Chapter 3

Design and Simulation

3.1 Introduction

The optical data storage density is dependant on the spot size which is proportional to the wavelength and inversely with the numerical aperture (NA). According to the new format announced in 1996, the wavelength used for DVD is 633 nm or 650 nm. Yet, the capacity density can further enhance by reducing the wavelength. The capacity density is supposed to reach about 30 GB with blue ray of 405nm. The DVD with this characteristic is called high density digital versatile disc (HD-DVD). The design and simulation of PBS for red and blue light pickup will be presented.

3.2 Design

To have the micro-PBS being perpendicular to the substrate, micro hinges and limiters are designed to support the out-of-plane optical devices. Micro hinge was proposed by Pister et al [17] and can be used to fix the micro plate made by surface micro machining after releasing, as shown in Fig. 3-1. To precisely define 90^{o} between the micro-PBS and the substrate, a limiter is designed, as shown in Fig. 3-2. As rotating the plate out of the substrate, the upper portion of the spring-latch will slide into the slot due to the deformation. By suitably controlling the geometrical size of the spring latch, the plate can be locked to be out of the plane vertically, as shown in Fig. 3-3. The vertical triangular relationship is composed of the length of the spring latches, the depth of the slot, and the space of the micro-PBS.

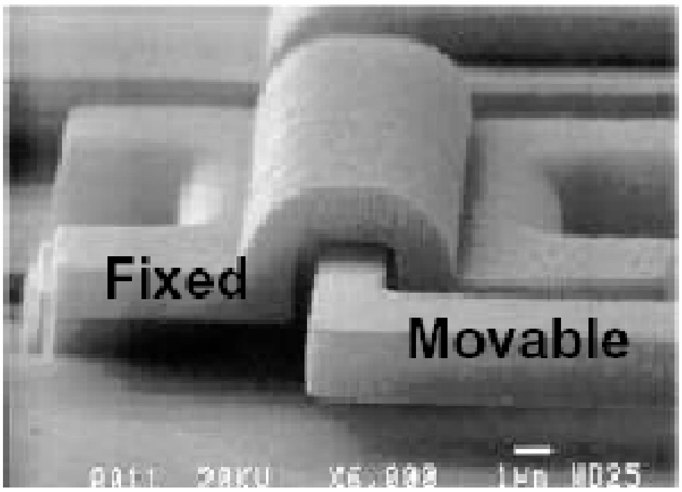

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Fig. 3-1 Diagram of the micro-hinge.

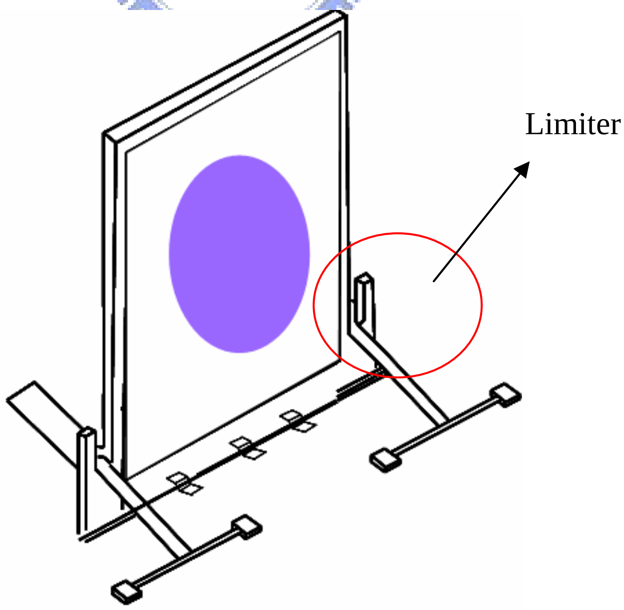

Fig. 3-2 Schematic of the limiter.

