Chapter 4

Fabrication Technologies

4.1 Introduction

To fabricate a micro PBS, an optical material which is transparent to the visible spectrum and compatible with the surface micro machining is required. Among the optical materials, low stress silicon nitride is selected for its good chemical, mechanical and optical characteristic. Before applying the SiN in the micro-PBS, the optical properties of the thin film need to be demonstrated, therefore, the planar PBS is fabricated to determine the optical performance of SiN. The fabrication processes of planar and pop-up micro-PBS are described in the following.

4.2 Low stress silicon nitride

The low stress silicon nitride was chosen for its desirable characteristic, including the low etching rate in drofluoric acid (HF) solution, high transparency in the visible spectrum and low stress. Besides, it is compatible with surface micromachining technology [18-22].

4.2.1 SiN for red light

The properties of the SiN for red light can be analyzed from the chemical, optical, and mechanical characteristics. For the chemical characteristic, the etching rate of SiN in HF solution is 4 nm/ min. The thickness of the thin film can be controlled well by the low etching rate. Besides, the SiN can be connected with poly-silicon frame and compatible with the MEMS fabrication process. For the optical characteristic: the reflective index n and absorption coefficient k are the main concerns. The SiN thin film was deposited by low pressure chemical vapor deposition (LPCVD) at 850° C and 180 mTorr with various SiH_2Cl_2/NH_3 ratio η under constant total flow rate of 102 sccm. The deposited films were then annealed at 1050℃ in nitrogen gas for various annealing time before the measurement of the film. With SiH_2Cl_2/NH_3 ratio =5 and annealing time=2 hrs. illuminated at λ=632.8 nm, the coefficients n and k of deposited SiN thin film are 2.13 and 0.0065. As calculated before, the transmittance of TM mode and reflectance of TE mode of the incident light have excellent performance under the conditions. Another issue should be considered is the mechanical characteristic of stress. Generally speaking, the stress should be reduced to be at least hundreds of MPa to avoid breaking and deformation mounted in poly-silicon frame. After annealing, the stress can be increased or decreased. According to Maier-Schneider *et al.* [23], the possible reason is the result of the competition of two mechanisms: one is the stress relaxation within the grain of the film; the other is the film shrinkage due to dehydrogenation. The stress for various annealing time is shown in Table 4-1. The stress was reduced to 44 MPa after annealing for 2 hrs. The SiN with low absorption coefficient and stress deposited with SiH_2Cl_2/NH_3 ratio=5 and annealing time=2 hrs. is suitable for the red ray application.

Table 4-1 The stress of a function of annealing time.

SiH_2Cl_2/NH_3 ratio	Stress (MPa) (Non-annealing)	Stress (MPa) (Annealing 1 hr.)	Stress (MPa) (Annealing 2 hrs.)
5	267	379	44

4.2.2 SiN for blue light

For the SiN film to be used for the micro PBS, it should have low stress and low absorption. The absorption coefficient k used for blue ray deposited with the previous parameters is so high with the value of 0.06 so that light utilizing efficiency is low. The characteristics of the thin film are related to the following parameters: temperature, ratio of gas flow, pressure, etc. Among those, the relationship between the ratio of gas flow and the refractive index proposed by Eric Miller [24] showed that the lower ratio of gas flow, the lower refractive index. Although the author did not mention the relationship between the gas flow, the absorption coefficients and the stress, the ratio of gas flow was suspected to be a potential solution producing the material with low absorption for the blue ray application. The dependence of the refractive index and absorption coefficient on the reaction gas ratio for various annealing time is shown in Fig. 4-1. The refractive index n increased nearly linearly with increasing η while the absorption coefficient k showed a sharp increase for $\eta > 3$, possibly due to the increased content of silicon in SiN with high index and high absorption. The results showed that the absorption can be enhanced by reducing the SiH_2Cl_2/NH_3 ratios. The dependence of the residual stress on the reaction gas ratio η for different annealing time is shown in Fig. 4-2. The film stress showed a general decreasing trend with increasing SiH_2Cl_2/NH_3 ratio due to the increased silicon content. Since higher SiH_2Cl_2/NH_3 ratios decrease the stress but increase the absorption, a trade-off is required. Therefore, a SiH_2Cl_2/ NH_3 ratio = 4 was selected to fabricate the micro PBS for its lower stress (189 MPa) and lower absorption (k=0.03431).

