Physical chemistry

Focusing on Metalenses

by Nancy McGuire

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News stories about metamaterials tend to home in on invisibility cloaks and lenses that let you see behind an opaque object. Most of these applications are still in the conceptual realm or exist as proof-of-concept devices.

Metalenses for scientific imaging, however, are much closer to being ready for commercialization. These metalenses produce wavelength-specific images for examining the spectroscopic properties of materials. They can block or transmit polarized light to create chiral images that reveal stereochemical properties. See “How Metalenses Work”.

Seeing the very small

Federico Capasso and colleagues at Harvard University (Cambridge, MA) and the University of Waterloo (ON) demonstrated planar metalenses that focus visible light (660, 532, and 405 nm) to produce magnified images of microscopic structures. These images clearly show features as small as ≈400 nm across—better resolution than the best available commercial lenses (see video).

The authors used mature nanolithography techniques to create arrays of TiO_2 “nanofins” on glass substrates that form lenses 0.24 mm across with a focal length of 90 µm. They foresee applications for their lenses in laser-based microscopy and spectroscopy. They have filed patents and are actively looking for commercial opportunities. (*Science* DOI: 10.1126/science.aaf6644)

Multispectral chiral imaging

Capasso’s group also produced a planar multispectral chiral lens (MCHL) that simultaneously forms two images, with opposite helicities, of an object in its field of view. The chiral properties of the object can be examined across the visible spectrum by using only their lens and a camera; no polarizers or dispersive optical devices are required.

How Metalenses Work

Metamaterials’ interactions with light can be tuned mechanically or electronically by tilting, rotating, or otherwise moving nanosized surface features on demand. Because the surface features are smaller than the wavelength of incident light, they interact with these waves the way a continuous surface would.

Conventional optical devices can require complex systems of beam splitters, polarizers, waveplates, wavelength dispersive elements, filters, and cameras. These systems are expensive and bulky; and each pass through a successive component reduces the image quality and spatial resolution.

Metalenses, which can be less than a millimeter across, perform one or more of the same functions as well as, or better than, their conventional counterparts. What’s more, metalens assembly processes completely bypass the painstaking tempering and polishing steps that drive up the cost of high-quality glass lenses.

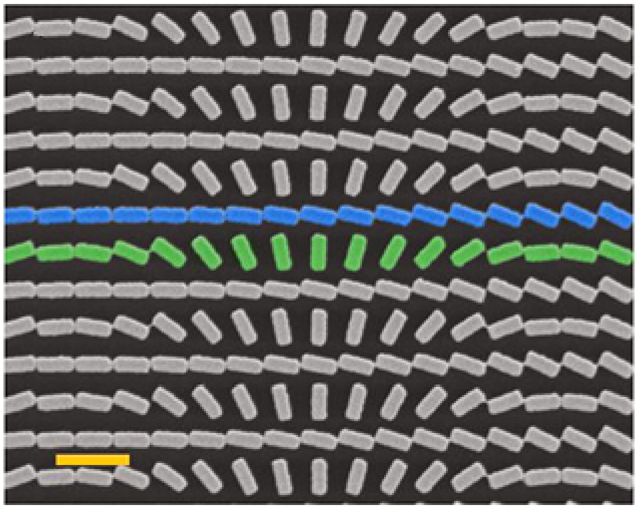

Figure 1

The authors used a one-step lithographic process to create a metasurface that integrates polarization and dispersive functionalities into one device. Its spatial resolution is limited by the MCHL's numerical aperture (the range of angles over which the lens receives and transmits light).

Figure 1 shows the top view of a lens (3 mm diam) with an array of nanofins that reflects light with the desired wavelength and polarity. The two interlaced arrays of nanofins are false-colored in blue and green. The yellow scale bar is 600 nm.

The researchers also demonstrated their MCHL by producing images of *Chrysina gloriosa*, a scarab beetle whose shell preferentially reflects left-circularly polarized light at green wavelengths. In Figure 2, the left-hand image is formed by focusing left–circularly polarized light reflected from the beetle. The right image shows the much weaker reflection from right–circularly polarized light. (*Nano Lett.* DOI: 10.1021/acs.nanolett.6b01897)

Figure 2

Holograms

Weiguo Chu, Yan Li, and coauthors at Peking University and the Collaborative Innovation Center of Quantum Matter (Beijing), the National Center for Nanoscience and Technology (Beijing), and Shanxi University (China) developed a dielectric metasurface by using nanostructures made from high–refractive index silicon nanoblocks. Three types of nanoblocks are multiplexed to form a "metamolecule" that manipulates phases for red, green, and blue light simultaneously.

Changing the in-plane orientation of the nanoblocks lets them function as narrow-band half-wave plates for non-overlapping wavelengths in a circularly polarized incident beam. This lets users manipulate the phases for each color almost independently.

The authors used three wavelengths of light to produce achromatic meta-holograms that consisted of identically sized, superimposed single-color images. They produced various colors by changing the relative intensities of the three incident beams. In Figure 3, (a) is the achromatic image and (b)–(h) are the colored images produced from it.