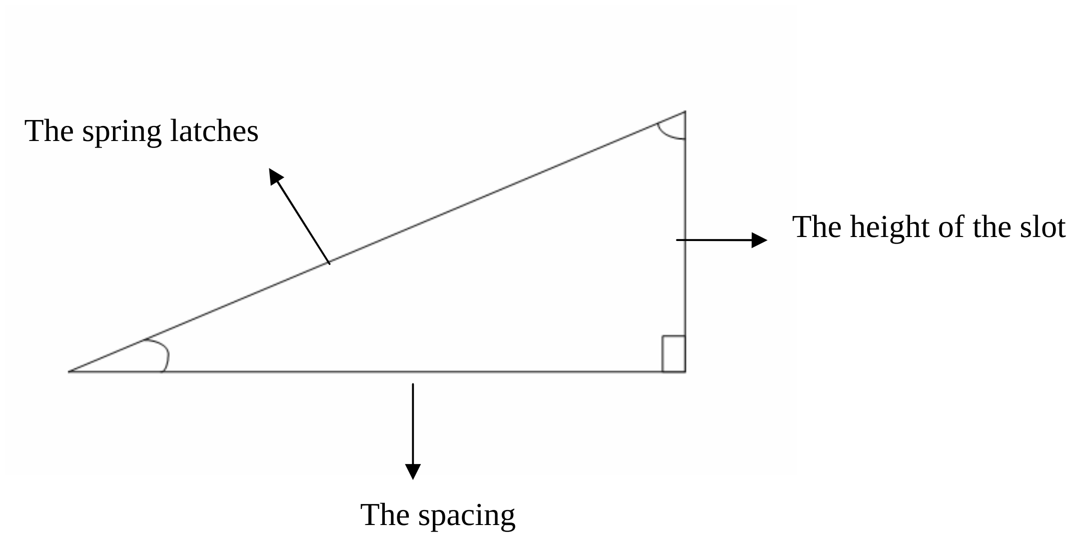

Fig. 3-3 The vertical triangular relationship of the length of the spring latches, the height of the slot, and the spacing between the spring latch and the plate.

3.3 Simulation

To apply in a micro optical system, the PBS with specific thickness at Brewster angle incidence can be of high transmittance for TM mode and high reflectance for TE mode. As shown in Fig. 3-4, the TM mode passing through the PBS can be used to read and write the data in the disc and, therefore, the transmittance of TM mode is expected to be as high as possible. The TE mode reflected from the PBS can be used to carry the data information from the disc to the photodiode array and the intensity information from the incident light source to the monitoring photodiode. The reflectance of TE mode is also expected to be as high as possible.

The SiN is applied as the optical layer of the micro PBS. Several properties about the SiN film required to be investigated, including the absorption coefficient for the operation wavelength, the drofluoric acid (HF) solution etch rate and the residual stress in the following sections. The properties of the SiN film used for red light (632.8 nm) and blue light (405 nm) systems are described, respectively.

