Space and time multiplexing for field curvature correction in miniature imaging systems

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Summary

The correction of field curvature by space or time multiplexing enables the design of a very simple imaging system for mobile device. Here, the optical design is presented and methods to correct the field curvature are discussed. This imaging system can be fabricated with wafer-level processes enabling large-scale and low cost production.

Introduction

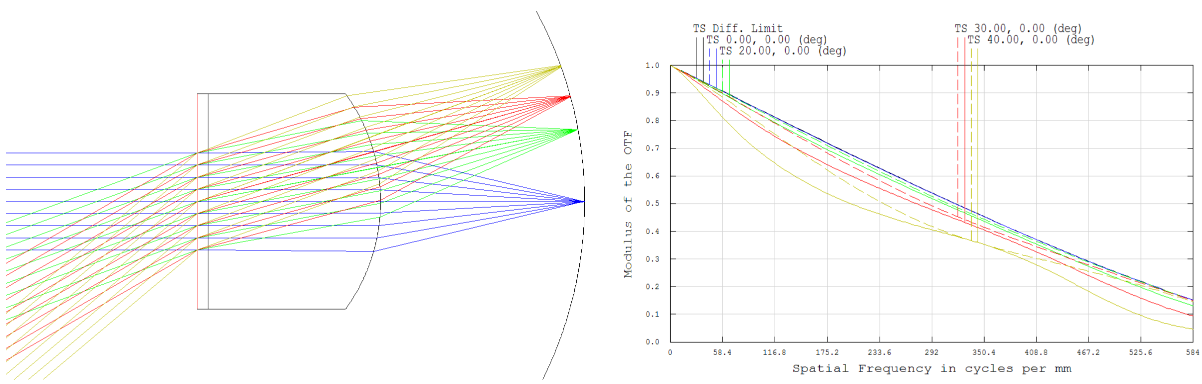
A monocentric lens is free from coma, astigmatism, and lateral chromatic aberration [1]. Here, we discuss the optical design of a small objective lens for wide-field imaging, leaving the field curvature correction to alternative methods discussed thereafter.

The monocentric plano-convex lens

Figure 1 (a) shows a cross-section drawing of the monocentric plano-convex lens. For a given material, the radius of curvature R of the convex surface is fixed by the desired lens power. The only remaining free parameter is the diameter of the aperture stop.

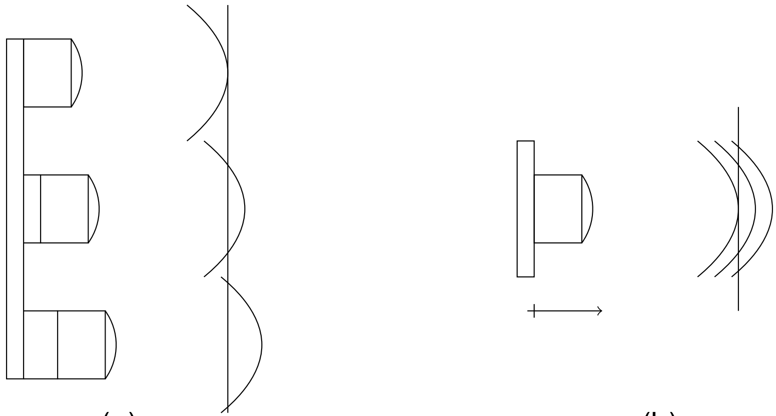
In reference [2], the author limits the spherical aberration of a 1-mm focal length lens using an aperture with a diameter of 0.33 mm ($F_{\#} = 3$). Here, we achieve an $F_{\#}$ of 2.2 by correcting the first order spherical aberration using a fourth-order aspheric surface at the aperture stop (see [3]). The size of the aperture is limited by high-order aberrations. Distortion is corrected digitally and the longitudinal chromatic aberration is corrected by the method used for field curvature correction.

Figure 1 (b) shows the modulation transfer function of the designed lens. The depth of focus is 14 μm for a circle of confusion of 3 μm. The field curvature induces a defocus of 140 μm at a semi-field angle of 40°.



(a) (b)

Fig. 1. (a) Drawing of the monocentric plano-convex lens; (b) Modulation transfer function of the designed lens with a $F_{\#}$ of 2.2.



(a) (b)

Fig. 2. (a) Spatial multiplexing; (b) Temporal multiplexing

Correction of field curvature

The effect of field curvature could be accounted for by using a curved image sensor [4, 5] if these sensors were commercially available. Traditionally, additional elements are used to correct the field curvature. This solution, however, leads to complex optical systems that are difficult to mount and align. Recently, the wavefront coding technique [6] was presented, providing another means of correcting this aberration. Here we shortly discuss two other methods. The field curvature is nothing else than a field-dependent defocus. By taking a series of images with proper focus, a full-field image can be reconstructed by digital post-processing. One method to obtain the images is by spatial multiplexing. A multichannel objective [2] with channel dependent focus can be used to acquire in a single frame all the necessary data as schematised in Fig. 2 (a). Another method uses time multiplexing. A sequential series of images is taken with a single objective and proper inter frame focusing as shown in Fig. 2 (b). This method requires a moving objective and a static object. For the design presented here, 10 frames or channel-focus positions are required to cover a field of 80°.

Discussion

A simple wide-field objective lens without field curvature correction was presented. This design is suitable for fabrication at the wafer level and benefits from the advantages of these processes. The imaging system is practicable when coupled with a method for field curvature correction using for example space or time multiplexing. The longitudinal chromatic aberration can be corrected in an identical fashion. Furthermore, three-dimensional imaging is possible, although it is limited by the short hyperfocal distance of the objective.

References

1. M. J. Kidger, *Fundamental Optical Design*, vol. PM92 (SPIE, Bellingham, 2002).
2. E. Logean *et al.* Proc. SPIE vol. 8667, (SPIE, Burlingame, 2013), p. 86671E.
3. D. A. Buralli and G. M. Morris, Appl. Opt. **28**, 3950 (1989).
4. H. C. Ko *et al.* Nature **454**, 748 (2008).
5. S.-B. Rim *et al.* Opt. Express **16**, 4965 (2008).
6. E. R. Dowski, Jr. and W. T. Cathey, Appl. Opt. **34**, 1859 (1995).