

Plasmonic Computational Compound-Eye Camera

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Traditional cameras used in photography and microscopy are based on the human-eye architecture, where a lens is used to project an image of the object of interest onto a photodetector array. This arrangement can provide excellent spatial resolution, but suffers from a fundamental tradeoff between small size and large field of view (FOV), originating from aberration effects. In nature, the solution devised by evolution to address this issue is the compound eye,¹ which in fact is universally found among the smallest animal species such as insects and crustaceans.

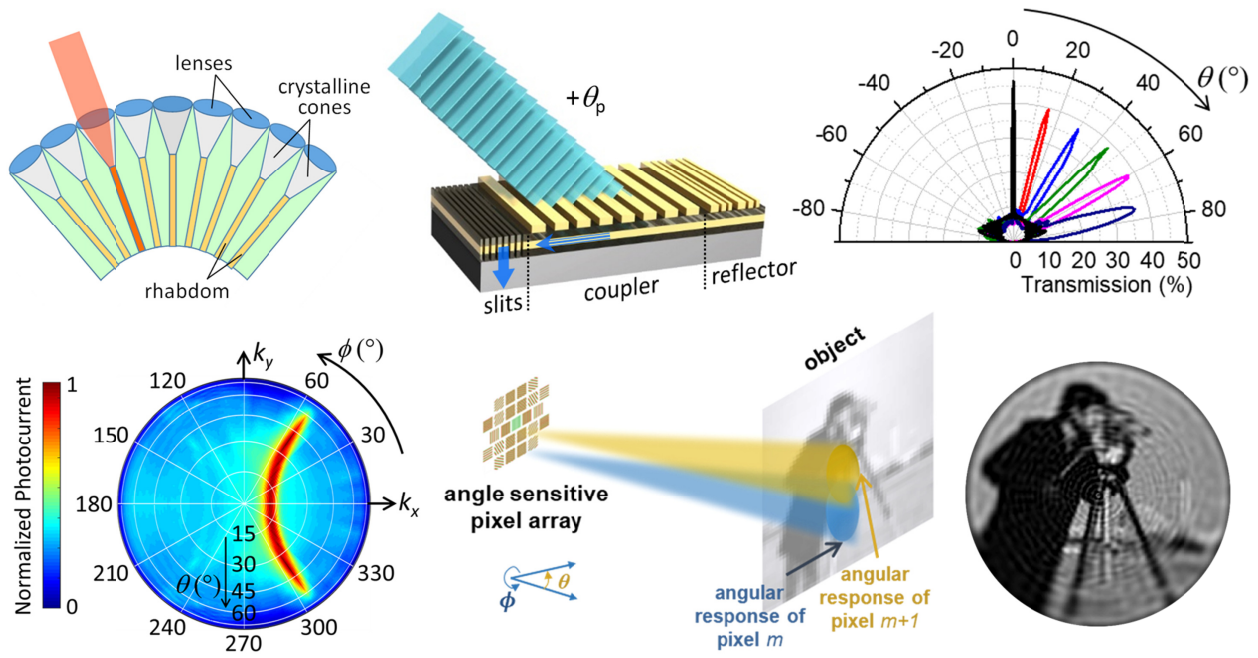
Typical compound eyes consist of a densely packed array of many imaging elements pointing along different directions. Unfortunately, their optoelectronic implementation is severely complicated by their curved geometry, which is not compatible with standard planar semiconductor technologies. As a result, it requires the development of complex nontraditional fabrication processes,^{2,3} which limit its manufacturability and achievable resolution. Planar geometries involving lenslet arrays have also been investigated,⁴ but suffer from small FOVs (under 70°) limited by the microlens f -number.

Recently, we have reported a novel compound-eye camera architecture that leverages the great design flexibility of metasurface nanophotonics and the advanced data processing capabilities of computational imaging to provide an ultrawide FOV of over 150° in a planar lensless format.⁵ In this architecture, each pixel of a standard image-sensor array is coated with a specially designed ensemble of metallic nanostructures that only transmits light incident along a small geometrically-tunable distribution of angles. Computational imaging techniques are then employed to enable high-quality image reconstruction from the combined signals of all pixels. A set of near-infrared devices providing directional photodetection peaked at different angles was designed, fabricated, and characterized, and their imaging capabilities were demonstrated based on their angular response maps.

By virtue of its lensless nature, this approach can provide further miniaturization and higher resolution compared to previous implementations, together with a potentially straightforward manufacturing process, compatible with existing image-sensor technologies. These results are significant for applications requiring extreme size miniaturization combined with ultrawide FOVs, such as chip-on-the-tip endoscopy, implantable or swallowable cameras, and drone autonomous navigation. Furthermore, they highlight the tremendous opportunities offered by the synergistic combination of metasurface technology and computational imaging to enable advanced imaging functionalities.

1. M. F. Land and D. E. Nilsson, *Animal Eyes* (Oxford University Press, 2002).

2. Y. M. Song et al. Nature **497**, 95 (2013).
3. K. Zhang et al. Nat. Commun. **8**, 1782 (2017).
4. J. Duparré, et al. Appl. Opt. **44**, 2949 (2005).
5. L. Kogos et al. Nat. Commun. **11**, 1637 (2020).



Top left: Compound eye of common arthropods. Top middle: schematic illustration of the devices developed in this work. Top right: Design simulation results showing the polar-angle dependence of the responsivity of different devices. Bottom left: Measured photocurrent of a representative device versus polar and azimuthal illumination angles. Bottom middle: Schematic illustration of the imaging geometry. Bottom right: Example of reconstructed image.