Science Bulletin 64 (2019) 797–798

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Research Highlight

Metalens in harmony with refractive optics

Xueyi Zhu [a], Shuming Wang [a,b,c], Xuejun Yan [a], Minghui Lu [a,b,d,*]

[a] Department of Materials Science and Engineering, College of Engineering and Applied Sciences and National Laboratory of Solid State Microstructures, Nanjing University, Nanjing 210093, China
[b] Collaborative Innovation Center of Advanced Microstructures, Nanjing University, Nanjing 210093, China
[c] School of Physics, Nanjing University, Nanjing 210093, China
[d] Jiangsu Key Laboratory of Artificial Functional Materials, Nanjing University, Nanjing 210093, China

Optical dispersion is an inherent property of all materials in nature. Due to the dispersion of the optical material and the phase accumulation of the light field at different wavelengths, chromatic aberration is inevitable in commercial optical lens. When taking pictures by lenses with severe chromatic aberration, the images will look blurred or noticeably colored edges (red, green, blue) around the objects, especially in high-contrast situations. Thus, achromatism, correction of the chromatic aberration, is extremely important in broadband optical applications. There are mainly two approaches in the correction of the chromatic aberration in existing optical systems: combining the refractive lenses with different dispersions or introducing the diffractive optical elements. However, it is still a technical challenge to achieve that goal in the entire visible light band.

In recent years, metasurfaces, which can be fabricated by standard techniques in the semiconductor industry, have been widely used to arbitrarily manipulate the light wave front so as to control the phase shift, amplitude and polarization of the scattered light. By using the specially designed metasurface unit cells, different groups have demonstrated the broadband achromatic metalenses and showed the achromatic focusing and imaging in visible or near-infrared regime [1–6]. However, limited by the group delay of metalenses, the focal ability (numerical aperture) and size cannot be large, simultaneously. Therefore, the diameters of the broadband achromatic metalenses are limited to the order of 100 μm.

Recently, researchers at Harvard University (Capasso's Group) and the National University of Singapore (Qiu's Group) have implemented a metacorrector that combines the strategy of controllable phase and artificial dispersion to achieve the correction of chromatic aberration in a large spherical plano-convex lens [7]. This hybrid scheme highly complements the advantages of conventional refractive optics and ultra-thin metasurfaces, realizing a millimeter-scale, broadband, and achromatic imaging system. Furthermore, metacorrector could be used to correct residual aberrations in a state-of-the-art immersion objective, thereby greatly increasing the bandwidth from violet to near infrared wavelengths, which further confirms the effectiveness of this approach. The concept of hybrid metasurface-refractive optics shows the advantages in size, scalability, complexity, and functionality.

In this work, researchers designed and built a metacorrector that used anisotropic nano-fins to maintain an accurate phase distribution, and then introduced artificial dispersion to correct the spherical and chromatic aberrations respectively (Fig. 1). By controlling the light confinement in the sub-wavelength nanostructures, the dispersion can be finely tailored in the single-layer surface, which is more efficient than refractive and Fresnel optics. It shows that a single metasurface with an artificially designed dispersion can be used to correct spherical and chromatic aberrations of refraction lenses. Meanwhile, experiments show that the focal length shift of the metasurface refraction lens is smaller compared with projective and diffractive double lens. The image of standard resolution target is achieved by the hybrid metasurface lens with incoherent illumination of different bandpass filters. In the case of using a metasurface corrector, the image shows a sharp edge profile, while it is blurred and shows a rainbow-like edge without using metasurface corrector.

To verify the performances forward, researchers use metasurface correctors to eliminate the residual aberrations in Zeiss' high numerical aperture (NA = 1.45) oil-filled fluorescence microscope objective, which consist of 14 lenses and 7 different lens glass materials. The composition increases the bandwidth from violet to near infrared significantly.

Moreover, to increase the size of the broadband achromatic imaging system based on the metasurface, the authors employed the conventional optical devices. Thanks to the correction of chromatic aberration from the meta-correctors, the compound system can simultaneously achieve a millimeter size and a large NA value (1.45), which is quite desirable in optical imaging field. These meta-correctors can collaboratively work with conventional refractive optics to provide significant performance improvements and reduce the complexity of the design and footprint at the same time. In the future, myriad of applications would benefit from the hybrid meta-system, such as the compact imaging systems in the cell phone cameras, lithographic techniques for large-scale patterning, mid-infrared optical devices, etc.

SPECIAL TOPIC: Electromagnetic Metasurfaces: from Concept to Applications.

