Laser Scanning Terahertz Imaging System for Material Science and Industrial Applications

Masayoshi Tonouchi

Institute of Laser Engineering, Osaka University, 2-6 Yamada-Oka, Suita-city, Osaka 565-0871 JAPAN, tonouchi@ile.osaka-u.ac.jp

One can observe terahertz (THz) radiation from various kinds of materials, when excited with a femtosecond laser, owing to ultrafast current modulation. THz waves reflect various kinds of properties such as local electric field, particularly ultrafast transient phenomena, in their waveforms. The observation of the THz waveforms enables us to explore ultrafast nature of electronic materials and devices as a THz emission spectroscopy.

When one excites the THz emission from a certain substance with the femtosecond optical pulses and visualizes the emission image by scanning the laser beam on it, the resolution of the image is limited by the laser beam diameter rather than THz wavelength. Thus construction of a laser-THz emission microscope (LTEM) would provide a new tool for material science and application. Here we review LTEM development, recent progress, and application to the material science

A mode-locked Ti:sapphire laser that produced femtosecond optical pulses with a pulse-width of 100 fs was used as the optical source. The center wavelength of the pulses was about 790 nm and the repetition rate was 82 MHz. The excitation pulses were split from the trigger pulses using a beam splitter and focused with an optical lens onto samples mounted on a computercontrolled x-y stage. The THz waves were collimated and focused onto a detector using a pair of off-axis parabolic mirrors. We used a bow-tie type photoconductive antenna as the detector. One of the parabolic mirrors had a hole with a diameter of 3 mm, through which the pump pulses were introduced to the sample. The detector was gated using trigger pulses. The amplitude of the THz emissions was monitored using a lock-in amplifier. To improve the spatial resolution, we employed beam expander and solid immersion lens. As a result, sub-micrometer LTEM images were successfully observed.

We apply it to observe ferroelectric domain imaging in multiferroic materials such as BiFeO3. The clear photoassisted polarization has been observed by LTEM, which proves that LTEM is strong new scientific tool. One can observe terahertz (THz) radiation from various kinds of materials such as semiconductors, high-Tc superconductors (HTSC), colossal magnetoresistance manganites, and multiferroic materials, when excited with a femtosecond laser, owing to ultrafast current modulation [1]. THz waves reflect various kinds of properties such as local electric field, particularly ultrafast transient phenomena, in their waveforms. The observation of the THz waveforms enables us to explore ultrafast nature of electronic materials and devices as a THz emission spectroscopy.

In addition to the normal LTEM, we present recent progress on the extension of the system for dynamic observation. Pump-and-Probe LTEM has been developed as DTEM, which traces dynamic response of optically excited materials and devices. We will discuss on the spatio-temporal response of photoconductive switched. Furthermore, we recently developed near-field type LTEM, which has a resolution less than 500nm.

As applications of LTEM, localization of LSI failure, evaluation of solar cell and quantitative evaluation of supercurrent density distribution in high Tc superconductive films will be discussed.

References

1. H. Nakanishi, S. Fujiwara, K. Takayama, I. Kawayama, H. Murakami M.Tonouchi, “Imaging of a polycrystalline silicon solar cell using a Laser Terahertz Emission Microscope”, Applied Physics Express, ,112301 (2012).
2. M.Yamashita, et al. "THz emission characteristics from p/n junctions with metal lines under non-bias conditions for LSI failure analysis", Optics Express 19, 10864(2011).
3. M. Tonouchi, S. Kim, I. Kawayama, H. Murakami, “Laser terahertz emission microscope” , Proc. SPIE 8023, 80230Q (2010).
4. M. Yamashita et al. “Backside observation of large-scale integrated circuits with multilayered interconnections using laser terahertz emission microscope”, Applied Physics Letters 94, 191104 (2009).
5. K. Takahashi, N. Kida, M. Tonouchi, “Terahertz Radiation by an Ultrafast Spontaneous Polarization Modulation of Multiferroic $BiFeO_3$ Thin Films”, Phys. Rev. Lett. 96,117402 (2006).
6. T Kiwa, M Tonouchi, M Yamashita, K Kawase, “Laser terahertz-emission microscope for inspecting electrical faults in integrated circuits”, Optics letters 28, 2058(2003).

978-1-4673-5225-3/14/$31.00 ©2014 IEEE