Applications of Terahertz Opto-Electronics

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Combination of ultra-short pulse laser having a hundred femtosecond duration and photoconductive materials having a sub-picosecond carrier life-time have been successfully used to generate, detect, and measure picosecond far-infrared terahertz pulses, and enabled to produce images of internal structure and composition. The picosecond pulses of the terahertz spectrum are transmitted through various objects and measured using lenses and mirrors to focus the signals. The change of the measured pulse is analyzed as they pass through objects, and convert the data into image form. Imaging is possible because of the highly specified frequency-dependent absorption in the terahertz range by many materials. Materials with high electrical conductivity, such as metals, are opaque to terahertz pulses, whereas plastics are transparent. These material properties, coupled with the ability to focus the terahertz transients to the diffraction limit, permit using terahertz beams for imaging application. This type of far-infrared imaging does not require cooled detectors. Potential applications include tissue imaging, chemical-reaction analysis, environmental monitoring, and material and package inspection. Especially it can possibly replace X-ray for non-destructive investigation. Many papers relating to the imaging by the photoconductive sampling and short pulse laser have been reported.[1][2][3] However, the reported imaging system is too complicated and have large sizes. The systems are needed to be reduced further for practical purpose. Moreover the imaging resolution is mainly constrained by the diffraction limit.

In this paper, we propose a compact-sized near-field imaging system using the photoconductive sampling principle with a near-field probe. The near field probe enable us to get away form the diffraction limit and works as a beam shaper for narrowing the pulse width. The size of the imaging system is substantially reduced compared to the previous system, by using a parallel pulse beam and removing the focusing parabolic mirrors. The experimental set-up is schematically depicted in Fig. 1 with the near-field probe. The size of the imaging system is about 12*10 cm^2 which is only a 1/4 of the previous systems. The near-field probe has a circular aperture, whose diameter is 1mm corresponding to $\lambda/3$ of 100GHz, a typical radiation frequency of the terahertz system. Fig. 2 shows the time-domain pulse waveforms propagating through the set-up without and with the aperture. The FWHM of pulse is found to be 3.8 ps without the aperture and 2.8 ps with aperture. But the signal-to-noise ratio (SNR) is decreased. The near-field probe acts as a terahertz pulse compressor. The terahertz imaging is used for inspecting the internal structure of a semiconductor integrated-circuit chip. The produced terahertz image is clearly shown in Figure 3, demonstrating the chip as well as the metal contacts and their integrity inside the plastic packaging. In this image, the spatial resolution is about 1mm. With a shorter pulse whose spectrum peak is over 1 terahertz and with a probe whose aperture size is less than 100 um, spatial resolution less than 100 μm is possible. Further, the imaging system is also used for the imaging of a PCB substrate. The Fig. 4 is showing the transmitting image using the probe.

References

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[2] D. M. Mittleman, R. H. Jacobsen, and M. C. Nuss, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 2, PP 679-692, 1996

[3] S. Hunsche, M. Koch, I. Brener, and M. C. Nuss, Optics Communication, Vol. 150, PP 22-26, 1998