* Corresponding author.
E-mail address: luminghui@nju.edu.cn (M. Lu).

https://doi.org/10.1016/j.scib.2019.04.010

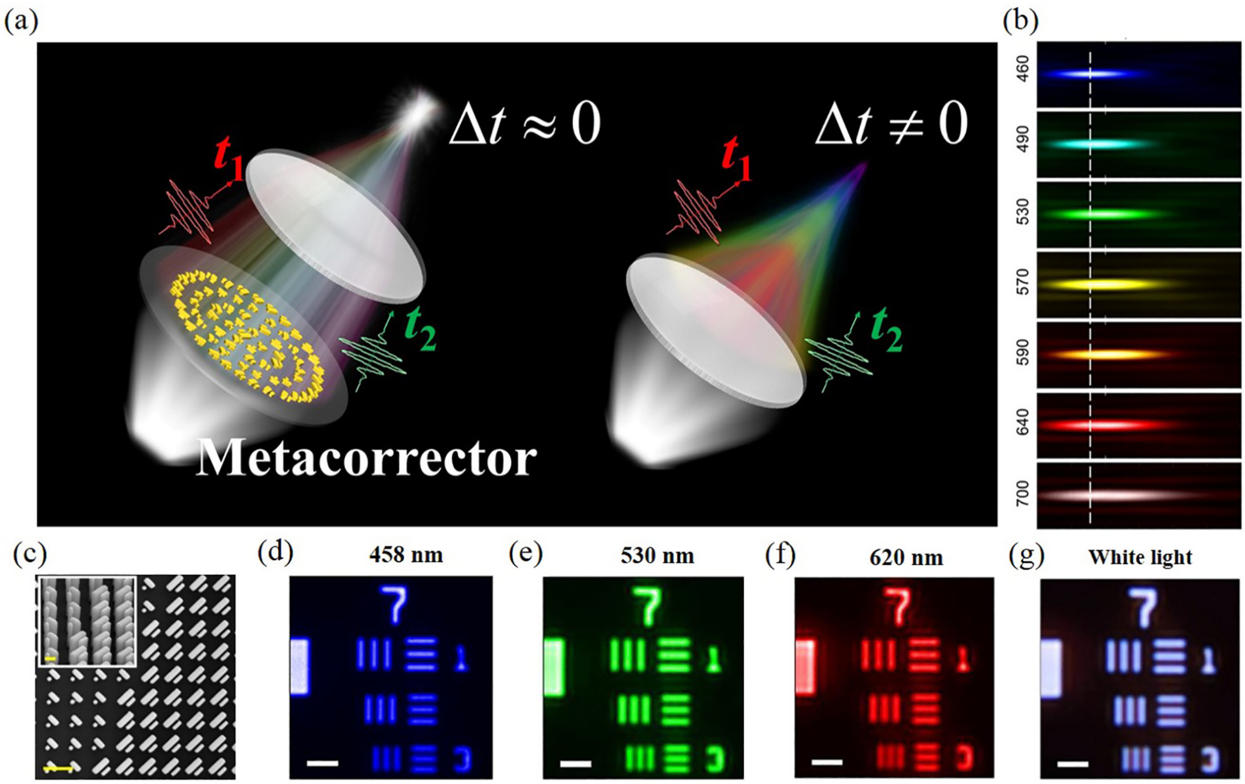

Fig. 1. Broadband achromatic metasurface lens in Ref. [7]. (a) Schematic of a hybrid lens consisting of a metacorrector and a spherical lens to illustrate wavepacket tracing. (b) Simulated phase shift of the transmitted electric field with the metacorrector. (c) Scanning microscope image from a region of the metacorrector, made of TiO_2 nanofins on a glass substrate. (d–g) Images of a 1951 USAF resolution target formed by the refractive spherical lens with the metacorrector. Adapted with permission from Ref. [7]. Copyright (2018) American Chemical Society.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

X. Zhu, S. Wang, X. Yan and M. Lu acknowledge the support from the National Key Research and Development Program of China (NKRDP) (2018YFA0306200 and 2017YFA0303702), and the National Natural Science Foundation of China (NNSFC) (11625418 and 51732006).

References

[1] Zheludev NI, Kivshar YS. From metamaterials to metadevices. Nat Mater 2012;11:917–24.
[2] Khorasaninejad M, Capasso F. Metalenses: versatile multifunctional photonic components. Science 2017;358:eaam8100.
[3] Huang K, Dong Z, Mei S, et al. Silicon multi-meta-holograms for the broadband visible light. Laser Photon Rev 2016;10:500–9.
[4] Li GX. Achromatic metasurface lens at visible wavelengths. Sci Bull 2018;63:333–5.
[5] Wang S, Wu PC, Su VC, et al. Broadband achromatic optical metasurface devices. Nat Commun 2017;8:187.
[6] Chen WT, Zhu AY, Sanjeev V, et al. A broadband achromatic metalens for focusing and imaging in the visible. Nat Nanotechnol 2018;13:220–6.
[7] Chen WT, Zhu AY, Sisler J, et al. Broadband achromatic metasurface-refractive optics. Nano Lett 2018;18:7801–8.

Xue-Yi Zhu received his B.S. degree in College of Engineering and Applied Sciences from Nanjing University in 2015. After that, he entered National Laboratory of Solid State Microstructure of Nanjing University for Ph.D. study. His research areas include new kinds of opto-electronic materials and nanophotonics with optical gain and loss. He is also interested in photonic topological insulator and topological phase transition.

Ming-Hui Lu received his Ph.D. degree from Nanjing University in 2007. He has been an Associate professor at Nanjing University since 2009 and a Professor in 2013. During 2012 to 2013, he visited SIMES of Stanford University as a visiting scholar. His current research interests mainly focus on fundamental study of photonic and acoustic artificial structures and metamaterials as well as their related applications.