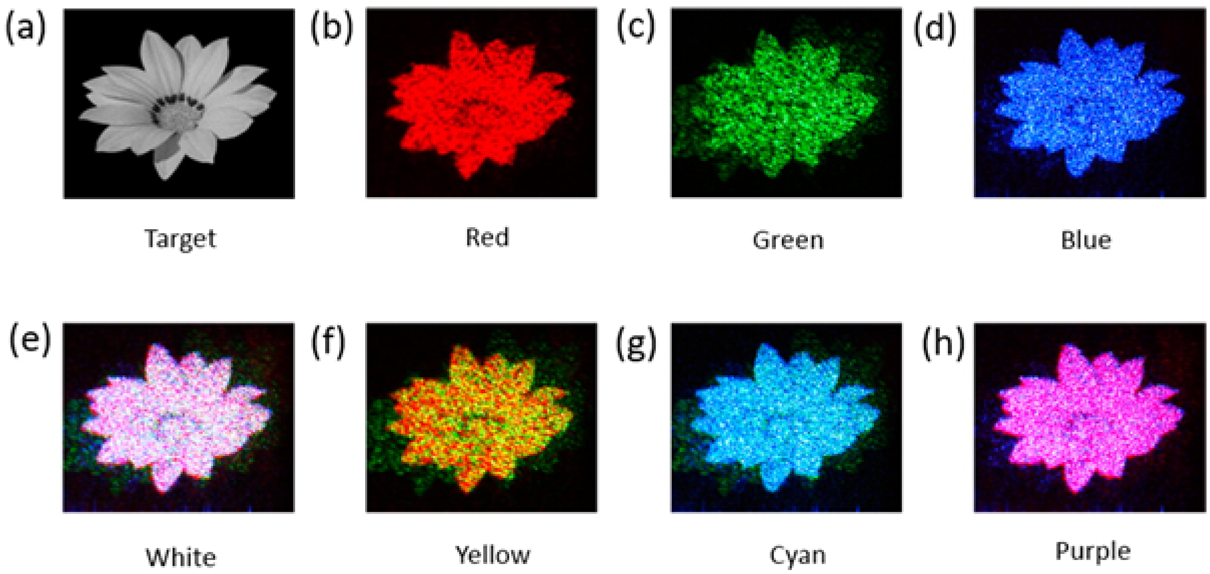

Figure 3

They also produced highly dispersive meta-holograms in which the three incident beams produced an image of a red flower with a green stem in a blue pot [(a) in Figure 4]. Images (b)–(d) are the image illuminated with only one color. (*Nano Lett.* DOI: 10.1021/acs.nanolett.6b02326)

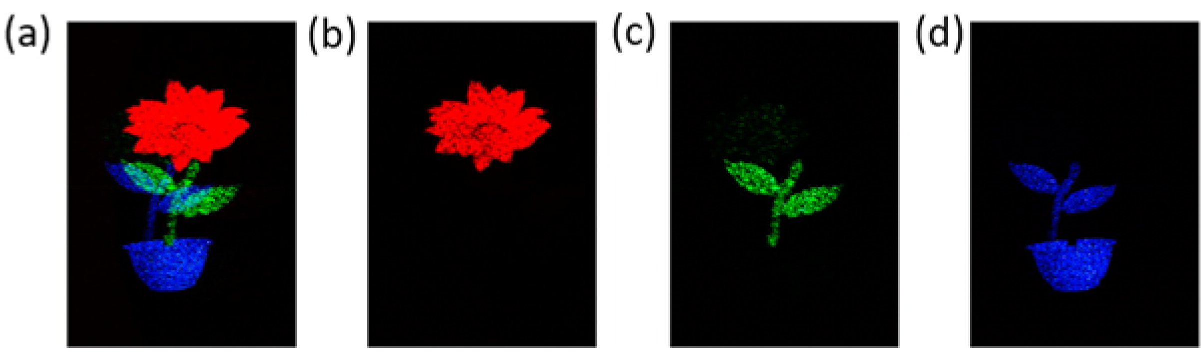

Figure 4

Expanding the focus

Other research groups are getting into the act. One developed multifocal lenses using conic-shaped resonators. (https://arxiv.org/abs/1606.09351) Another extended the useful wavelength range into the terahertz region. (*Opt. Commun.* DOI: 10.1016/j.optcom.2016.03.031)

Metalenses that minimize background scattering by selectively deactivating specific fluorophores are being developed for use in stimulated emission depletion microscopy. This technique produces optical images of protein structures at the sub-organelle level, a capability that once required electron microscopy.

And that's just the beginning. A cell phone camera equipped with a telephoto metalens could capture a touchdown pass from the nosebleed seats. Virtual- or augmented-reality headsets could clip onto a pair of eyeglasses. "Smart" contact lenses could correct several visual conditions all at once, which is less glamorous, but probably more useful than an invisibility cloak anyway.

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