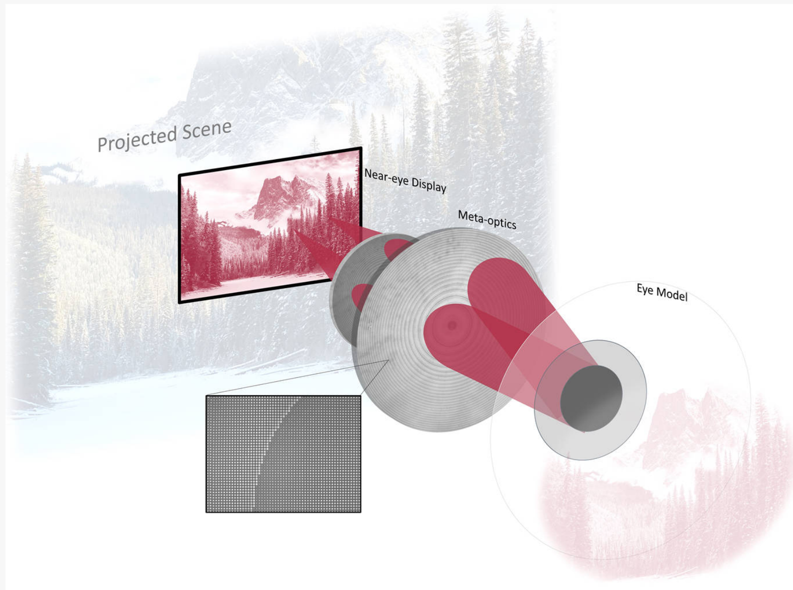
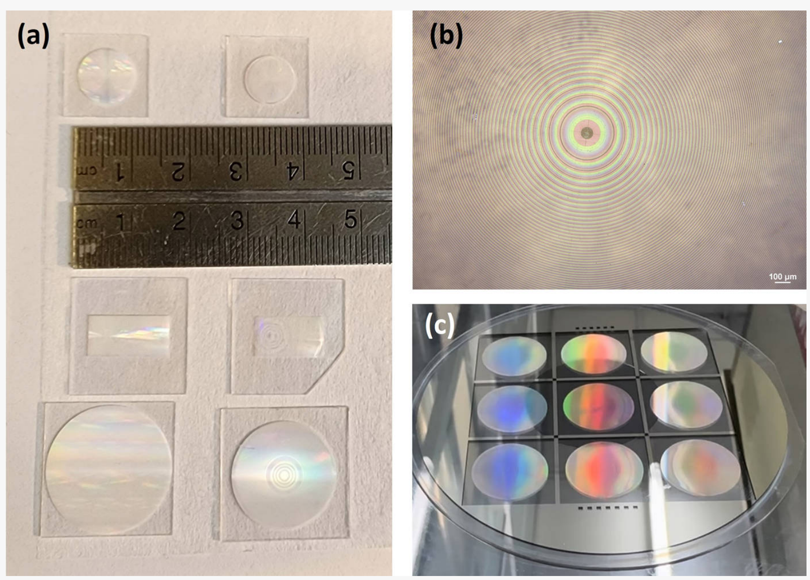
Eyepiece optics enabled by ultra-flat metasurfaces

GA, UNITED STATES, January 8, 2025 /EINPresswire.com/ -- Wide field of view and light weight optics are critical for advanced eyewear, with applications in augmented/virtual reality and night vision. Conventional refractive lenses are often stacked to correct aberrations at wide field of view, leading to limited performance and increased size and weight. In this new report, the authors demonstrate a wide field of view (greater than 60°) and large aperture (2.1 cm) eyepiece based on compact meta-optics.



Schematic Diagram of the Meta-optic Eyepiece.



Fabricated Meta-optics

Alongside advances in artificial intelligence and widespread availability of digital content, demand for augmented / virtual reality (AR / VR) near-eye displays has surged. There is great commercial interest in developing such technologies for education, gaming, and social interactions, and there is perennial defense and national security interest for improved night vision and enhanced vision technologies. The human eye is a highly optimized system, so exceptional optical performance is required to facilitate the interaction between the user and the near-eye display. At the same time, near-eye optics must be thin and lightweight for user comfort and safety. The simultaneous demand for uncompromising optical performance and compact form-factor presents a unique set of engineering challenges.