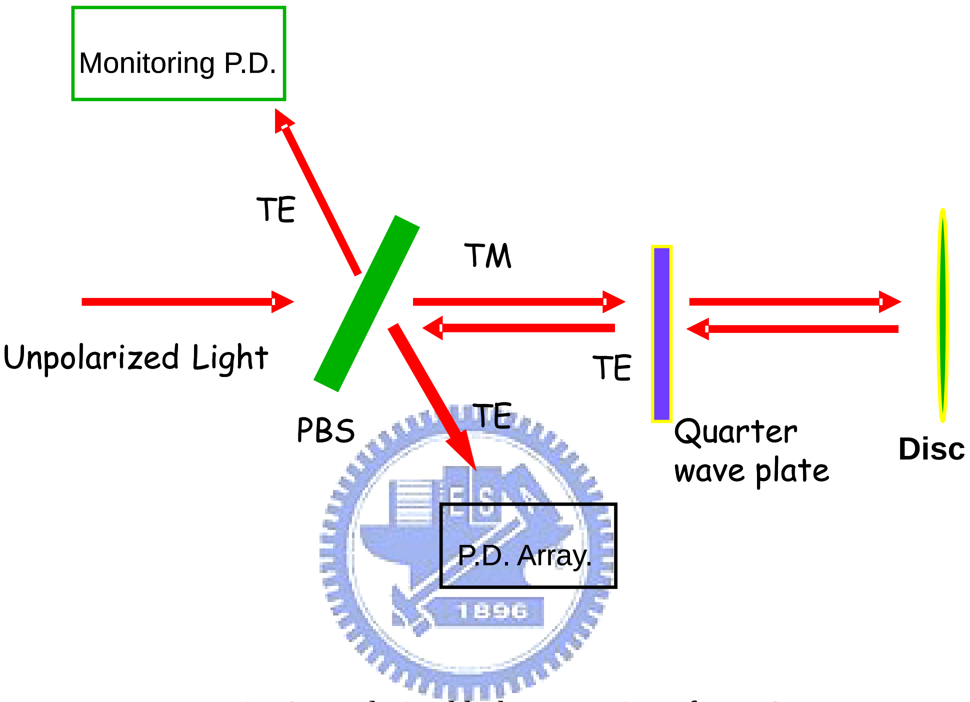

Fig. 3-4 Polarized light separation of a PBS

3.3.1 PBS for red light

The SiN film operated at 633 nm needs to be of low absorption and low stress. After investigation, the film used for the red light is of low absorption with refractive index n 2.13 and absorption coefficient k 0.0065, and low residual stress below 50 MPa.

3.3.1.1 Incident angle

According to the nature of Brewster angle described in chapter 2, the light is assumed to be incident at the angle, and the TM mode will be totally transmitted, leaving the reflective light to be pure TE mode. It is not easy to exactly direct the incident light at the Brewster angle. Hence, the tolerance analysis of incident angle is required to be investigated. The refractive index n_f and absorption coefficient k of low stress SiN thin film used for red light are 2.13 and 0.0065. At λ=632.8 nm, the Brewster angle is 64.85^{o}. The transmittance of TM mode is 1 at Brewster angle in the case of no absorption. The maximum transmittance of TM is 0.94 with k=0.0065 at the same angle, as shown in Fig. 3-5. The transmittance of TM mode is still larger than 80% within ±10° around the Brewster angle compared with the variation of Brewster angle ±2° caused by assembling issue. The tolerance is large and feasible with the current fabrication process.

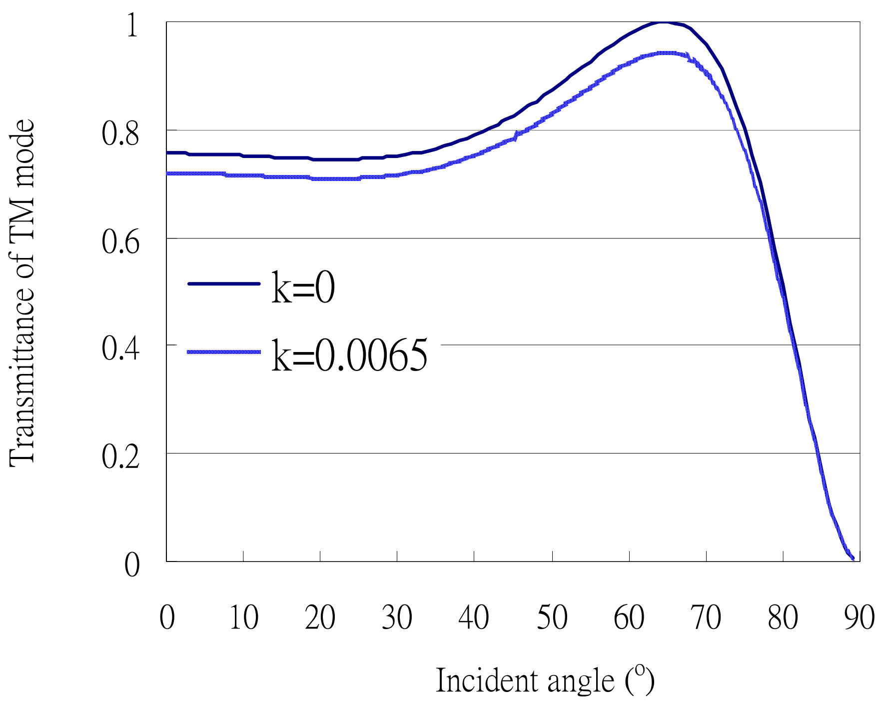

Fig. 3-5 Simulation of transmittance of TM mode as a function of incident angle.

