Solution of Exercises
Lecture Optical design with Zemax for PhD – Part 9

9.1 Achromate

a) Calculate a classical achromate with the basic data:
- object at infinity
- focal length $f = 10$ mm
- image side numerical aperture $NA' = 0.05$
- glass materials BK7 and SF6
- wavelength used: d, F, C

Performance:
1. spherical correction at the aperture boundary zero
2. achromatic correction with identical image position for F and C

Is the system diffraction limited on axis?

b) Describe the performance for a finite field angle of $2^\circ$.

c) If the glass SF6 is used instead of SF12, can a system with equivalent quality be obtained?

9.2 High-NA Collimator

An achromatic system is typically diffraction limited for a numerical aperture not larger then $NA = 0.1$. For a point on axis, by adding an aplanatic-concentric meniscus-shaped lens, the numerical aperture can be increased by a factor correponding to the refractive index of the lens. This principle is shown in the exercise 6.1

a) Load an achromate with focal length $f = 100$ mm from a vendors catalogue with a diameter of at least $30$ mm. Take the wavelength to $\lambda = 632.8$ nm. Reduce the entrance pupil diameter to achieve a diffraction limited system according to the Marechal criterion of $W_{rms} < \lambda/14$. Add one aplanatic-concentric meniscus lens of a high-index medium of appropriate distance and thickness.

b) Now add more meniscus lenses, until the image space NA is larger than 0.6. The thickness of these lenses should again be chosen appropriate to get manufacturable components (ratio of diameter to thickness not larger then 10). Show, that the spherical aberration contribution of the meniscus is zero for all orders of spherical aberration. What is the resulting free working distance of the final system?

c) Now try to further improve the system by numerical optimization. Is it possible to get better performance? Think on the definition of proper constraints to get a reasonable and comparable system.

9.3 Correction with Buried Surface

Select an achromatic system with focal length $f = 50$ mm out of a vendor catalog. For an incoming collimated beam diameter of $10$ mm this gives a nearly diffraction limited imaging quality for $\lambda = 546$ nm. Now increase the numerical aperture by inserting a aplanatic concentric lens with thickness $3$ mm
and made of the glass F9. Now a broadband spectrum is considered, which is characterized by the wavelengths e F' C'. Show, that the performance for blue and red is not diffraction limited. In the next step, the meniscus lens is splitted into a cemented component, where the second lens is made of the glass SK16. This gives a buried surface lens. Show, that the correction for green is not perturbed. Is the spot better or unchanged ? Improve now the chromatic correction by optimizing the cemented surface of the burier component. Is the performance diffraction limited over the complete spectral range ? Now re-optimize the first achromatic component only with the radii. What is the overall performance now ?

In a last step, combine the system with a the reversed version to get a perfect symmetrical system. The distance between the two parts should be 2 mm. Show that for a finite field of height 3 mm the asymmetrical aberrations vanish completely. What is the remaining and dominating aberration ?