Sensitive spectrometers for material analysis

Electron paramagnetic resonance (EPR) is an important tool in science, enabling researchers to gain deeper insights into the structure and function of different materials, yet classical methods have relatively low levels of sensitivity. The PETER project is developing a new, more sensitive method to analyse species and materials at a microscopic level, as Professor Tomáš Šikola explains.

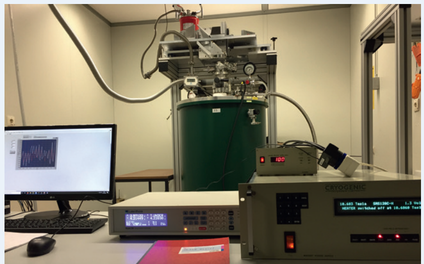
A plasmon can be thought of as a type of quasiparticle related to the oscillations of free electrons in a metallic material, where light causes the oscillations of those electrons. When electrons oscillate inside a metal, then the radiation related to it is highly concentrated in the immediate vicinity of those metallic particles. "There is a very high electromagnetic field in this tiny area," explains Tomáš Šikola, a Professor of Applied Physics at Brno University of Technology (BUT) and leader of the research group "Fabrication and Characterisation of Nanostructures" at CEITEC BUT in the Czech city of Brno. This means it is in principle possible to get more information about a material's properties through enhancing the local magnetic field component of this radiation, a topic at the heart of the PETER project, in which Professor Šikola and his colleagues are developing a new micro-spectrometer instrument. "The magnetic near-field component is enhanced by plasmons, then we can get information just from small areas in the vicinity of those particles," he says.

Plasmonic antennas

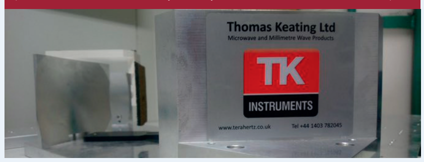
This capability is built on the use of resonant microstructures, or plasmonic antennas, which help to intensify the magnetic component of terahertz electromagnetic radiation in the vicinity of metallic particles and so significantly improve sensitivity. The electro-magnetic field is enhanced when the dimensions of these plasmonic antennas are closely related to the wavelength of the electromagnetic radiation. "We fabricate these microstructures by either electron beam lithography, or optical lithography," outlines Professor Šikola. It's important here to tune the microstructures to a high level of precision, as Professor Šikola says there is a relationship between the resonant wavelengths and the dimensions of the structures. "We can simulate those structures using numerical methods, and we can establish relatively clear relationships," he continues. "Once we come to fabricate the microstructures, we can be confident that the resonance is as we expected."

These resonant microstructures – plasmonic antennas – are then fabricated on planar substrates for EPR spectroscopy applications. "If we manage to fabricate one antenna on a probing tip of a specially developed atomic force microscope (AFM), then we can use the EPR methods for microscopic investigation of analytes with a spatial resolution deep below the diffraction limit (≈ 1μm). And this would be a real breakthrough in this EPR field" Tomáš Šikola adds.

The wider aim in this research is to develop a new, more sensitive method of analysing paramagnetic species and materials, with the project bringing together four partners from across Europe (BUT, Univ. of Stuttgart, IC nanoGUNE, and Thomas Keating Ltd.) with different areas of expertise. While CEITECs role in the project has primarily centred around the development of plasmonic antennas and the AFM system, Professor Šikola is very much aware of the wider potential of a more sensitive micro-spectrometer with improved spatial resolution. "It could be used for example to analyse batteries, for understanding the function of catalytic centres, while there are also potential applications in quantum computing," he says. Researchers are working to develop the instrument further to a point where it can eventually be commercialised. "We would like to offer our prototype to the Electron Paramagnetic Resonance (EPR) community. Our prototype is currently ready in Stuttgart," says Professor Šikola.



Prototype of the developed instrument for Plasmon Enhanced THz EPR spectroscopy and microscopy installed in Stuttgart (Bottom: a view of THz quasi-optics used in the instrument)



The electromagnetic field is **enhanced by plasmons,** then we can get information just from small areas in the vicinity of those particles.

A number of tests still need to be conducted before the prototype can be made available more widely, but the idea is very much on the agenda, with researchers aiming to bring it to a technology readiness level (TRL) of 5 or 6. This would represent an important step towards producing an off-the-shelf machine available to the EPR community. "This is a major driving force in the project," stresses Professor Šikola.

PETER

Plasmon Enhanced Terahertz Electron Paramagnetic Resonance

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