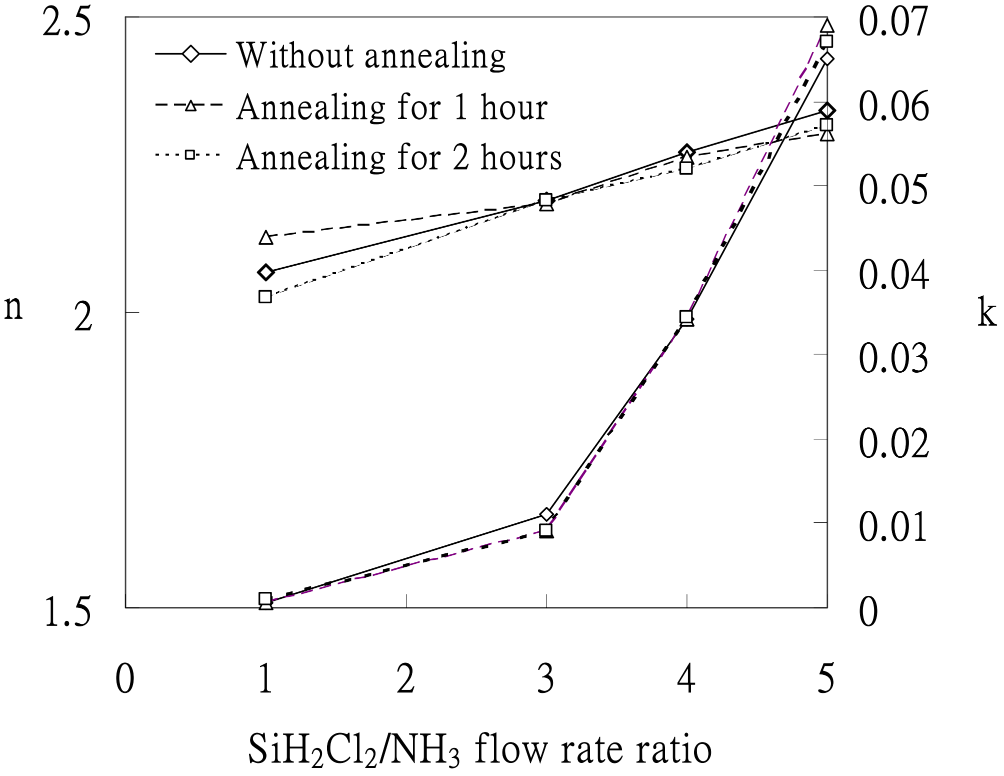


Fig. 4-1. Dependence of the refractive index n and coefficient k on the reaction gas ratio for various annealing time.