3.3.1.2 Transmittance of TM mode

At Brewster angle, the TM mode is totally transmissive and independent of the thickness without the absorption. The existence of the absorption results in the transmittance of TM mode reduced with the increased thickness. According to Beer-Lambert's Law, it shows that the absorption is an exponential function of the absorption coefficient and the thickness of the SiN thin film, as shown in Fig. 3-6. For the feasibility of fabrication and Eq.(2.2-14), the thickness of the thin film is chosen to be 410 nm. Fortunately, the transmittance of TM mode is higher than 0.94 within thickness of 410±20 nm, which is doable in the fabrication process.

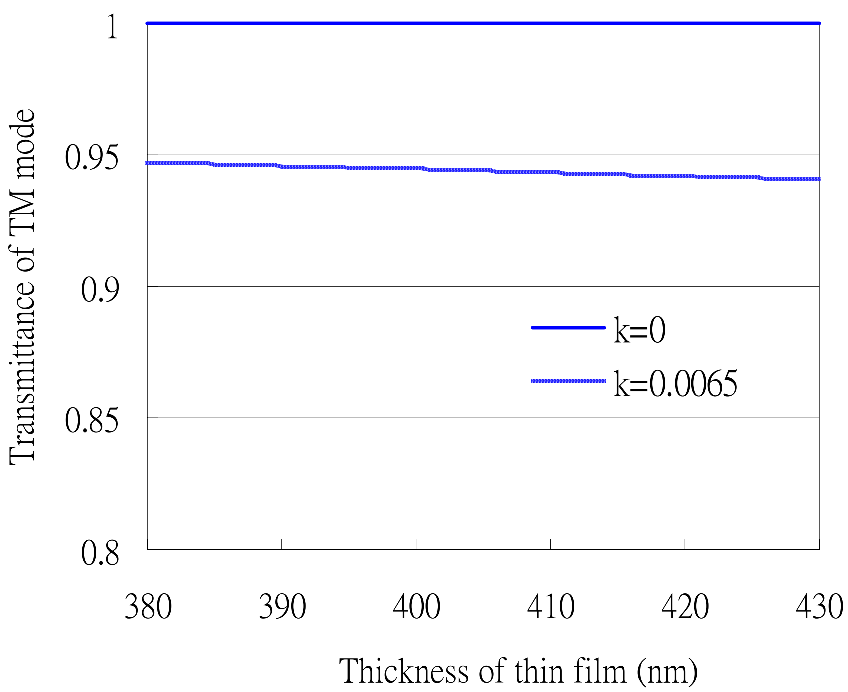

Fig. 3-6 Simulation of transmittance of TM mode as a function of SiN thickness.

3.3.1.3 Reflectance of TE mode

Similarly, the reflectance of TE mode is affected by the absorption, too. The maximum reflectance is 0.82, occurring at the thickness of 410 nm without the absorption; while the maximum reflectance of the thin film 0.8 at the existence of absorption, as shown in Fig. 3-7. Although the reflectance of TE mode in an absorptive thin film is reduced by about 2 %, it is nearly over 0.75 within the region from 380~430 nm.

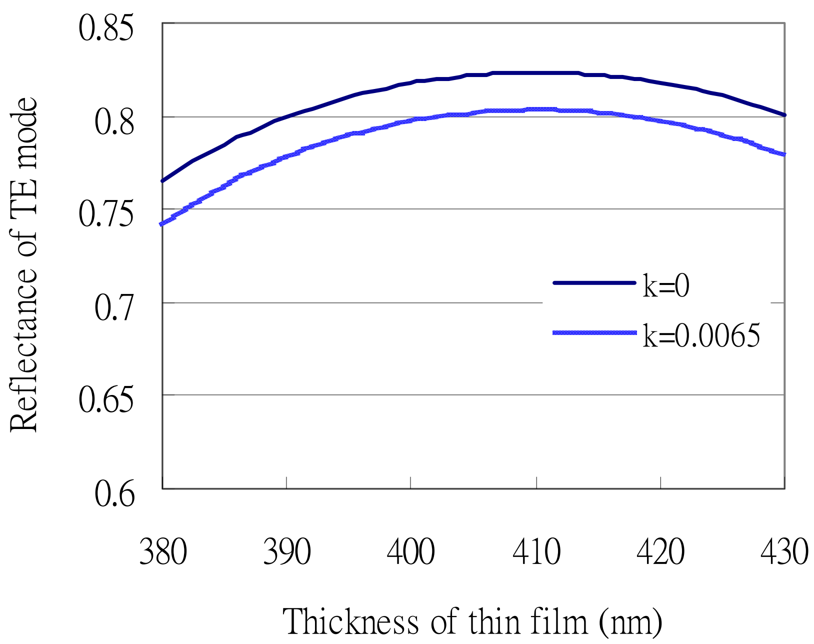

Fig. 3-7 Simulation of reflectance of TE mode as a function of SiN thickness.

