

# **THz Wave Emission Microscope**

by

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## ABSTRACT

Sensing and imaging using Terahertz (THz) radiation has attracted more and more interest in the last two decades thanks to the abundant material ‘finger prints’ in the THz frequency range. The low photon energy also makes THz radiation an attractive tool for nondestructive evaluation of materials and devices, biomedical applications, security checks and explosive screening.

Due to the long wavelength, the far-field THz wave optical systems have relatively low spatial resolution. This physical limitation confines THz wave sensing and imaging to mostly macro-size samples. To investigate local material properties or micro-size structures and devices, near-field technology has to be employed.

In this dissertation, the Electro-Optical THz wave emission microscope is investigated. The basic principle is to focus the femtosecond laser to a tight spot on a thin THz emitter layer to produce a THz wave source with a similar size as the focus spot. The apparatus provides a method for placing a THz source with sub-wavelength dimension in the near-field range of the investigated sample. Spatial resolution to the order of one tenth of the THz wavelength is demonstrated by this method. The properties of some widely used THz wave emission materials under tight focused pump light are studied. Experiment results and calculations show that this method does not have much potential to improve the spatial resolution further because 1) the best theoretical spatial resolution available is the focus spot size of pump laser. 2) The further focusing down the pump light may damage the THz emitter; therefore there is an up limit of pump intensity. 3) Under the maximum pump intensity condition, the THz signal still has a cubic dependence on the THz source size under the maximum pump intensity condition.

As an important branch of THz time domain spectroscopy (THz-TDS), THz wave emission spectroscopy has been widely used as a tool to investigate the material physics, such as energy band structure, carrier dynamics, material nonlinear properties and dynamics. As the main work of this dissertation, we propose to combine the THz wave emission spectroscopy with scanning probe microscopy (SPM) to build a tip-assisted THz wave emission microscope (TATEM), which is a valuable extension to

current SPM science and technology. Illuminated by a femtosecond laser, the biased SPM tip forms a THz wave source inside the sample beneath the tip. The source size is proportional to the apex size of the tip so that in theory the best resolution is comparable to that of a scanning probe microscope. Primary results are encouraging: 1) The dependence of tip THz signal on the tip-sample distance is similar to that of tip tunneling current on tip-sample distance in a STM. 2) A dipole-like angular distribution of tip THz wave emission is observed. 3) Spatial resolution from 1 nm to sub-10 nm has been demonstrated. 4) The tip-assisted THz wave emission of various semiconductor samples indicates the material and bias dependent tip THz wave emission spectroscopy.

The system may provide a useful tool for investigating the local properties of nano-size substances. Nano-structure or electronics device may also be studied by this system.