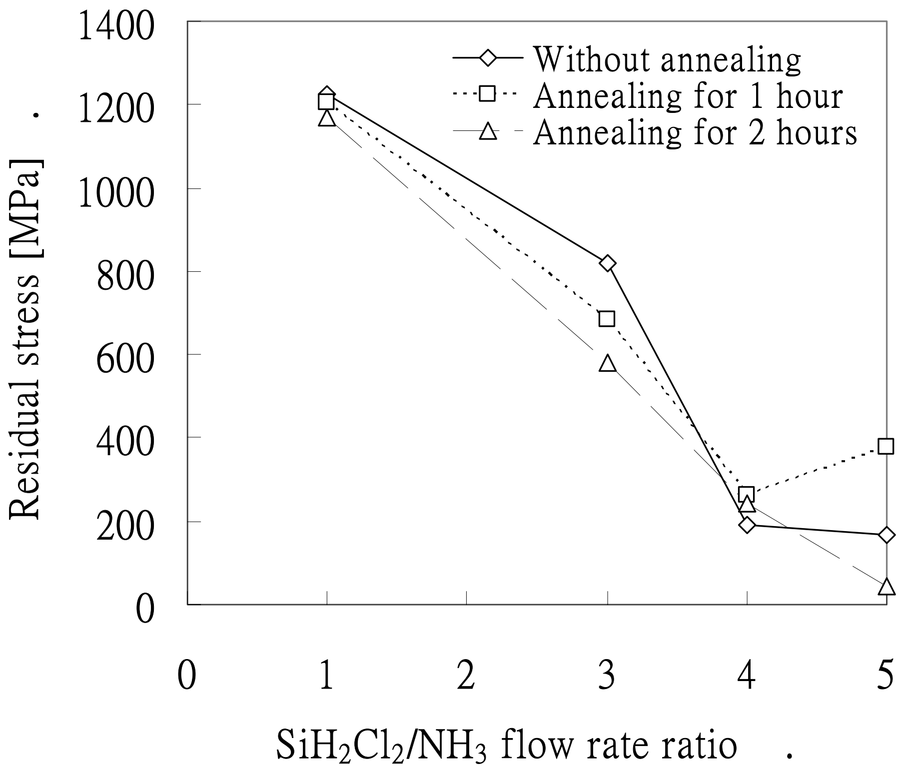


Fig. 4-2. Dependence of the stress on the reaction gas ratio for various annealing time.

4.3 Planar micro-PBS

The micro-PBS was fabricated based on the bulk micromachining technique. This process flow is shown in Fig 4.3. First, a 0.5um-thick low stress SiN layer was deposited on the Si substrate as the PBS thin film by low-pressure chemical-vapor deposition (LPCVD) using dichlorosilane (DCS) and ammonia (NH3). The temperature and pressure were 850° C and 180 m Torr. The flow rate ratio between the DCS and NH3 is 5. Stress in such a silicon nitride layer was below 300 MPa, as calculated from the radius of curvature of a silicon wafer with and without a silicon nitride layer on one of its surface. The thickness of the silicon nitride layer was modified to the target value by a BOE solution. Following was a silicon dioxide deposited by PECVD to protect the surface. After that, the backside pattern was defined by RIE etching and the suspended membrane was formed by KOH back-side etching. Finally, HF was used to remove the silicon dioxide layer.

