Antenna tips for sub-15 nm resolving THz nanoscopy

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Terahertz imaging and spectroscopy enables numerous fundamental and applied studies of electronic and chemical sample properties [1, 2]. Due to the long THz wavelengths, however, conventional techniques do not allow for nanoscale-resolved imaging, which is highly demanded for characterization of modern nanoelectronics devices or nanocomposite materials. A highly promising technique to overcome this problem is THz scattering-type scanning near-field optical microscopy (THz s-SNOM) [3]. Like infrared (IR) s-SNOM - which has enabled already numerous nanoscale infrared characterisation possibilities – it is based on atomic force microscopy (AFM). The tip of the AFM is illuminated with laser radiation. Acting as an antenna, it concentrates the light at its very tip apex to a nanoscale near-field spot that locally interacts with the sample surface. This interaction modifies the tip-scattered THz radiation. Thus, by recording the tip-scattered radiation, nanoscale imaging of the optical sample properties can be achieved. The AFM tips of a typical length of 10 to 20 micrometer are rather efficient IR antennas, owing to their length being on the scale or even larger than mid-IR wavelength. This makes them highly suitable for IR s-SNOM. At THz frequencies, however, their length is much smaller than the wavelength, which makes them poor antennas. THz s-SNOM to date thus suffers from limited signal-to-noise ratio and has not become yet a standard tool. Recently we developed AFM tips of much longer tip length (Fig.1a), by focused ion beam (FIB) machining, and showed via photocurrent measurement its capabilities of THz-resonant near-field concentration at the very tip apex owing to geometric antenna resonances [4].

Here, we report the development of a THz s-SNOM system based on our custom-made tips. By sophisticated milling processes we achieved tips of many tens of micrometer length and apex radii R of less than 10 nm. Imaging a well-defined topography test sample (Fig. 1b), we demonstrate that with these tips we can achieve a spatial resolution better than 15 nm at a wavelength of 119 micrometer (2.52 THz). We further represent advanced numerical modelling of the near-field scattering process, i.e. how near-field information is transferred into far-field scattering, the latter being actually measured in s-SNOM experiments. Our combined exerimental and numeridal findings provide novel insights into the near-field scattering process of AFM tips, which will be of great benefit for further pushing the sensivity and resolution in THz nanoscopy to its ultimate limits.

(a)

(b)

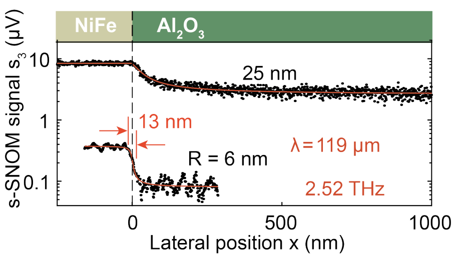

Fig. 1 : (a) Left : THz-resonant AFM-tip, fabricated by focused ion beam machining. Middle : Numerical calculation of the field distribution around a 35 mm long tip, revealing the fundamental dipolar antenna mode. Right : Near-field intensity at the tip apex, measured via a graphene-based THz split-gate detector [4]. (b) THz s-SNOM line scan across a metal (NiFe)/dielectric (Al_2O_3) interface using a commerical Pt-coated AFM tip (R = 25 nm, 20 mm tip length) and our custom made AFM tip (R = 6 nm, 40 mm tip length).

References

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