<u>Press Release</u>

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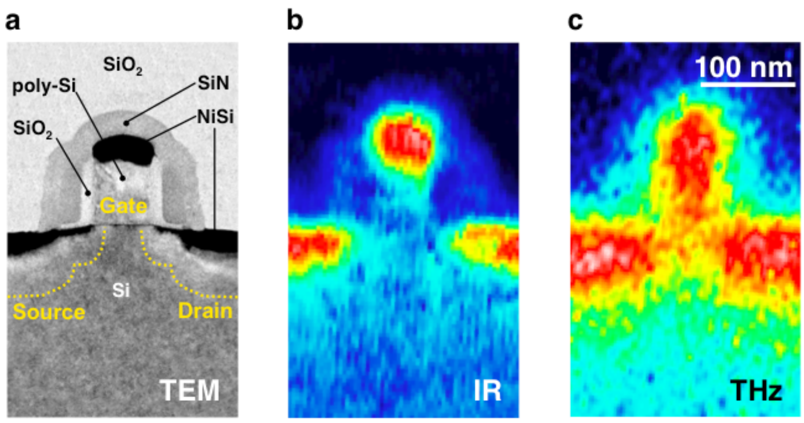
Terahertz Goes Nano

A forthcoming report in *Nano Letters* describes a breakthrough in modern microscopy: the achievement of extremely high-resolution imaging using light in the Terahertz (THz) region (wavelengths between 30 and 1000 µm). Contrary to textbook wisdom, the unusually long illuminating wavelength of 118 µm did not at all preclude researchers from the Max-Planck-Institute of Biochemistry (MPIB) to resolve details as small as 40 nm (= 0.04 µm). This was made possible by the use of extreme THz field concentration at the sharp tip of a scanning atomic force microscope (AFM). The THz nanoscope thus breaks the diffraction barrier by a factor of 1500, and with its 40 nm resolving power matches the needs of modern nanoscience and technology. As a first application, the researchers demonstrate the mapping of free-carriers in state-of-the-art industrial transistors of the 65 nm-technology.

The MPIB team had pioneered near-field microscopy both at both visible and infrared frequencies over the last decade, enabling nanoscale resolved chemical recognition of nanostructured materials. Only recently they realized, when imaging semiconducting nanostructures of state-of-the art processor chips, the importance of using far-infrared or THz radiation (the 118 µm wavelength radiation corresponds to 2.5 THz). THz illumination offers a 100-fold increased sensitivity to the conductivity of semiconducting materials when compared to infrared light. This extreme sensitivity is difficult to achieve by any other optical microscopy technique, rendering the described microscopy technique highly desirable for quality assurance and analysis of failure mechanisms in industrially produced semiconductor nanodevices.



THz near-field image (right) of a single industrial transistor structure of the 65 nm technology (Infineon AG) reveals the central device components source, drain and gate and also visualizes the distribution of mobile carriers below the metallic NiSi contacts. For comparison, a TEM image (left) and an infrared near-field image (middle) of the transistor show the metallic NiSi contracts but not the mobile carriers.

An external theory collaborator (Javier Aizpurua, Donostia International Physics Center, Spain) joined the MPIB team to help predicting that indeed the long-wavelength THz radiation would develop a highly concentrated field right at the end of the scanning tip. With this assurance, the MPIB team set out to illuminate their home-built near-field microscope with 2.5 THz radiation from a gas laser. Doctoral student Andreas Huber succeeded to record the first THz images with 40 nm resolution. In collaboration with Infineon Technologies AG (Jesper Wittborn, München) he applied the new microscopy technique to characterize state-of-the-art transistors of the 65 nm-technology that before had been inspected with a transmission electron microscope (TEM). Comparing THz and TEM images of the transistors, the researchers could demonstrate that all major parts of the transistor (source, drain and gate) can be seen in the THz image. Strikingly, the THz images reveal mobile carrier concentrations around $10^{18}cm^{-3}$ (that is one mobile carrier for each 100,000 Si atoms) which are essential for functional transistor devices. Mobile carriers are a central key for the practical transistor functionality but unfortunately they are not directly visible in TEM.

Hitherto, no powerful metrology tools are available allowing for simultaneous and quantitative mapping of both materials and carrier concentrations with nanoscale resolution. Therefore, the added values of seeing and even quantifying conducting carriers opens an enormous application potential for the THz near-field microscope. In fundamental physics research of conducting materials, the non-contact, non-invasive and quantitative mapping of mobile carriers with nanoscale resolution should trigger crucial insights into open scientific questions from the areas of superconductors, low-dimensional conductors, and correlated conductors. "After 40 years of THz research in three Max-Planck-Institutes I am now looking forward to THz nanoscopy solving basic conduction puzzles such as superconductivity" says Fritz Keilmann. THz nanosopy could be furthermore an interesting tool for chemical and structural analysis of compounds and biological systems, as THz radiation is also highly sensitive to vibrations of crystal lattices and molecules. "Future improvements of our technique could allow for THz characterization of even single nanocrystals, biomolecules or electrons" says Rainer Hillenbrand, leader of the Nano-Photonics Group at MPIB and the Nanooptics Laboratory at the newly established nanoGUNE research center (San Sebastian, Spain).

The demonstrated achievement is the direct outcome of a research plan subsidized since 2003 within a Nanofutur grant of the German Federal Ministry of Education and Research endowed to Rainer Hillenbrand. The plan had already anticipated a start-up company which indeed was founded in 2007 (Neaspec GmbH).

Original publication:
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