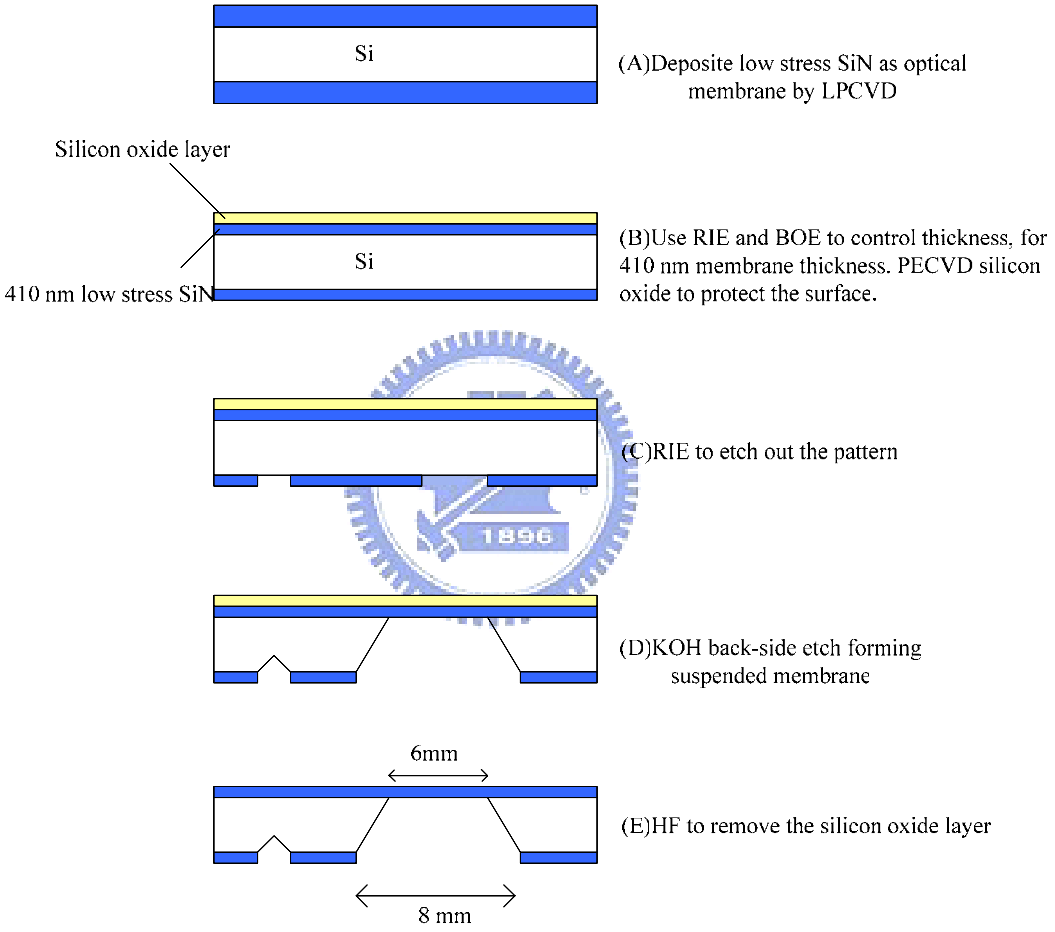


Fig. 4.3 Flow of fabricating planar micro-PBS

4.4 Pop-up Micro-PBS

The pop-up micro-PBS was fabricated based on a two-layer poly-silicon surface micromachining process. The mask of the whole structure is shown in Fig. 4-4.

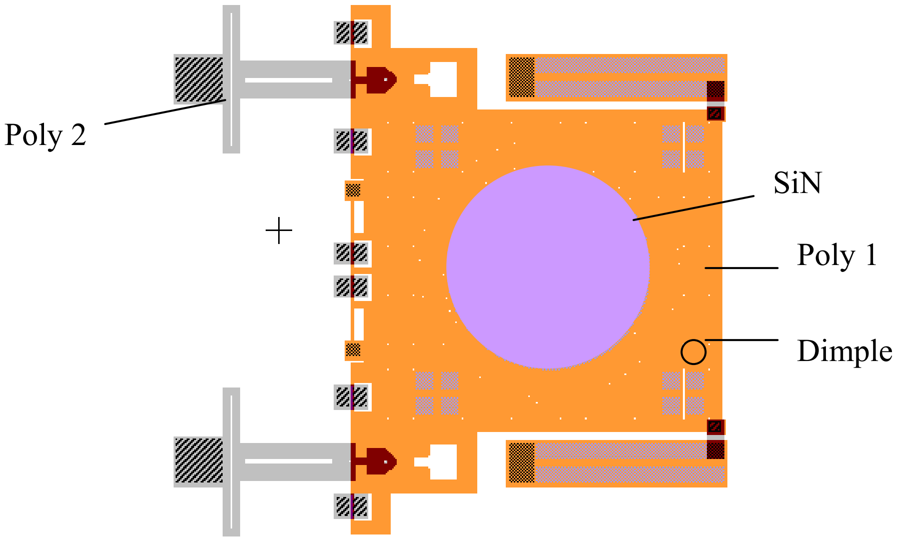
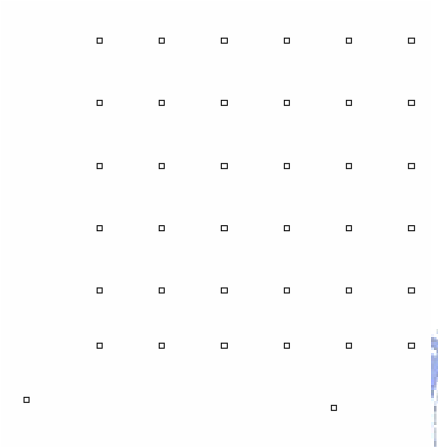


Fig. 4-4 The scheme of the pop-up PBS

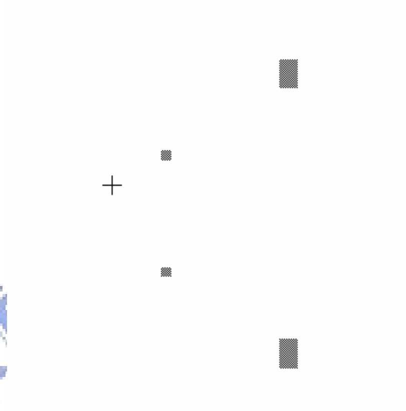
A 2um SiO_2 was deposited by PECVD as the sacrificial layer and the dimple was defined by the first mask to reduce the stiction problem, as shown in Fig. 4-5 (a). Then the second mask was used to define the anchorl for contacting both the upper and lower layers. A 2um Poly-Si was deposited by LPCVD as the structure layer. The Poly1 was patterned through the third level mask to form the ring of the optical device. The optical pattern of SiN and the upper layer of the residual stress beam were formed by the fourth mask, shown in Fig. 4.5(b).The second sacrificial layer of 2 um SiO_2 layer was deposited by PECVD. The POLY1_POLY2_VIA layer was lithographically patterned through the fifth level to provide a connection between the POLY1 and POLY2 layers, as shown in Fig. 4-5 (c). After that, the Anchor 2 was defined by the sixth mask to connect both the Poly 2and substrate. Following, a 2um Poly-Si layer deposited by LPCVD which was patterned by the seventh level was used to be the fixed micro structure, as shown in Fig.4-5(d). Finally, the structure was released by HF.

