Perturbation Analysis of Terahertz Confocal Microscopy

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***Abstract*—We propose a terahertz (THz) confocal microscope. The THz field is modulated by dithering an objective lens, and the signal is detected through a pinhole. The modulated signal is converted to an image using an analytic model based on perturbation analysis. The analytic model can successfully predict the surface profile of a test sample. This confirms that the proposed confocal microscope has a great potential for sample profiling in a THz imaging system.**

I. Introduction

RECENT years have seen much interest in the use of terahertz time domain spectroscopy (THz-TDS) for imaging[1]. Many efforts have been devoted to develop imaging techniques at THz frequencies[2-5]. THz imaging technique based on THz-TDS can provide information on both the amplitude and phase of the THz waveform[6-7]. It enables THz imaging technique to be useful for spectroscopic investigation of materials, particularly biological materials. However, because of the longer wavelength of the THz radiation compared to the visible range, its spatial resolution is diffraction limited. To improve the spatial resolution, confocal microscopy has been proposed.

The confocal microscopy was originally developed for the observation of a sample surface, but it is now used both to investigate the structure of samples and to study the physiology of biological samples[8-11]. The confocal microscopy can provide high resolution images because it decreases image distortion due to out-of-focus information by using a pinhole in an optically conjugate plane in front of a detector[12]. In this work, we present a method to obtain a sample image by calculating the THz signal reflected from a sample and extracting only the fundamental frequency component of the modulated THz signal using the confocal microscopy.

II. Theory and Results

The structure of the confocal microscope is shown in Fig. 1. The proposed confocal microscope is composed of three lenses, a beam splitter (BS), a pin-hole (PH), and a detector. The three lenses are classified based on function: a collimation lens (L1), an objective lens (L2), and a condenser lens (L3). The sample has a rectangular groove and is perfect electric conductor.

The THz field is generated with Gaussian distribution in space from a light source. Its beam waist is 300 μm at a wavelength of 300 μm. The THz beams are guided by the collimation lens to form collimated beam. After passing through the beam splitter and the objective lens, they are reflected from the sample, and collimated again by the objective lens. The THz beams are modulated by dithering the objective lens at a frequency, ω_0, using a tuning folk. The pin-hole is mounted in the focal plane of the condenser lens. When the test sample surface is in the objective focal plane, the collimated beam is focused on the pin-hole. When the sample surface is out of the focal plane, however, a defocused spot is formed at the pin-hole, and the detected THz signal is greatly reduced. The detector measures amplitude and phase of the THz field simultaneously, and a lock-in detection method can be applied to improve the detection sensitivity.

Applying perturbation theory, the modulated and detected THz field can be calculated. From this, we assessed whether the analytic model of the confocal microscope can predict the test sample roughness. Fig. 2 shows the THz confocal image of the sample surface. The groove size is 600 x 800 x 100 μm^3. The image is obtained from the fundamental frequency component of the normalized THz field (E_1) at the detector by using equation as follow:

$$E = \sum_{n=0}^{\infty} E_n \cos(n\omega_0 t) \qquad (1)$$

where ω_0 is the dithering frequency of the objective lens and t is time. The calculation is based on the following assumptions: (i) the sample surface is located at the objective focal plane; (ii) a rectangular pinhole is used; and (iii) the diffraction at the groove edge is ignored.

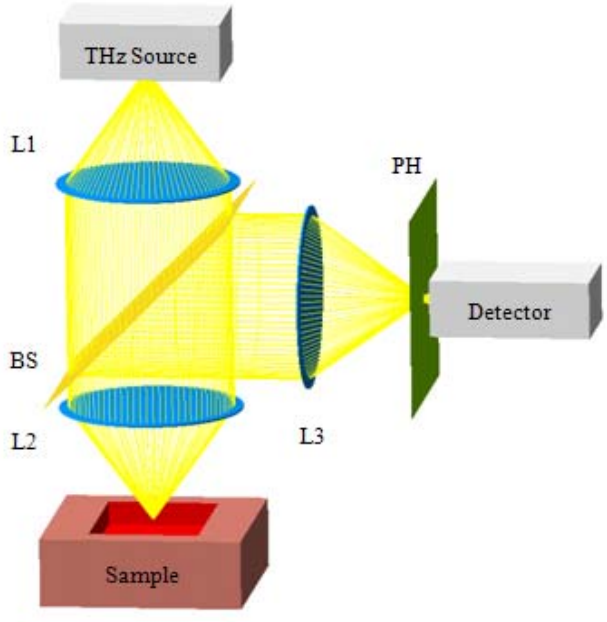

Fig. 1. Schematic setup of the THz confocal microscope.

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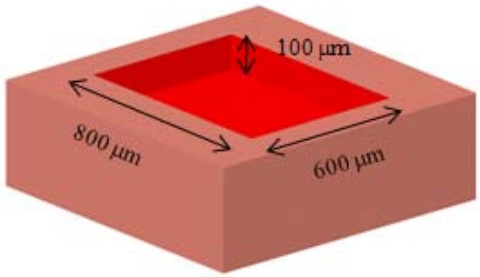
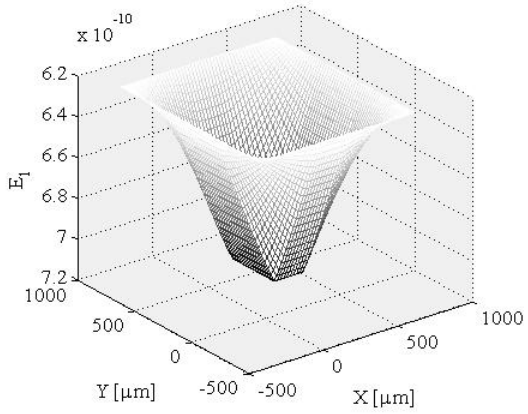
The calculated THz signal depends on the relative position of the sample surface to the objective focal plane. In this reason, the groove depth determines the difference between the THz signals reflected at the top and the bottom of the groove. The spatial resolution is affected by the pinhole size, and is maximized when the pinhole's half-length is about 0.7 times of the THz beam waist. The calculated resolution is 400 μm when the optimum pinhole size is used.



(a)



(b)

Fig. 2. Calculated THz signal (E_1) detected through a rectangular pinhole; the groove size of the test sample is 600 x 800 x 100 μm^3. (a) the test sample structure. (b) the 3-dimensional image of the sample surface.

III. Conclusion

In this study, we obtained THz images of a sample surface by using the confocal microscopic technique. The surface image is obtained from the THz signal detected through the finite-sized pinhole. The signal is calculated by the analytic model based on a perturbation theory. The THz confocal microscope can reduce the out-of-focus noise and provide better resolution than the conventional THz imaging techniques.

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