'Quasiparticles' reveal incredibly minute distortions in light waves

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Optics researchers have discovered a new way to measure incredibly small distortions in light waves by indirectly studying the behavior of curious 'quasiparticles' - ripples in the electric field that emerge when light and solid surfaces interact. This new technique holds significant promise for applications in metrology and chemical sensing, as well as potential improvements in adaptive optics for microscopy and biomedicine.

As light travels through turbulent materials - water, the atmosphere, and even human tissue - the wavefronts become distorted, blurring images and reducing resolution. It's possible to correct for these distortions by precisely measuring the shape of the wavefront.

Astronomers routinely make such measurements for adaptive optics, but only for relatively large-scale fluctuations. On much finer scales - down to the nanoscale - these measurements are beyond the capabilities of normal wavefront sensor technology.

Researchers Brian Vohnsen and Denise Valente, University College Dublin, Ireland, have found a way to overcome these limitations and measure the wavefront distortions of light with a precision never before achieved.

Their breakthrough sensor technology is based on a curious phenomenon: a quasiparticle that emerges when light waves couple with the electrons' oscillations of certain solid surfaces. By measuring how efficiently incoming light creates these quasiparticles, the researchers are able to derive previously undetectable distortions in the wavefronts.

"I am excited about the new sensor because it enables new pathways for nanoscale sensitivity for a whole host of applications," said Vohnsen. "These amazingly fine measurements make it possible to extract wavefront information right at the point where air, light, and surfaces interact."

The results of this research are published today in The Optical Society's high-impact journal *Optica*.

Quasiparticles Reveal the Shape of Light

Currently, measurement of the shape of a wavefront of light is done with devices known as wavefront sensors. They work in one of two ways. The first is by studying the interference patterns of light, but that approach requires the extra step of ensuring that the interacting light waves are in phase - meaning their waveforms overlap precisely.

The other method is to mechanically sample the wavefronts: for example, with an array of microlenses.

Though extremely efficient for applications like adaptive optics, which enable telescopes to reduce the apparent blurring of the Earth's atmosphere, these systems are relatively bulky and are blind to distortions on very fine scales.

To reach new levels of precision, the researchers considered using the well-studied resonance behavior of quasiparticles known as surface plasmon polaritons (SPPs), which respond to even extremely small-scale wavefront distortions. SPPs arise when light meets an electrically conducting surface at a specific angle. At the point where they interact, electrons oscillate, forming a wave-like pulse that travels across the surface. Just as light can be described in some cases as a particle and a wave, so too can these SPPs, which is why scientists refer to them as quasiparticles.

"Since these polaritons are perfectly coupled to the light that forms them, any changes in their behavior would indicate a change in the waveform of light," said Vohnsen.

Measuring Minute Changes

The researchers first direct the wavefront to be measured onto a gold film sensor. The strength with which SPPs are formed depends on the angle the light meets the sensor. Any changes in that angle, as would occur from a distortion in the wavefront, would affect the way the SPPs are formed. This then directly effects how much light is reflected back from the surface.

It is this change in reflected intensity that the researchers measure. "We make use of the attenuation of the signal from the gold surface to simply convert the wavefront shape - or slope - into an intensity difference in a beam of light," explained Vohnsen. This change is easily captured with cameras that are sensitive to very minute changes in intensity.

To fully reconstruct the wavefront, the system requires two separate measurements made at 90 degrees to one another. It is then possible to use basic mathematical calculations to determine the tiny changes in the actual wavefront based on these two, orthogonal intensity data points. The speed of the measurement is therefore only limited by the speed of the cameras.

This method is a significant improvement over using interference patterns for wavefront sensing because the wavefront changes are captured directly, producing the potential to greatly increase the speed with which measurements can be made. It also samples the wavefront continuously across the entire beam, creating a higher resolution result than can be achieved with a microlens array.

Though SPPs are well studied, they have yet to be harnessed for actual technologies in any broad fashion. "They are currently used to enhance certain weak signals in spectroscopy and for the development of compact optical components known as integrated optical/plasmonic interconnects," observed Vohnsen. "Our method may be the first to use surface plasmons to address a classical optics problem such as the detection of aberrations."

Vohnsen and Valente speculate that this type of sensor may find applications in the quality inspection of planar materials, films, and coatings. It could possibly replace some of the other wavefront sensors currently used in astronomy, microscopy and vision science.

The researchers are working to overcome two limitations in the current setup. The first is the requirement for simultaneous measurement of wavefront changes with two cameras. The second is improving the method by which the SPPs are "excited" on the surface of the gold film.

"These additional enhancements will help bring this frontier study in optics to an actual technology that has significant real-world applications," concludes Vohnsen.

More information: "Surface-plasmon-based wavefront sensing," Brian Vohnsen, *Optica*, Vol. 02, Issue 12, pp. 1024-1027 (2015). DOI: 10.1364/OPTICA.2.001027