Observation of Semiconductor Test Circuits after Building-in Defect using Laser THz Emission Microscope

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***Abstract*— To evaluate the performance for non-contact testing of large scale integrated circuits, we observed various simple test circuits after build-in defect using laser THz emission microscope (LTEM), which detects THz wave amplitude emitted from semiconductor test circuits excited by focused ultrafast laser pulses.**

I. Introduction And Background

THE terahertz (THz) spectral range has been an active field of research for the past two decades. This research has been stimulated by the development of ultrafast lasers and of the gated THz emission and detection techniques that facilitated various applications such as THz spectroscopy and imaging. In Ref. 1-3, we proposed and demonstrated the laser THz emission microscope (LTEM) as a novel tool for inspection and failure analysis of large scale integration circuits (LSIs). For LSI inspection, LTEM measures the THz waves emitted by photoconductive switching in an LSI chip by scanning it with focused fs laser pulses. The electrical failures such as wire disconnection can be identified by comparing the LTEM images between normal chips and damaged ones. Several LSI testing techniques such as infrared optical beam induced resistance change, infrared emission microscope, electron beam testing etc. are practically used to inspect and localize electrical failures of LSIs. However, these techniques require the electrical contacts between the chip and outside equipment to apply the bias voltage to or to read the electrical signal from LSIs. Therefore, the inspection techniques for electrical failures in LSIs without electrical contact are strongly required to accelerate the LSI R & D and achieve high quality and reliability.

II. Results

The schematic diagram of the LTEM system for the investigation of an LSI chip from the backside of the chip is shown in Fig. 1. For the generation of the THz waves from the sample, we used a synchronously pumped optical parametric oscillator (OPO) excited with a mode-locked Ti:sapphire laser. In this experiment, the wavelength of 1.06 μm was used for the excitation of p-n junctions and generation of the THz emission through the silicon substrate of the sample. The position of the laser excitation in the LSI can be observed by a CCD camera.

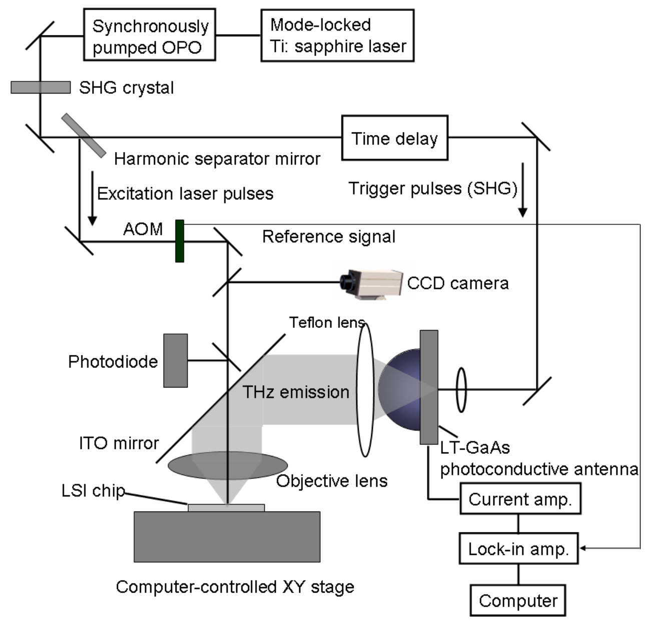

Fig. 1 Experimental setup of the near-infrared laser THz emission microscope for backside observation of LSI chips.

THz waves emitted through the silicon substrate of the sample are collected and focused onto a low-temperature-grown GaAs (LT-GaAs) photoconductive antenna which is triggered by the second harmonic (530 nm) of the OPO. The signal from the detector is fed into a lock-in amplifier synchronized with the acousto-optic modulator (AOM) that modulates the excitation laser at a frequency of 50 kHz. THz emission images can be acquired by moving the sample mounted on the computer-controlled *XY* stage with fixing the time delay stage at the peak of the THz waveforms. The spatial resolution of the system is below 2 μm which is limited by the excitation laser spot size at the pn junctions in the sample.

