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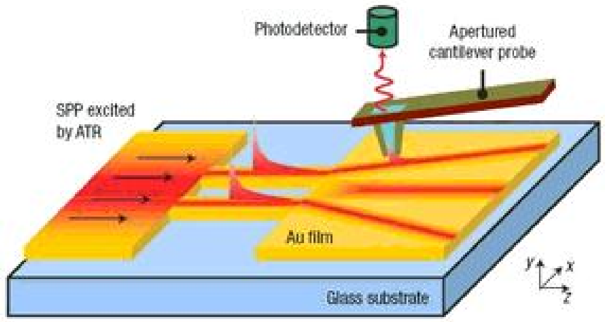
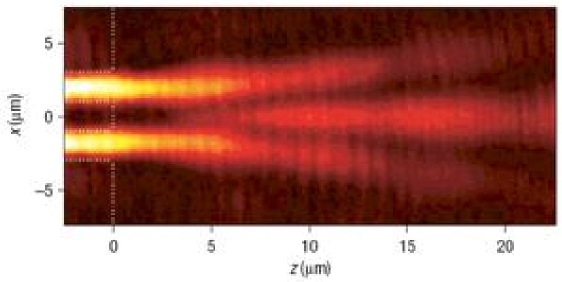
# Understanding light at the nanoscale: a nano-sized double-slit experiment



Experimental configuration of the SPP double-slit experiment. SPPs excite the polariton modes on the metal waveguides (“slits”). The probe taps into the SPP waves and scatters the light toward a photodetector. Image credit: Rashid Zia and Mark Brongersma. ©2007 Nature Publishing Group.

**Before nanotechnology can reach its full potential, researchers must understand the way things work on the nanoscale—which is often very different from the macroscopic world. One of these areas is light, and how light interacts with matter on tiny scales.**



PSTM image of SPP polariton interference. Image credit: Rashid Zia and Mark Brongersma. ©2007 Nature Publishing Group.

Recently, Stanford University researchers Rashid Zia (now with Brown University) and Mark Brongersma have investigated light on the nanoscale with an adaptation of one of the most familiar optics tests: the double-slit experiment. The test described the propagation, interference, diffraction, and a possible diffraction limit of a type of electromagnetic wave called a surface plasmon polariton.

Surface plasmon polaritons, or SPPs, occur on the surface of a metal film when struck by a light wave. Because SPP waves run parallel to the metal film, they can help to enhance the surface sensitivity for spectroscopic measurements that use light scattering techniques. Other potential uses of this technology—known as “plasmonics”—include the ability to confine light to very small dimensions, control the colors of materials, and transmit information on a computer chip.

However, before these applications can be realized, researchers must understand the fundamentals of the interaction of light and matter on the nanoscale. To do so, Zia and Brongersma designed a version of the 19th century double-slit experiment first used by Thomas Young to detect interference patterns of light waves. (Today the experiment is most famously known in quantum mechanics, where single particles such as atoms or photons also exhibit wave-like interference.)

“The experiments have shown that carefully engineered structures are needed to manipulate light at the nanoscale,” Brongersma told *PhysOrg.com*. “However, such structures do exist and enable new devices to be realized and interesting fundamental studies on the nature of light at the nanoscale. It is exciting to think about the possibilities. Every application where light is used can now potentially be miniaturized with plasmonics, and experiments can be performed at smaller length scales. With conventional (dielectric), lenses we were never able to explore the nanoscale with light or the nature of light at the nanoscale.”

In their study, Zia and Brongersma created a slightly different version of Young's original experiment. Two gold stripes protruding on a 48-nm-thick gold film, which served as waveguides for the SPPs, played the role of the traditional two slits. The stripes' dimensions—each 2 micrometers thick and separated by a gap of 2 micrometers—were important because, as waveguides, they support only the lowest-order SPP mode (called a "quasi-transverse magnetic leaky mode").

The researchers used a photon scanning tunneling microscope (PSTM) to visualize the SPP propagation by scanning the tip over the metal structure. In a sense, this microscope played the role of the screen located at a fixed distance from the slits, where observers view the interference pattern. In contrast, the PSTM had the ability to image the flow of SPPs over the metal structure.

When put in action, an optical evanescent wave was used to launch SPP waves along the surface of the gold. As the SPPs traveled along the waveguides, they excited specific polariton modes in the stripes, enabling these waves to propagate only along these stripes. Further along above the patterned film, an apertured cantilever probe scattered the waves toward a photodetector, which measured the local field intensity and enabled imaging of the diffraction pattern by scanning the surface.

Zia and Brongersma's results closely resembled the interference pattern of Young's double-slit experiment. Like macroscopic light waves, the pure SPPs exhibited an interference pattern where the two diffracted beams overlap. These experimental results also closely correlated with the researchers' simulations.

The experiment may also help to settle a subject of contention among scientists, by giving support to the idea of an effective diffraction limit for the lateral confinement of SPPs on metal stripe waveguides. In other words, some SPP wave modes will be too small to exhibit interference on a metallic waveguide. The researchers explain that this limit will have important implications for how photonic systems can interface with electronic devices, which can have deeply sub-wavelength dimensions.

"Nanoscale photonic systems will have to rely on more strongly confining SPP waveguides that exhibit a deep subwavelength optical mode," Brogersma explained. "The notion of a diffraction limit for stripe waveguides is not in disagreement with the existence of such strongly guiding SPP waveguides that allow for short distance information transport with nanoscale optical modes/beam diameters. It would have been great if metal stripes on a substrate would have guided light (SPPs) below the diffraction limit, as such structures resemble metallic interconnects that currently carry electronic signals on a chip."

This ability of some metallic (plasmonic) waveguides to guide light well below the diffraction limit, however, is unique to metal structures and impossible to attain in dielectric waveguides or optical fibers.

"Despite this substantial difference [between light at the nanoscale and at the macroscale], it turns out that light propagating in dielectric waveguides exhibits a lot of similarities to light (SPP) propagation along the surface of metallic structures," Brongersma said. "The similarities can be exploited to help the design of new plasmonic components by leveraging decades of work on dielectric structures."

Brongersma added that some of these devices may include plasmonic sources, modulators, transistors, and detectors that operate at the nanoscale.

Citation: Zia, Rashid, and Brongersma, Mark L. "Surface plasmon polariton analogue to Young's double-slit experiment." *Nature Nanotechnology*, Vol. 2, July 2007, doi:10.1038/nnano.2007.185.