Surfing a wake of light

Researchers observe and control light wakes for the first time

By Leah Burrows | July 6, 2015

When a duck paddles across a pond or a supersonic plane flies through the sky, it leaves a wake in its path. Wakes occur whenever something is traveling through a medium faster than the waves it creates — in the duck's case water waves, in the plane's case shock waves, otherwise known as sonic booms.

Wakes can exist wherever there are waves, even if those waves are light. While nothing travels faster than the speed of light in a vacuum, light isn't always in a vacuum. It is possible for something to move faster than the phase velocity of light in a medium or material and generate a wake. The most famous example of this is Cherenkov radiation, wakes produced as electrical charges travel through liquids faster than the phase velocity of light, emitting a glowing blue wake.

For the first time, Harvard researchers have created similar wakes of light-like waves moving on a metallic surface, called surface plasmons, and demonstrated that they can be controlled and steered. The discovery, published today in the journal **Nature Nanotechnology**, was made in the lab of **Federico Capasso**, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering at the **Harvard John A. Paulson School of Engineering and Applied Science** (SEAS).

"The ability to control light is a powerful one," said Capasso. "Our understanding of optics on the macroscale has led to holograms, Google Glass and LEDs, just to name a few technologies. Nano-optics is a major part of the future of nanotechnology and this research furthers our ability to control and harness the power of light on the nanoscale."

The creation and control of surface plasmon wakes could lead to new types of plasmonic couplers and lenses that could create two-dimensional holograms or focus light at the nanoscale.

Surface plasmons are confined to the surface of a metal. In order to create wakes through them, Capasso's team designed a faster-than-light running wave of charge along a one-dimensional metamaterial — like a powerboat speeding across a lake.

The metamaterial, a nanostructure of rotated slits etched into a gold film, changes the phase of the surface plasmons generated at each slit relative to each other, increasing the velocity of the running wave. The nanostructure also acts like the boat's rudder, allowing the wakes to be steered by controlling the speed of the running wave.

The team discovered that the angle of incidence of the light shining onto the metamaterial provides an additional measure of control and using polarized light can even reverse the direction of the wake relative to the running wave — like a wake traveling in the opposite direction of a boat.

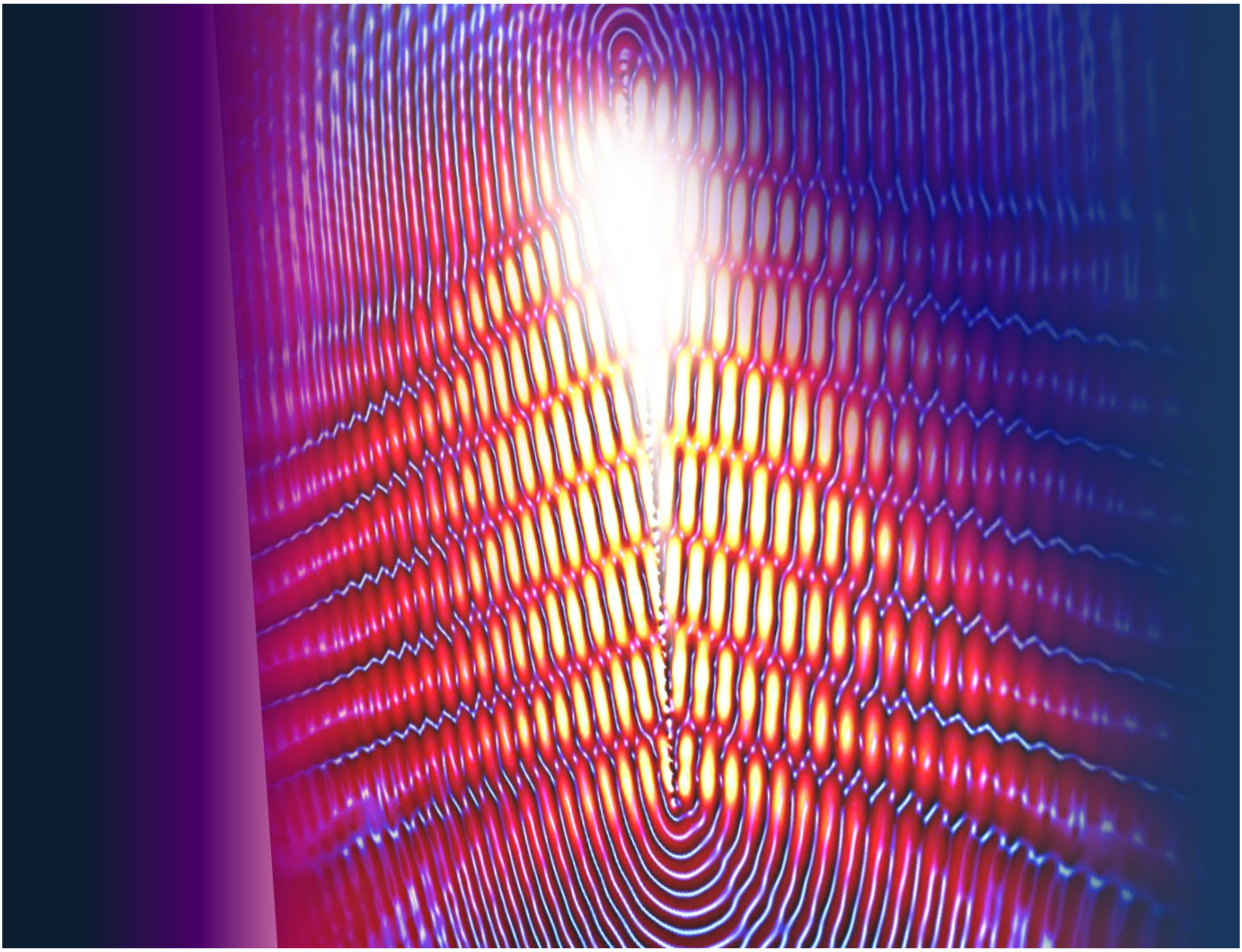
"Being able to control and manipulate light at scales much smaller than the wavelength of the light is very difficult," said Daniel Wintz, a lead author of the paper and graduate student in the Capasso lab. "It's important that we not only observed these wakes but found multiple ways to control and steer them."

The observation itself was challenging, as "surface plasmons are not visible to the eye or cameras," said co-lead author Antonio Ambrosio of SEAS and the Italian Research Council (CNR). "In order to view the wakes, we used an experimental technique that forces plasmons from the surface, collects them via fiber optics and records the image."

This work could represent a new testbed for wake physics across a variety of disciplines.

"This research addresses a particularly elegant and innovative problem in physics which connects different physical phenomena, from water wakes to sonic booms, and Cherenkov radiation," said Patrice Genevet, a lead author, formerly of SEAS, currently affiliated with the Singapore Institute of Manufacturing Technology.

This paper was co-authored by Alan She, of SEAS and Romain Blanchard, of SEAS and Eos Photonics. This research was supported by the National Science Foundation and the Air Force Office of Scientific Research.



Artistic rendition of the superluminal running wave of charge that excites the surface plasmon wakes. Credit: Daniel Wintz, Patrice Genevet, and Antonio Ambrosio.

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