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Broadband achromatic aplanatic flat doublet in mid-infrared

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Abstract: We propose a broadband achromatic aplanatic flat doublet, which works at 3.8 μm to 4.4 μm. The combination of sapphire flat lens and fused silica flat lens suppress the chromatic aberration and off-axial aberrations simultaneously.

OCIS codes: (110.3080) Infrared imaging; (050.1965) Diffractive lenses

1. Introduction

The applications of mid-infrared (Mid-IR) have drawn increasing attentions in many areas, such as biomedical screening and therapy, night version systems, and airborne seekers. Although researchers have put efforts into developing new Mid-IR sources and detectors, the development of Mid-IR lenses, which play critical roles in Mid-IR systems, is insufficient. Conventionally, the Mid-IR lenses are fabricated through cutting material, grinding the surface, fine polishing, and coating process, which makes them bulky and unfavorable for system miniaturization. Flat lenses, which have been experimentally demonstrated [1-3], unfolds unprecedented opportunities for novel compacted optical systems. Although Mid-IR flat lens has been demonstrated, the achromatic aplanatic flat lens in Mid-IR, which is necessary for real applications, has not been achieved yet. In this connection, we propose the design of broadband achromatic aplanatic flat doublet working at 3.8 μm to 4.4 μm. Both the off-axial aberration and chromatic aberration are greatly suppressed, which is imperative for real applications like night vision and airborne seekers.

2. Mid-IR doublet design

Sapphire and fused silica are utilized for this design, the working wavelengths range from 3.8 μm to 4.4 μm, which lies in the infrared atmospheric window. As a prototypical design, the focal length, semi-field of view (FOV) and numeral aperture (NA) are set to be 92 μm, 1.5° and 0.47, respectively. The vectorial Rayleigh-Sommerfeld (VRS) diffraction theory [4] is applied for the propagations. The schematic lens structure is shown in Fig. 1(a). Optimization is used to determine the rings' positions of the doublet and thickness of two materials; the target function is given by:

$$\begin{aligned} &\max\ c_1 I_{on-axis}(z_0) + c_2 I_{off-axis}(z_0) + \frac{c_3}{\Delta} \\ &\text{s.t.}\ \ a_{m+1} - a_m > l, \\ &\qquad b_{m+1} - b_m > l, \\ &\qquad a_1 > d, b_1 > d, \\ &\qquad \text{NA} \geq NA_{\min}, \\ &\qquad t_l \leq t_1, t_2 \leq t_2 \end{aligned} \tag{1}$$

where $I_{on-axis}$ and $I_{off-axis}$ are light intensities on focal plane under normal illumination and semi-FOV illumination, respectively. Δ is the distance between foci of 3.8 μm and 4.4 μm. The c_1, c_2 and c_3 are the weight factors in optimization, which are all set to be one. The a_m and b_m are the rings positions for sapphire and fused silica, respectively. The l denotes the minimum distance between conjoint two rings, which is 800 nm. The d is the minimum radius requirement for first ring on both surfaces of substrate, which is set to be 1.4 μm. The $NA_{\min}$ is the minimum NA requirement in the optimization, which is set to 0.45. For the sake of fabrication accuracy, the width of all rings is set to be 400 nm. The lower bound and upper bound of the thicknesses of sapphire and fused silica are t_1 and t_2, respectively. Moreover, the phase delay caused by the ring structure is assumed to be 0.17π.

Figure 1(b) shows the R-Z focusing intensity of this doublet, the axial point spread functions (PSFs) comparison is illustrated in Fig. 1(c). The Δ is 15.5 μm, which is smaller than the axial Rayleigh diffraction limit 18.6 μm with NA=0.47 and central wavelength of 4.1 μm.

The on-axial and off-axial PSFs at focal plane are shown in Fig. 2. No comas appear for the oblique illustration (@Fig. 2 lower row), and the all the lateral PSFs are Rayleigh diffraction limited.

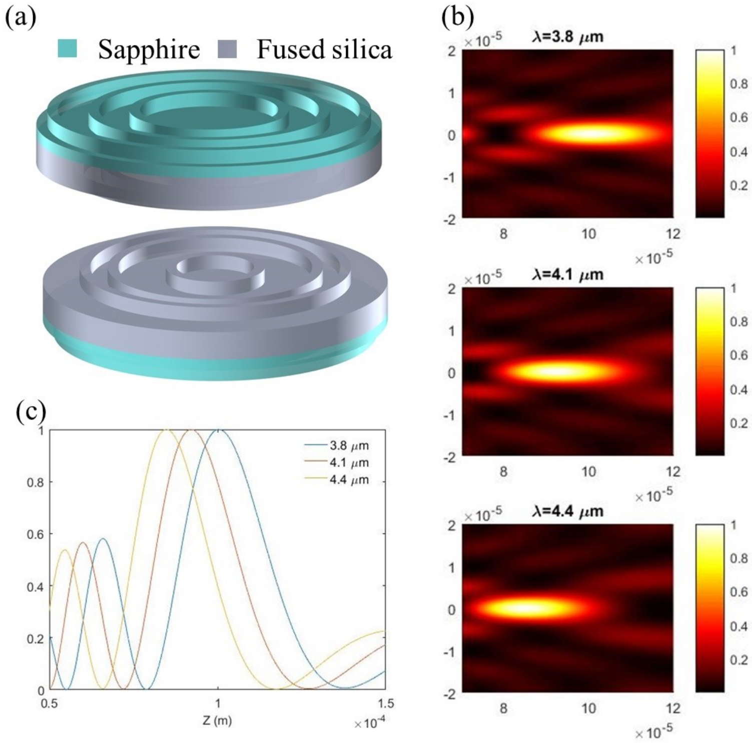

Fig.1 (a), Schematic of flat lens; (b), R-Z focal intensities comparison; (c) PSFs comparison along Z axis.

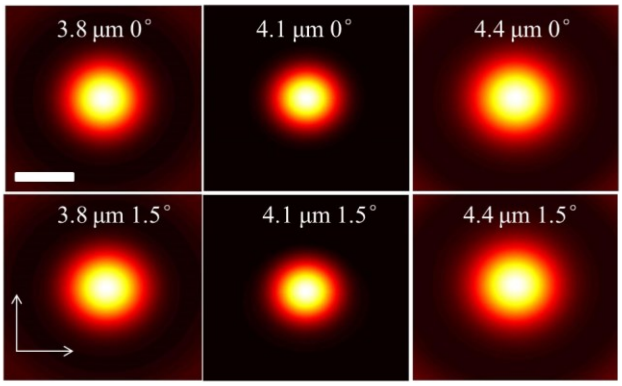

Fig.2 PSFs comparisons for normal incidences and oblique incidences with three wavelengths

3. Conclusion

In this paper, we propose and numerically demonstrate the broadband achromatic aplanatic flat lens with semi-FOV of 1.5°, working at 3.8 μm to 4.4 μm. This prototypical design unfolds unprecedented opportunities for practical imaging applications such as night vision systems and airborne seekers.

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