In particular, wide field of view is required in near eye displays to facilitate an immersive experience for the wearer. For reference, human vision's full field of view is approximately 120°, which exceeds the performance of most wide-angle lenses. The conventional solution to achieve wide field of view optics is to stack refractive lenses in series to correct aberrations at large field angles, which leads to a bulky and heavy optical system. Especially for near-eye optics, both size and weight are constrained; excess weight in a head-mounted system results in torque on the neck and fatigue for the user, meanwhile sufficient space between the optics and the eye must be maintained for comfort and safety.

Meta-optics have emerged as a promising technology for miniaturizing and enhancing imaging systems for a variety of applications, including compact near-eye display systems. Meta-optics consist of quasi-periodic arrays of sub-wavelength pillars that locally impart a phase shift to the light, and a global operation like steering or lensing can be achieved by arranging these pillars across a surface. Thanks to advancements in nanoscale lithography techniques, the fabrication of meta-optics at near-infrared and visible wavelengths is now regularly accomplished. However, simultaneous achievement of a large aperture (near 1 inch) and wide field of view (greater than 60°) meta-optics based eyepiece is a difficult task that has not yet been demonstrated. Firstly, fabricating large aperture meta-optics for visible wavelength applications presents a formidable practical challenge due to the high resolution (sub-100 nm) lithography required over a large surface area. Secondly, simultaneous achievement of wide field of view and large aperture is fundamentally challenging because aberrations scale with aperture and increasing angle of incidence; therefore, careful optical design involving more than one optical element is required.

In a new paper published in Light: Science and Applications, a team of researchers, led by Professor Arka Majumdar at the University of Washington and Dr. Tian Gu at the Massachusetts Institute of Technology, have designed and demonstrated a large aperture, wide field of view eyepiece based on meta-optics. The meta-optics are designed considering the realistic constraints of sufficiently large aperture (2.1 cm), pupil size (5.4 mm), and eye relief (15 mm). To simultaneously achieve large aperture and wide field of view, the design employs a doublet system consisting of two layers of meta-optics. In this system, the first optic acts as both an aperture and a corrector plate, and the second optic acts as a focusing lens. Together, the two layers of meta-optics are used to demonstrate high-quality imaging up to 60° full field of view. In a step-by-step approach, the authors first demonstrate optical performance in a 1 cm aperture prototype, and then scale up to the full 2.1 cm aperture eyepiece. There is excellent experimental agreement with the theoretical model for both sets of optics. Further, compared to a similar commercially available refractive lens eyepiece system, the meta-optic system is superior in terms of improved image quality over wide field of view at the design wavelength and reduced total track length.

In addition to the challenge of correcting optical distortions and aberrations in large aperture optics, this work also addresses the practical challenge of fabricating large area meta-optics at visible wavelengths. To achieve sub-wavelength resolution, visible meta-optics require lithography resolution on the order of 100 nm or less. Electron beam lithography is one of the highest resolution nanofabrication techniques; however, the technique is expensive and difficult to scale, making it unsuitable for commercial applications. To progress towards the goal of realizing large aperture meta-optics with commercially viable fabrication techniques, this work also presents a version of the 2 cm eyepiece doublet that compatible with mass production-friendly deep ultraviolet (DUV) stepper lithography.

This work represents promising results for the integration of meta-optics into full-scale near-eye display systems, including AR/VR and night vision. We do note, however, that this meta-optic doublet is designed for single-wavelength illumination at 633 nm. This makes it immediately suitable for monochromatic applications such as night vision, while more work is required for extension to applications requiring full color. Nevertheless, this work pushes the state-of-the-art in meta-optic design and nanofabrication techniques. With surging interest in AR / VR technologies and perennial demand for improved night vision technologies with compact form-factor, we envision that meta-optics will play an important role in the development of these technologies.

DOI
10.1038/s41377-024-01674-0

Original Source URL
https://doi.org/10.1038/s41377-024-01674-0

Funding information
Funding for this work was supported by the DARPA-ENVision program.
Part of this work was conducted at the Washington Nanofabrication Facility / Molecular Analysis Facility, a National Nanotechnology Coordinated Infrastructure (NNCI) site at the University of Washington with partial support from the National Science Foundation via awards NNCI-1542101 and NNCI-2025489.
Part of this work was performed in the UCSB Nanofabrication Facility, an open access laboratory.

Lucy Wang
BioDesign Research
email us here