3.3.2 PBS for blue light

For the silicon nitride film to be used in the micro PBS, it should have low stress and low absorption. 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=0.034). Since the stress is inversely proportional to the thickness of the thin film, the thickness is chosen to be between 480~730 nm to avoid breaking due to the high stress.

3.3.2.1 Incident angle

With n=2.27 and k=0.03431 for SiN at λ=405 nm, the Brewster angle is 66.23^{o}. According to Eq.(2.2-14), the thickness is chosen to be 536 nm, at which the maximum reflectance occurs around the region. For the thickness of SiN can be controlled under ±10nm in the fabrication, the transmittance of TM mode as a function of incident angle is shown in Fig. 3-8. Even through with different thickness, the transmittance is higher than 0.5 when the incident angle varies from 55° ~72°. As mentioned before, the tolerance of incident angle is feasible in the fabrication.

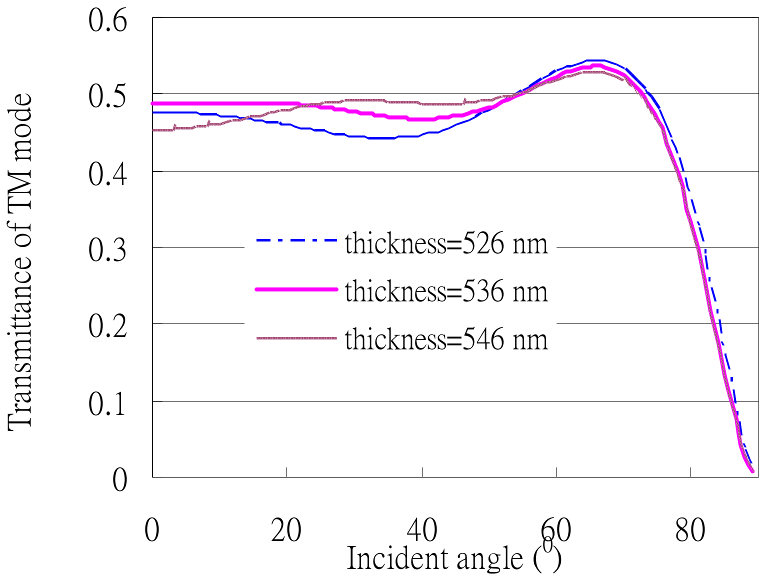

Fig. 3-8 Simulation of transmittance of TM mode as a function of incident angle.

3.3.2.2 Transmittance of TM mode

The thickness is directly proportional to the absorption and inversely to the stress. The maximum transmittances are 0.57 when the thickness is 480 nm. As shown in Fig. 3-9, the calculation implies the transmittance can be enhanced by reducing the thickness.

