Chapter 4

Reflow objective lens

4.1 Introduction

The feasibility of using reflow process to make refractive lens will be discussed in this chapter. For NA = 0.6, the available range of photoresist refractive indices is assessed based on the equations in previous chapter. After that, the trade-off with lens size will be examined. Finally, the aberration analysis of lens satisfying the NA and the minimum feasible diameter will be designed.

With the given lens parameters of the reflow lens, the aberration are evaluated by using ZEMAX. The spot diagram and the point spread function show the overall behavior of the aberration coefficients mentioned in Chapter 2. Of the geometrical spot size smaller than Airy disk in the spot diagram, geometrical aberration of the lenses can be negligible. The point spread function signifies exact FWHM of the focal spot in the disk with the consideration of the diffraction effect. In addition, the optical path difference must be smaller than 0.25 ? to meet Rayleigh criteria. Therefore, the rays arrive at the focal plane with almost the same phase difference forms a focus spot of high illuminance [1].

4.2 Fabrication issues

The reflow process will be used to make the convex-plano elements in spherical shape. The focal length which determines the working distance and the profile of the objective lens depends on the refraction index of photoresist. The optical performance of photoresist is mainly affected by the fabrication parameters, such as baking temperature and time, which can cause the change of material density [2].

The variations of focal length with respect to the change of refractive index are shown in Fig. 4-1 where the photoresist with cylinder thickness of 30 µm is used. In Fig. 4- 1, each curve corresponds to a specific cylinder diameter. In addition, with different fabrication parameters, the refractive index of photoresist span over the range of 1.6 to 1.8. The focal lengths decrease as refractive indices increase. When the refractive index rises from 1.6 to 1.8, the focal length is reduced by 25 % as shown in Tab. 4- 1. From paraxial point of view, the focal shift can be explained by the definition of focal length f which can be expressed as $f = \frac{R}{n-1}$, where R is the reflow surface curvature and n is the refractive index. The power of bending light $\frac{1}{f}$ becomes larger as n increases. Therefore, the fabrication process should be well-controlled to reduce focal length variation.

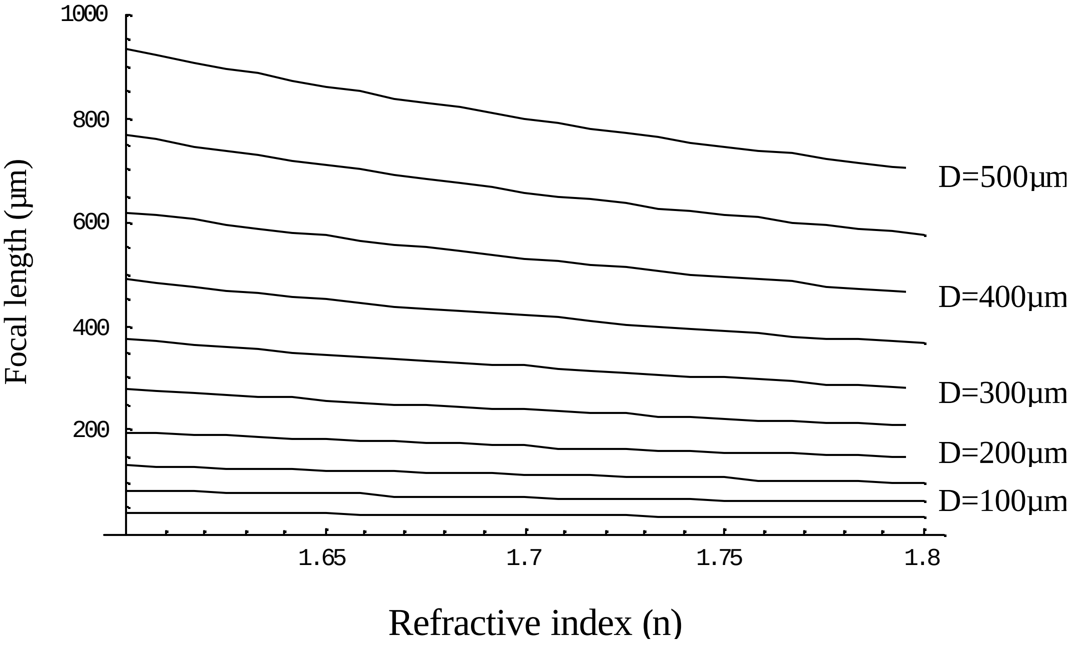


Fig. 4- 1 The variation of focal length as functions of refractive index (n) and lens diameter (D)

