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► **To cite this version:**

Romain Lecaque, Samuel Gresillon, Nicolas Barbey, Romain Peretti, Jean-Claude Rivoal, et al.. Terahertz near-field optical imaging by a local source. 2005. hal-00012681

HAL Id: hal-00012681

<https://hal.science/hal-00012681>

Preprint submitted on 26 Oct 2005

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THz near-field optical imaging by a local source

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Abstract

A new THz imaging system based on a local illumination by a near-field source is presented. Model object is imaged, and sub-wavelength spatial resolution is demonstrated for the first time to our knowledge with this configuration. The contrast and the resolution are confirmed by a theoretical study based on the diffraction in near-field zone.

Key words: Terahertz, Imaging, optical rectification, diffraction, near-field optics

The THz domain (0.1 to 10 THz) is a part of the electromagnetic spectrum laid between IR and microwaves domain. This field has been barely explored and exploited. Nevertheless as noninvasive light, the use of such waves to image systems is highly attractive (1; 2). THz imaging brings an improved optical contrast and if coupled with spectroscopy, it enables the identification of unique rotational and vibrational responses of various materials within this frequency range. However one main drawback limits THz imaging : the usually weak resolution of THz images. At best, this resolution is limited by diffraction, and thus by the wavelength, i.e. $300\mu\text{m}$ for 1 THz. To overcome this resolution limitation, near-field microscopy seems to be an efficient technique for obtaining sub-wavelength resolution in optical imaging (4; 5). Recently, there have been reports showing how near-field microscopes can be adapted to the THz domain (3; 6; 8; 9). Most of THz near-field microscopes use a metallic diffusor to achieve a sub-wavelength resolution; these systems are called THz Apertureless Near-field Scanning Optical Microscopes (ANSOM). In this paper we present a new and unique THz near-field scanning microscope working in an illumination mode. The realization of a sub-wavelength THz source emitting a broad spectrum allows sub-wavelength imaging without the need of a near-field tip. Model objects were imaged by our microscope,

and a lateral resolution of less than $75\mu\text{m}$ were obtained. This result confirms the ability of the instrument to provide sub-wavelength resolution images. Moreover contrast on the images has been explained by a model based on the diffraction of a local source by the model objects.

The laser source (the near infrared (NIR) pump) is a Ti:sapphire laser with a 30-fs pulse duration at 800 nm and a repetition rate of 80 MHz. THz pulses are generated by the pump beam through optical rectification (7) in a nonlinear crystal (Fig. 1.a). 500 μm -thick $\langle 110 \rangle$ -cut nonlinear crystals (ZnTe as well as GaAs) are used for both characterization of the source and THz imaging. Samples are deposited on the surface of the nonlinear crystal. A "Cassegrain" microscope objective (x36, 0.5 numerical aperture) and an off-axis parabolic mirror are used to focus IR or THz radiation from the nonlinear crystal onto the detector. 2D images (fig. 1.a) are collected in the xy plane (plane perpendicular to the direction of light propagation z). Depending on the spectroscopic range different detectors are used. A bolometer is used in the THz domain (between 0.1 to 10 THz in frequencies, or 30 μm to 3 mm in wavelengths), and a HgCdTe detector for the 8-15 μm wavelength domain (20 to 37.5 THz). However the bolometer is an ultra broadband detector, 1mm thick teflon and dark polyethylene filter the Ti:Sa laser thus reducing the spectral range to the interval 0.3 to 3 THz.

Previous studies have shown that a diffracting fourier transform far-infrared (FTFIR) spectrometer can be used to analyse the spectrum radiated by the THz source (10). As depicted in figure 1.a, two identical time-delayed visible pulses are focused in the FIR generator. The limited numerical aperture of the cassegrain objective allows us to obtain only the interference signal of the two emitted FIR pulses by optical rectification. With the bolometer the measured spectrum peaks near 1.5 THz with a Full Width at Half Maximum $\Delta\lambda=2$ THz. The normalized width is $\Delta\lambda/\lambda=1.33$. With the HgCdTe detector, it is near 24.5 THz with $\Delta\lambda=14$ THz, and $\Delta\lambda/\lambda=0.57$. Therefore a very large (but not continuous) spectral band is measured (Fig 1.b). The usable bandwidth is only limited by the additional filters in front of the bolometer used to block the NIR pump and by the semiconductor nature of the HgCdTe detector. The emitted power is limited to a $2 \cdot 10^{-6}$ yield (for 0 to 5 THz range), defined as the ratio of the average collected optical power to the average incident optical power as in this case optical rectification occurs under the non phase matching condition.

Since THz radiation via optical rectification depends on the second-order dielectric tensor of the material, radiated intensity depends on the crystal azimuth (defined as the angle between the polarization of the NIR field and the crystallographic axis $\langle 110 \rangle$ of the ZnTe or GaAs crystal), the angle of incidence of the pump and the pump optical power. Previous works have shown that THz radiation due to the acceleration of photoexcited carriers (11) or to