Mask #1 [Dimple]



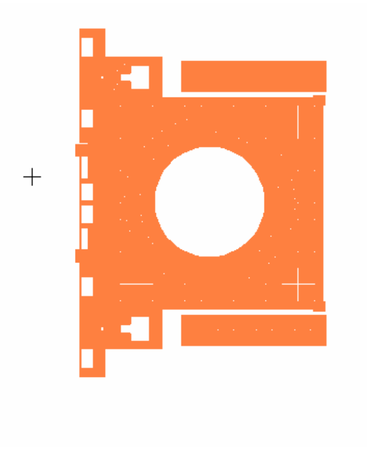
(a)

Mask #2 [Anchor 1]



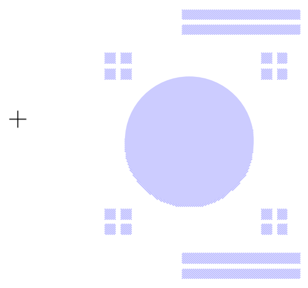
(b)

Mask #3 [Poly 1]



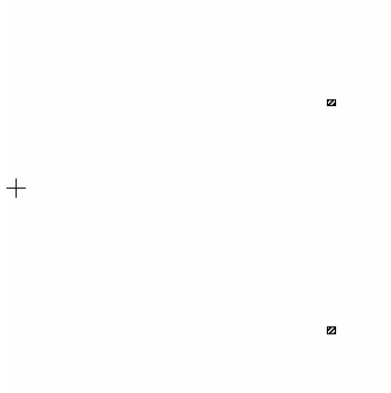
(c)

Mask #4 [SiN]



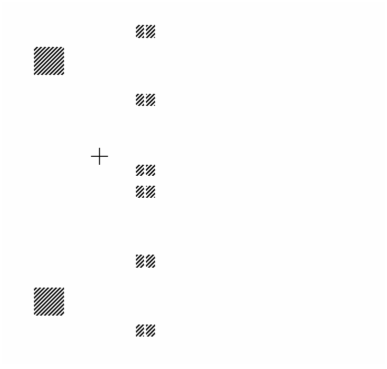
(d)

Mask #5 [C21]



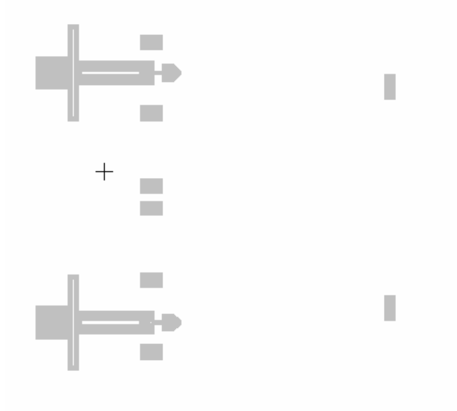
(e)

Mask #6 [Anchor 2]



(f)

Mask #7 [Poly 2]



(g)

Fig. 4-5 Flow of fabricating pop-up micro-PBS (a) Dimple patterning (b) Anchor 1 patterning (c) Poly 1 deposition and patterning (d) SiN deposition and patterning (e) Poly 1_Poly 2_Via layer patterning (f) Anchor 2 patterning, and (g) Poly 2 deposition and patterning

4.5 Summary

The pop-up type micro-PBS was fabricated using a two-layer poly-silicon and one-layer SiN process. The SiN thin film was compatible with surface micromachining technology and the thickness of it can be controlled well for its low etching rate in HF solution. For red ray application, the SiN with superior characteristics of low absorption coefficient k=0.0065 and low stress of 44 MPa was fabricated. Further, the SiN thin film with low absorption coefficient of 0.034 and low stress of 179 MPa which can avoid the membrane from breaking and high absorption in blue ray was deposited. The experimental results and discussion of planar PBS and pop-up PBS using the SiN will be presented in the Chapter 5.