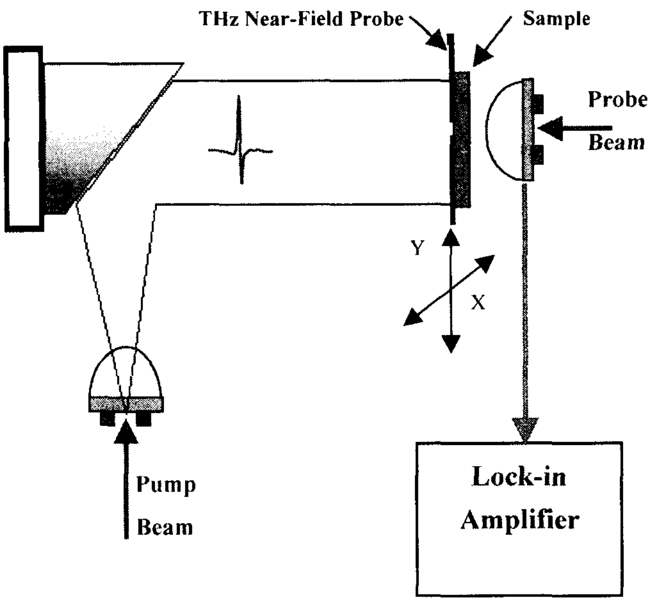

Figure 1. Experimental set-up for the transmission near-field imaging. Broadband FIR radiation is created and detected with photoconductive antennas gated by femtosecond laser pulses with variable time delay given by a fast-scanning optical delay line(not shown). The parallel beam is produced using a parabillic mirror and near-field was generated using a circular aperture probe.

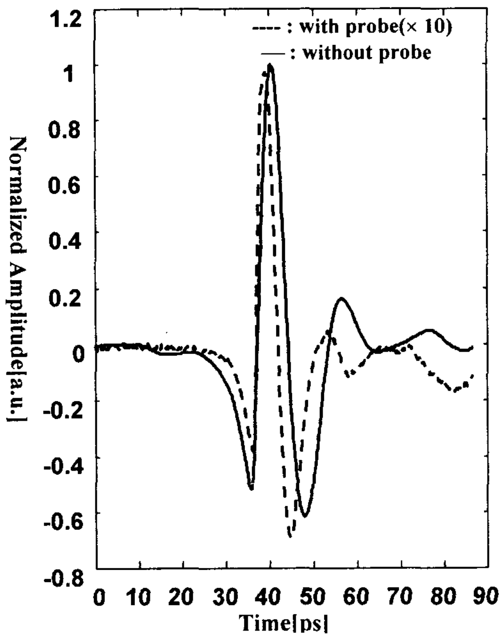

Figure 2. Waveform transmitted through the probe(dashed line) and without the probe (solid line). The waveform without probe works as a reference pulse. The aperture works as a high-pass filter.

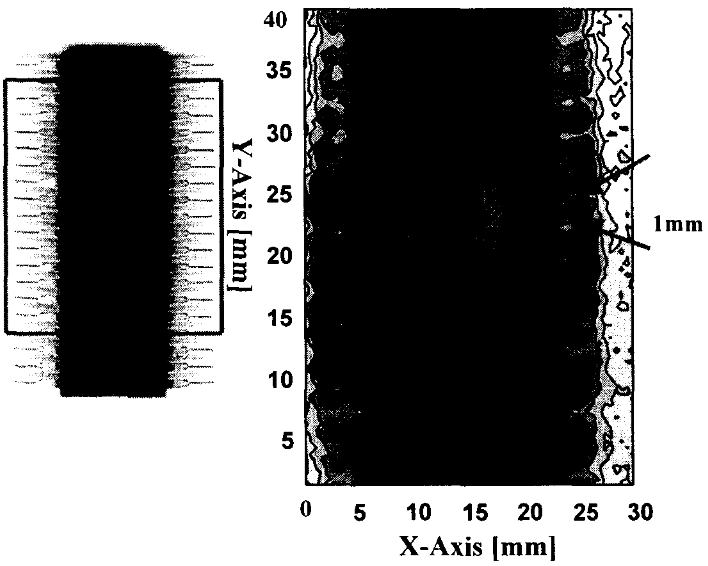

Figure 3. Terahertz transmitting image of a semiconductor IC using the near-field probe. Imaging resolution is less than 1 mm.

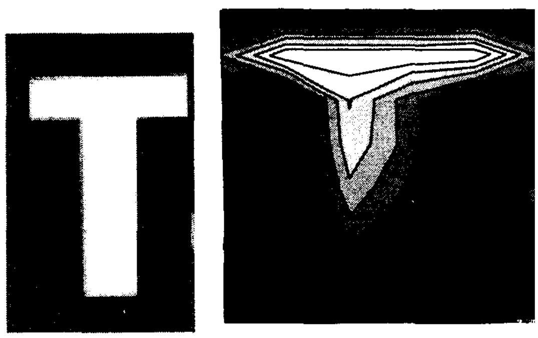

Figure 4. Terahertz transmitting image of a Character T in PCB