Nanoscale Infrared&THz Mapping of Conductivity

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***Abstract*—Near-field microscopy of scattering type (s-SNOM) has well-known merits in chemical recognition at 20-nm spatial resolution, using infrared vibrational-fingerprint resonances of molcules or crystal lattices. Here we report on s-SNOM application in semiconductor technology and correlated-metal physics, performed both at 10 µm and 118 µm wavelength.**

I. Introduction And Background

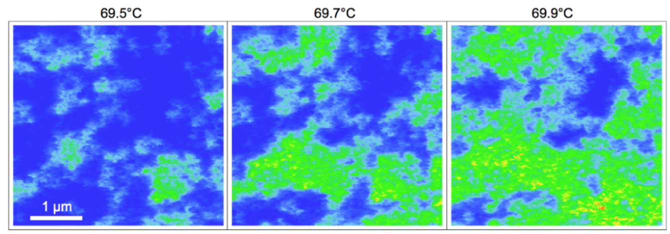
THE use of near-field focusing has revolutionized optical microscopy. Particular impact will arise simply because all infrared, THz and microwave radiation—which could in the past not be used for sub-micrometric microscopy because of diffraction—can now be used for 20 nm-resolved imaging. Thus the wealth of spectroscopic information in these spectral regions is now open to be exploited for solving a myriad of questions in the nanosciences.[1]

II. Results

Our s-SNOMs are all based on custom AFMs (atomic force microscopes) with standard, tapping cantilevers, where the sample is scanned and the topography is recorded at 10-nm spatial resolution. Our added infrared/THz channel uses focused illumination of the tip, and recording of the back-scattered infrared/THz radiation. The signal is demodulated at the tapping frequency to filter out unwanted "background" scattering that occurs at the cantilever and at sample inhomogeneities. The resulting signal yields an infrared/THz image that can be overlaid with the topography to recognize chemical composition and structural variety. Present activity deals with using broadband, coherent infrared/THz sources to obtain a broad spectrum at each pixel while scanning.[2, 3]

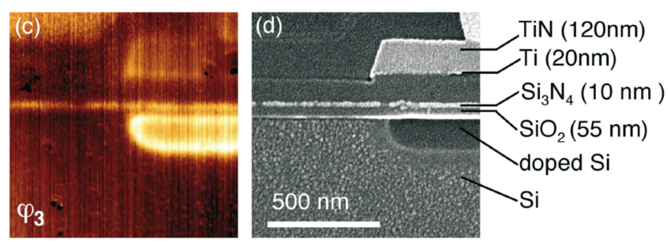
Beyond molecular/lattice vibrational features the infrared/THz spectrum reveals rich information on free-carrier properties in metals, semiconductors and, especially, in exotic conductors such as superconductors, correlated semi-conductors, low-dimensional electron systems or conducting biopolymers—which all possess intrinsic excitations at infrared/THz quantum energies and thus should exhibit resonant contrast.

One problem of fundamental physics interest is how in certain material classes mobile electrons interact to form Cooper pairs or higher correlations. We have recently used our mid-infrared s-SNOM to investigate VO_2 films in the temperature range where this material transforms from an insulator into a metallic conductor.



These near-field images let us not only discover that the phase transition proceeds by initial nucleation of nanometric-sized conductive puddles (green) which then grow and coalesce, but also, that the conductivity within the puddles is distinctly different from the asymptotic value reached above puddle percolation, demonstrating the unexpected inter-mediate phase of a heavy-electron metal.[4]

An application of great industrial relevance is the mapping of semiconductor devices. We have shown that mid-infrared and recently, THz, s-SNOM can advantageously be used for the inspection and characterization of microelectronic transistors.[5,6] The infrared s-SNOM image (left) has not quite the resolution obtained by SEM (right), but does show contrast from mobile electrons whose density can be mapped quanti-tatively.



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