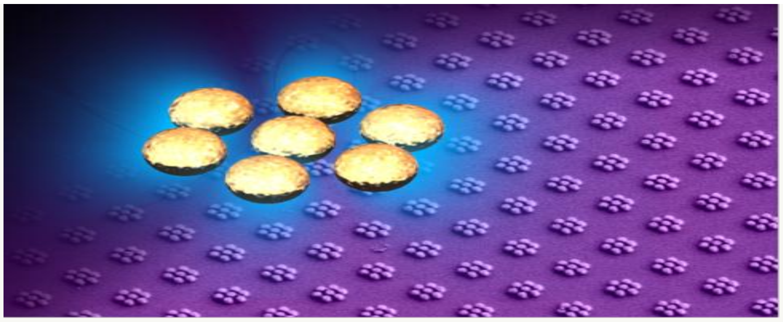
THE DARK SIDE OF PHOTONICS



Gold heptamer structures show strong Fano resonances. The gold nanoparticles are only about 150 nanometers in diameter. (c) Sven Hein, Na Liu, Harald Giessen, University of Stuttgart, Germany.

Photonics is all about light. Processing of light for applications ranging from holograms and displays to optical telecommunications. Thanks to a better theoretical understanding and to advances in fabrication technology, photonic devices and gadgets have become increasingly versatile and powerful.

But photonics also has a dark side. In many light-processing devices and structures there are dark modes — oscillations of the light wave that while not forbidden cannot be directly excited by a given experimental configuration. In a violin for example, the strings are best sounded by drawing the bow perpendicular to their length.

However, the dark modes in photonic devices are not lost to applications. In the past months, researchers have developed new approaches that can make use of the dark modes by using interference effects with the allowed, bright modes. The resonances created by this interference are called Fano resonances, after Ugo Fano who first described them in 1961.

“Fano resonances are cool because they are the manifestations of dark modes that cannot be excited directly. In any system there are only a few bright modes but an infinite number of dark modes. The Fano resonance is the interference between a bright mode and one of the dark modes,” explains Peter Nordlander, a physicist from Rice University in Houston, Texas.

Fano resonances are very sharp, with a spectral shape that is much narrower than what can be achieved with comparable regular oscillators and their Lorentzianlineshape. This advantage makes them attractive for sensing applications. Because the spectra of Fano resonances are so narrow, the tiniest changes to the local environment of the resonator structures lead to noticeable shifts of the resonance wavelength. Even the presence of a single molecule could be detected.

There are many possibilities to create Fano resonances. One is the use of metamaterials. Metamaterials are patterned on a scale smaller than the oscillations of light. In the visible, light has wavelengths roughly between 400 nm and 800 nm. Therefore, metamaterials in the visible are made from resonators, small ring structures and wires that each of them is only a few tens of nanometers in size. These resonators can couple to the dark modes and show Fano resonances. The Fano resonances of metamaterials are very sensitive to changes in their surrounding. One atomic layer of carbon is sufficient, says Nikolay Zheludev from Southampton University in the UK: “we found that applying one layer of graphene changes the light transmission of metamaterials at the Fano line by a factor of 4!”

The advantage of using Fano resonances in metamaterials is their versatility and their large variety of potential uses (such as invisibility cloaking, imaging). Fano resonances could tie into those properties. On the other hand, metamaterials with such complex functionality typically require a larger amount of individual resonator structures, and are therefore comparatively large.

An alternative is to use only a single resonator. For this, Nordlander and colleagues have proposed heptameres made from an assembly of seven gold nanoparticles. Gold nanostructures are known for their unusual interactions with light due toplasmonic effects. Even Romans artists unwittingly used the scattering of light from gold nanoparticles. An often cited example is the famous Lycurgus Cup, whose glass appears green unless held against light, when the gold nanoparticles dispersed in it scatter some of the light and the cup looks red.

The predicted Fano resonances in heptamer resonators have been realized experimentally a few weeks ago by a collaboration that amongst others includes Nordlander, Naomi Halas also from Rice University, and Federic Capasso from Harvard University. In parallel, Harald Giessen from the University of Stuttgart in Germany and colleagues achieved similar results in gold nanostructures defined by a lithographic process (see Figure).

The Fano resonance of a single heptamer structure is highly sensitive to the presence of even the tiniest presence of foreign molecules, says Giessen: "Fano resonance spectra can be obtained from single nanostructures. This allows sensing volumes of attoliters [10^{-18} liters] at zeptomolar [10^{-21} mol] concentrations. Even single molecular events should be detectable."

There is of course still a long way ahead before devices that make use of Fano resonances can make it into commercial sensing apparatus. The requirements for sensing devices are stringent in terms of repeatability and robustness of the devices. But this is only the beginning says Stefan Maier, a physicist from Imperial College London, who is working on plasmonic nanostructures. "The whole field of Fano resonances in nanosystems is a beautiful example of the possibilities of designer nanotechnology. We've come a long way from the red glasses from Roman times."

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