

Science Publication

The orbital angular momentum of plasmons caught on video

Transmitting huge volumes of data and even moving matter using light: these are two of the visions that physicists working in the field of plasmonics have for the future. In a collaboration with colleagues from Haifa (Israel), Kaiserslautern and Stuttgart, Scientists at the Center for Nanointegration (CENIDE) at the University of Duisburg-Essen succeeded in producing nanometer-sized plasmon swirls on a metal surface, filming the cycles at 100 attosecond intervals.

The image on the screen looks like a tiny version of a spiral galaxy. In reality, the images resemble the spiralling motion of a light-stimulated electron wave (plasmon) on a metal surface, recorded as individual images at virtually incomprehensible time-intervals of 100 quintillionths of a second.

To make it possible to observe the motion of the spiralling plasmons in space and time required a concerted effort of the four involved research groups. Researchers from the University of Stuttgart fabricated small monocrystalline gold ‘islands’ on silicon substrates and carved Archimedean spirals into them, using focused ion beam lithography. If such spirals are illuminated with a femtosecond laser pulse, plasmon waves are excited at the spiral, adopt the shape of the spiral, and, in time, propagate towards the spiral’s center.

For imaging of the propagating plasmon waves, the scientists employed time-resolved two-photon photoelectron microscopy (2PPE PEEM). This advanced surface microscopy technique is mastered by only a handful of research groups around the world, amongst them the groups in Kaiserslautern and Duisburg-Essen. The time-resolution of the experiment is accomplished via a pump-probe scheme: an initial (pump) femtosecond laser pulse starts a plasmon wave at the spiral, and a second, time-delayed (probe) femtosecond pulse is used to image the plasmon wave by exploiting constructive and destructive interference between plasmon and laser pulse. If the time interval between pump- and probe pulses is systematically increased in steps of approximately 100 attoseconds, the resulting images can be combined to create a super-slow motion movie of the spiralling plasmons.

The researchers found that two plasmons with different wavelengths could be excited — one propagated on top of the gold surface, while the other was located at the interface between the gold and the silicon substrate.

The lower spiral had a significantly shorter wavelength (180 nm) than its counterpart on the top (780 nm) and was the focus of CENIDE physicist Prof. Frank Meyer zu Heringdorf’s team from the University of Duisburg-Essen. The small size of the spiral opens up new possibilities for optical applications, where the smallest possible wavelengths are required in order to overcome the diffraction limit of light. Also, the use of circularly polarized laser pulses, in conjunction with the spiral shape, created a plasmon wave with orbital angular momentum. It is the first time, that the spiralling motion of a plasmon wave with such orbital angular momentum has been “filmed” in slow motion.

One possible application of orbital angular momentum is the fast and reliable transmission of large volumes of data via fiber optic cables. “We are also already considering how to move matter,” reveals Meyer zu Heringdorf. “This would require particles positioned in the centre of the spiral that would absorb the angular momentum.” Then a light pulse could be enough to rotate a nanoparticle.

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