., member, *IEEE Proceedings of the IEEE*, vol. 70, no.5, May 1982.
5. Schwesinger, N., "The anisotropic etching behaviour of so called isotropic etchants", *Microsystem Technologies 96, proceedings p.Potsdam*, pp.481-486, 1996.
6. Schwesinger, N., "Wet chemical isotropic etching procedures of silicon a possibility for the production of deep structured microcomponents", *SPIE* Vol. 3223, pp.72-79, 1997.



Downloaded From: http://proceedings.spiedigitallibrary.org/ on 04/28/2014 Terms of Use: http://spiedl.org/terms