Tab. 4- 1 Focus shift due to refractive index variation

D (μm)	f1 (μm) (n = 1.6)	f2 (μm) (n = 1.8)	? f = f2-f1 (μm)	Deviation (%)
50	44.34	33.26	11.09	25.00
100	83.55	62.66	20.89	24.00
150	133.68	100.26	33.42	25.00
200	198.16	148.62	49.54	25.00
250	278.49	208.86	69.62	25.00
300	375.35	281.51	93.84	25.00
350	489.10	366.83	122.28	25.00
400	619.94	464.95	154.98	25.00
450	767.95	575.97	191.99	25.00
500	933.21	699.91	233.30	25.00

Next, the F-number can be derived from Eq. 3-6 to obtain NA of lens.

$$f\,/D = F\,/\# = \frac{h^2 + \frac{D^2}{4}}{2h(n-1)} \qquad \text{(Eq. 4-1)}$$

The beam is assumed to fill the aperture of the objective lens. The paraxial evaluation of NA as a function of lens diameter with n=1.8 and photoresist cylinder thickness t = 5, 10, 15, 20, 25, 30 μm is described in Fig. 4- 2, where the maximum NA are the same for all t value. Thus, the maximum is independent of the reflow lens thickness t. However, the maximum NA is a function of refractive index. The relationship between the maximum NA and the refractive index is shown in Fig. 4- 3. Accordingly, refractive index should be larger than 1.75 to achieve an objective lens of NA=0.6.