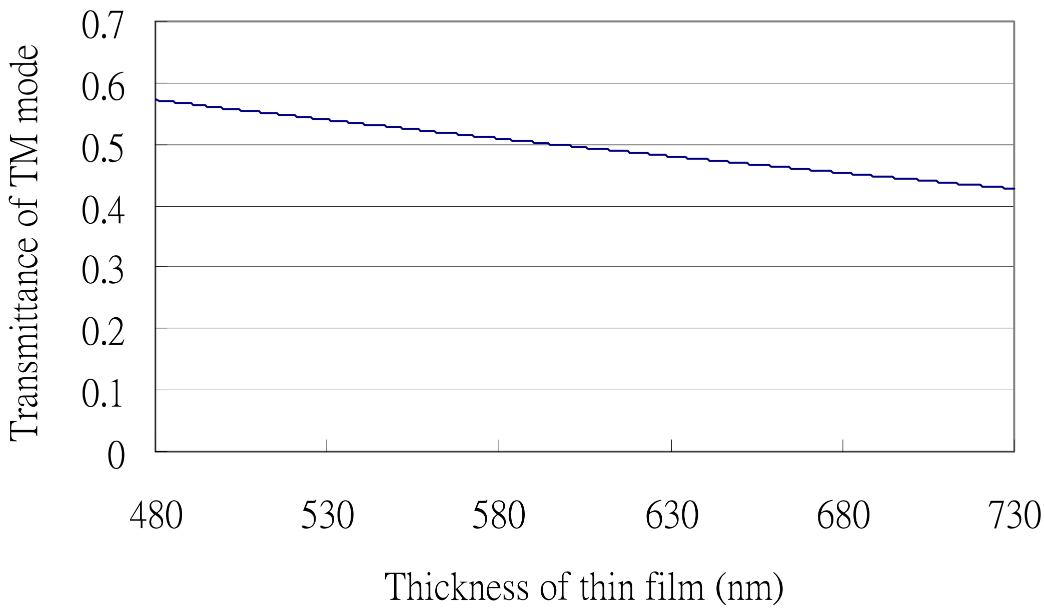

Fig. 3-9 Simulation of transmittance of TM mode as a function of SiN thickness.

3.3.2.3 Reflectance of TE mode

Under the Brewster angle incidence, the transmitted light is still a mixture of TE and TM mode. By choosing a proper thickness z of the thin film, the reflectivity of the TE mode can be easily turned to be higher. The maximum reflectance occurs at the thickness of 536 nm and maintains higher than 0.6 with the thickness tolerance of ±20nm, which is doable in the fabrication process, as shown in Fig. 3-10. Although the reflectance reduces with the thickness, it is noted that the tolerance is nearly the same as that in red spectra.

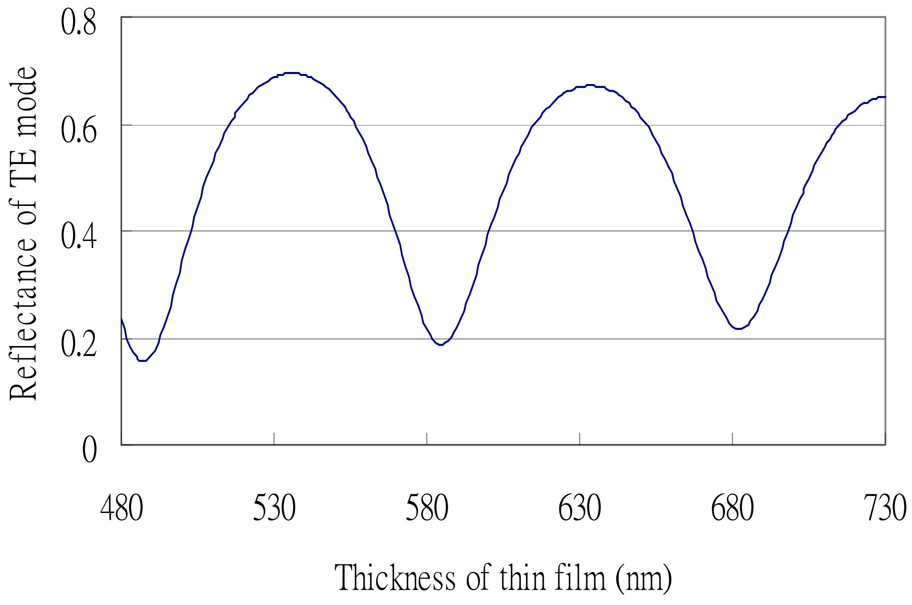

Fig. 3-10 Simulation of reflectance of TE mode as a function of SiN thickness.

3.4 Summary

The design of micro-PBS with high transmittance of TM mode and reflectance of TE mode is demonstrated. The PBS can be held perpendicular to the substrate by the micro-hinge and limiter. Under Brewster angle incidence, the transmittance of TM mode can approach higher than 80 % at the incident angle of $\theta_B \pm 10°$ and the reflective TE mode can be higher than 75 % with the thickness of the thin film of 410 nm ± 20nm for red ray application. On the other hand, the transmissive TM mode is over 50 % at the incident angle of $\theta_B \pm 5°$ and the reflectance of TE mode can approach to 60 % with the thickness of the thin film of 536 nm ± 20nm for blue ray application, respectively.