Meta-lenses bring benchtop performance to small, hand-held spectrometer

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A research team of physicists from Harvard University has developed new hand-held spectrometers capable of the same performance as large, benchtop instruments. The researchers' innovation explained this week in *APL Photonics*, derives from their groundbreaking work in meta-lenses. The hand-held spectrometers offer real promise for applications ranging from health care diagnostics to environmental and food monitoring.

Spectrometers are instruments that are widely used to quantify the presence of various biological or chemical compounds based on their interaction with light. However, to be a practical tool for users, such as physicians at the bedside or food-safety inspectors out in the field, spectrometers have to be portable, low-cost and easy to use without specialized equipment or training. Typically, however, there is an inherent trade-off between the size and performance of the spectrometer. To maintain performance while reducing spectrometer size, this team of researchers has developed a spectrometer incorporating meta-lenses that combine the functionalities of a traditional grating and focusing mirror into a single component, as well as having much greater ability to spatially separate wavelengths (the so-called dispersion). In all, the overall size of the spectrometer is significantly reduced without sacrificing performance.

"This research has its roots all the way back to 2011, when we were investigating the fundamental properties of light as it interacts with two dimensional metamaterials (metasurfaces) and discovered generalized laws for the refraction and reflection of light for metasurface, which are

powerful generalizations of the textbook laws valid for ordinary surfaces," explained Federico Capasso of Harvard.

Unlike traditional refractory lenses that are millimeters thick and have a characteristic curved surface, a meta-lens is a completely flat or planar lens made up of millions of nanostructures. Using lithographic techniques, proper placement and fabrication of these nanostructures enables similar or better functionalities compared to traditional lenses. These meta-lenses can be customized to a user's specifications, and mass-produced using the same foundries that produce computer chips. "For these reasons, we believe meta-lenses to be game-changers," Capasso said. "In fact, our work on metalenses in the visible, published last year, was hailed by Science magazine as one of the top breakthroughs of the year in 2016."

"The potential applications of these new smaller spectrometers are significant for portable monitoring of biological and chemical compounds" said Alex Zhu, lead author of the paper. "For example, physicians could bring hospital-level diagnostic capabilities to patients in the field where sophisticated equipment and highly trained personnel are not available, providing data on a timescale of minutes to hours, as opposed to days or weeks from usual chemistry-based methods." The same is true for environmental monitoring: Data about pollutants, or toxic chemicals could be collected and processed in real time on site at various locations with ultra-compact, high performance spectrometers.

The next step toward realizing the full potential of these meta-spectrometers is to improve the performance of the prototype for both the working wavelength range and spectral resolution. This would allow it to be used for a wide variety of analyses, including highly specialized ones to identify proteins or gene markers (Raman spectroscopy), which typically involve onerous processes with sophisticated equipment in a full-size laboratory.

"The goal is to be able to achieve comparable levels of performance with a simple 'plug-and-play' two-component device, i.e., a meta-lens and a detector, which together function as a meta-spectrometer," Zhu said. "The potential for this already exists in the meta-lens technology; it is simply a question of finding the right configurations and making it work."

More information: Alexander Y. Zhu et al. Ultra-compact visible chiral spectrometer with meta-lenses, *APL Photonics* (2017). DOI: 10.1063/1.4974259

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