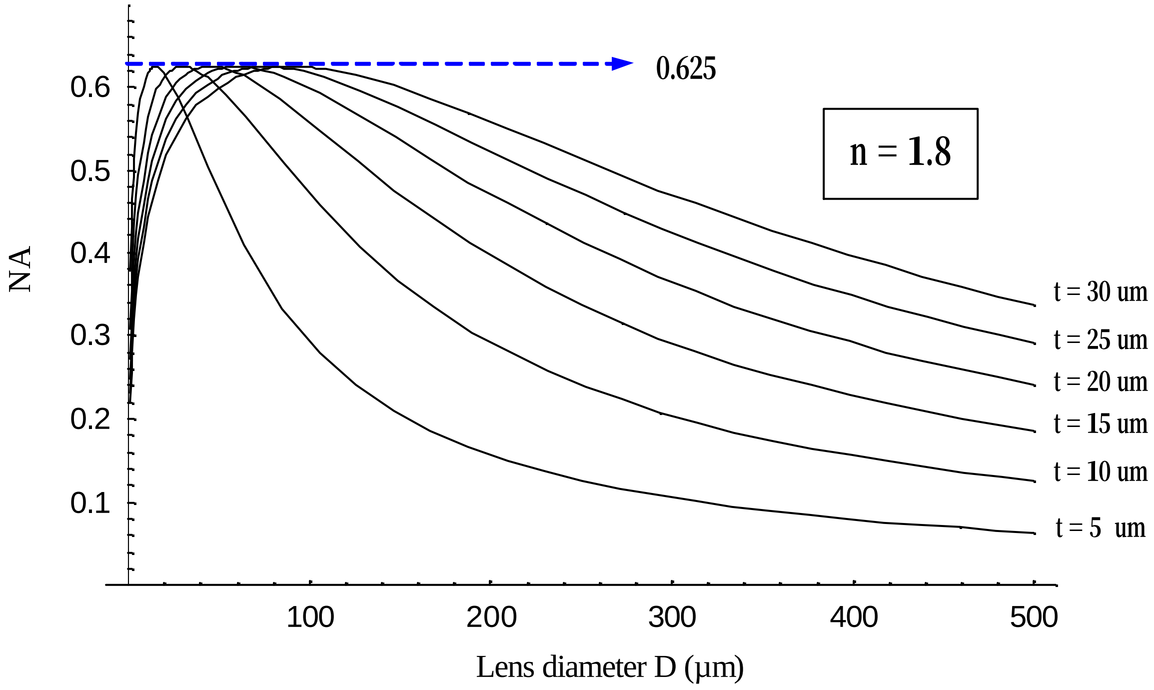


Fig. 4- 2 NA as functions of lens diameter and patterned photoresist thickness t

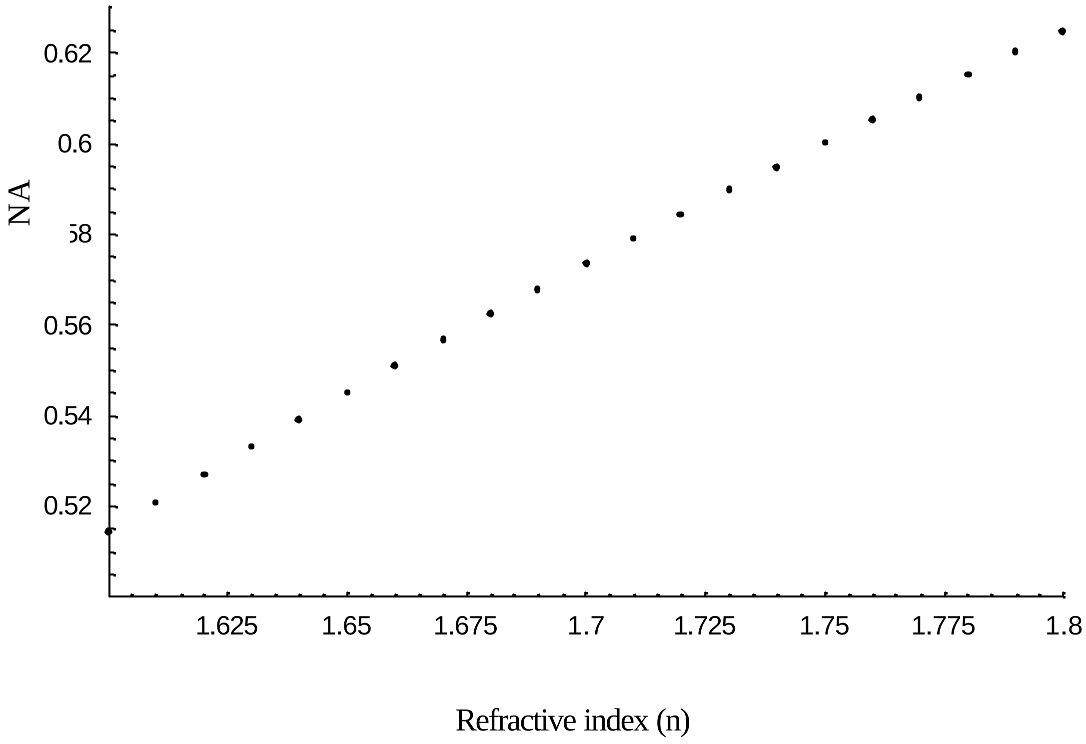


Fig. 4- 3 Maximum NA as a function of refractive index

4.3 Design tradeoff

From the discussion in the previous section, n>1.75 is needed to achieve NA> 0.6. Besides, with a desired spot size, the required NA can be determined. For disk removability, a large focal length is preferred. On the other hand, a small lens diameter D is preferable for a low weight lens. Large f and small D can not be met simultaneously with a fixed NA, which imposes a trade-off in designing the objective lens. The spot size focused on the disk has to satisfy,

$$\text{Spot size} = 1.18\frac{l}{NA} \qquad \text{(Eq. 4-2)}$$

With a specific wavelength of 0.65 μm, the NA computed from the required spot size of 1.08 μm for DVD is 0.6. In addition, the focal length will be restricted by a given thickness of the layer A in front of the recording layer. For a large NA, a short focal length and large clear aperture is needed.

In addition, the minimum focal length restricted by the thickness of the layer A in front of the recording layer determines the minimum lens diameter. To find the minimum focal length with paraxial approximation, the focal length is sum of working distance and the equivalent air thickness of the layer A shown in Fig. 4- 4.

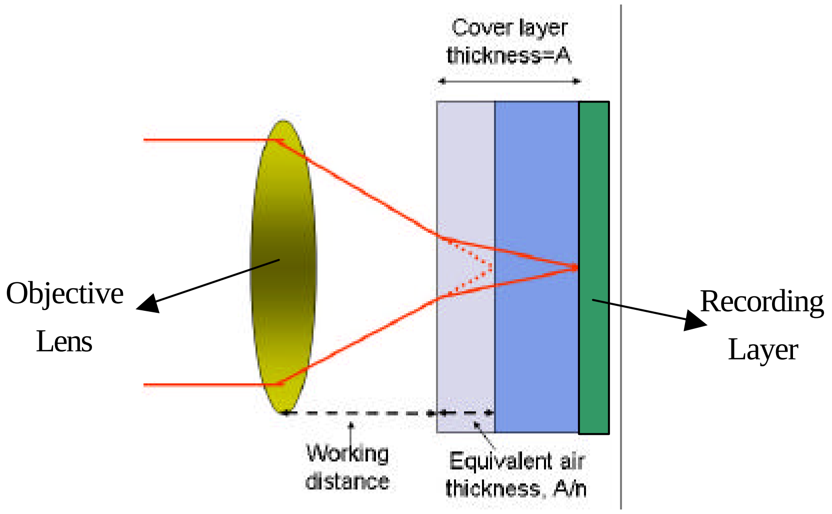


Fig. 4- 4 Schematic diagram of focal length

For aplantic system like objective lens of optical pickup, NA is approximately equal to D/f. For DVD application, NA is 0.6 and the layer A is the substrate of the disk. But the 0.6 mm thickness of the substrate needs large diameter of lens, and some modifications are made. The 0.1 mm thickness of the cover layer was adopted instead of 0.6 mm thickness of substrate. For the cover layer thickness A of 0.1 mm, the thickness can be replaced with an equivalent air thickness of A/n in the air. Therefore, for n = 1.8, the minimum focal length is restricted to 62.5 μm. Thus, the minimum lens diameter becomes 67 μm, which is calculated from NA = 1/[2(F/D)], with the consideration of cover layer on the disk.

4.4 Simulation results of objective in ZEMAX

The simulation of a lens which satisfies n> 1.75 and D> 67 μm for NA = 0.6 has been performed. The reflow lens shape can be calculated by using Eqs. 4-3 and 4-4.

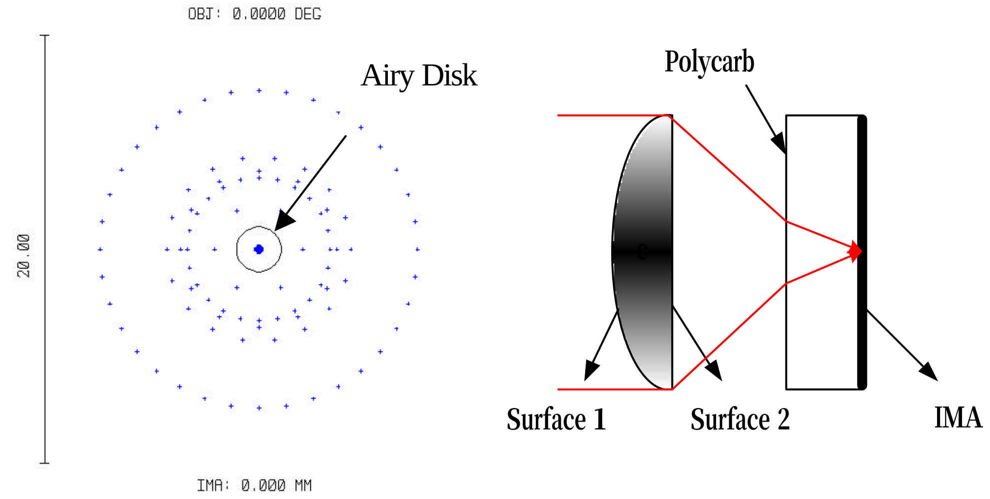
$$r_c = \frac{h^2 + \frac{D^2}{4}}{2h} \qquad \text{(Eq. 4-3)}$$

$$f = \frac{h^2 + \frac{D^2}{4}}{2h(n-1)} \qquad \text{(Eq. 4-4)}$$

For a refractive index n = 1.8, patterned photoresist thickness t = 30 μm, and reflow lens diameter D = 500 μm, the lens shape was designed. For these parameters, NA of the reflow lens is only about 0.34. The computed radius, thickness, and the material are tabulated in Tab. 4- 2. The lens performance is evaluated by using ZEMAX in Fig. 4- 5. In Fig. 4- 5 (a), the spot size of focused laser beam is larger than airy disk, indicating that the geometrical aberration of reflow lens can not be eliminated. The resulted performances of reflow lens are shown Tab. 4-4. From the simulation result, The optical path difference (OPD) of reflow lens is too large to meet the Rayleigh criteria. Thus, the reflow lenses are not feasible to be used for DVD pickups.

Tab. 4- 2 Surface parameters of reflow lens (surface 1 and 2) and disk cover layer

Surface	Radius (μm)	Seperation (μm)	Refractive indices
Surface 1	560	58.9	1.8 (AZ4620)
Surface 2	0	568.9	1.0 (air)
Cover layer	0	100.00	1.6 (polycarb)
Recording layer	0	0	0



(a) (b)

Fig. 4- 5 (a) The spot diagram and (b) the system overview of reflow lens with D = 500 μm and t = 30 μm. The black circle denotes the Airy disk

Tab. 4-3 Data of reflow lens

Parameter	Value
Effective focal length (mm)	0.70
Free working space (mm)	0.57
NA	0.34
Optical path difference (?)	2

4.5 Conclusion

According to the simulation and analyses on the objective lens with the considerations of fabrication process, the spherical reflow objective lens is not viable due to the blurring of focal spot resulting from the difficult-correcting spherical aberration shown in Fig. 4- 5 (a). Therefore, the aspheric lens fabricated by gray-scale mask will be exploited and will be described in the next chapter.