To elucidate the ability for the inspection of electrical failures in semiconductor devices, we measured various test circuits with defects such as wire disconnections and short circuits. Figure 2 shows the schematic illustration of the test circuit observed by LTEM. The test circuit consists of two n-type diffusion layers (N1, N2) connected to wires (M1, M2) with Al pads fabricated on p-type substrates. In addition to the normal circuit, we prepared three short circuits with different failure positions *d*=0, 10, 150μm. Figure 3 (a)-(d) show LTEM images of test circuits by fixing the time delay position at peak

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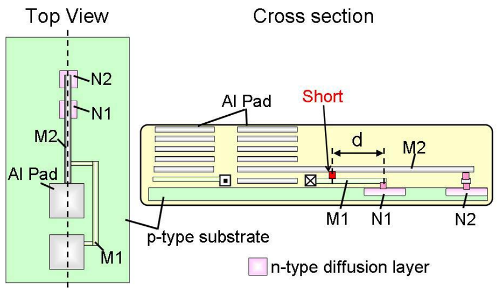

Fig. 2 Schematic illustration of the test circuit.

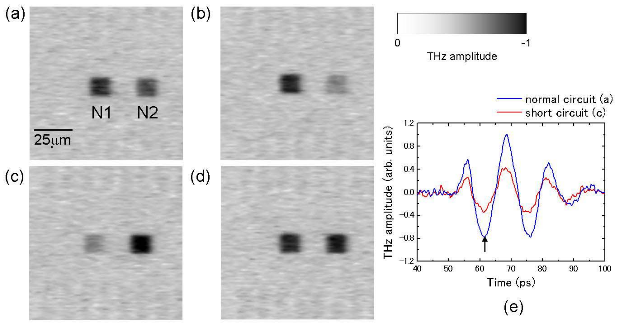

Fig.3 LTEM images of Normal test circuits (a) and short circuits with different short positions d= (b) 0μm, (c)10μm, (e)150μm shown in Fig. 1. Inset shows THz waveforms generated by exciting N1 of normal circuit (a) and short circuit (c) with fs laser pulses.

amplitude indicated by an arrow in Fig. 3 (e). Black contrast in Fig. 3 indicates the negative amplitudes of THz waves and it can be seen that THz waves were strongly emitted from n-type diffusion layer. Figure 3 (e) shows that the THz emission waveforms in the normal circuit and short ones between M1 and M2, resulting in the change of LTEM image. This indicates that the THz emission waveforms are strongly influenced by the wire structure connected to p-n junctions. By comparing LTEM images, it is possible to distinguish the normal circuit from short circuits.

Test circuits composed of Si pMOSFETs with wire disconnections were also measured. Schematic illustrations of test circuits are shown in Fig. 4 (a). In addition to the normal circuit (labeled MOSN), we prepared three defective ones (MOSD1-MOSD3) with a different position of the disconnection of the line between the heavily doped areas in n-type and the electrode pad as shown by circles in Fig. 4 (a). MOSD1 and MOSD2 have disconnections on the lines from both areas A and B, differing in the fact that in MOSD1 the lines are interrupted near A and B, while in MOSD2 there is a single interruption near pad C. MOSD3 has a disconnection only on the line from the area B. The THz emission images of the test circuits from the backside of the chip are shown in Fig. 4 (b). Figure 4 (c) shows the waveform of the THz emission measured on MOSN by exciting the pMOSFET indicated with a white circle in Fig. 4 (a). All THz emission images were acquired with a time delay fixed at the position indicated by an arrow in Fig. 4 (c). By comparing the THz emission images in Fig. 4 (b), one can distinguish the normal circuit from the defective ones. Furthermore, it can be seen that the THz emission images change depending on the positions of the disconnections. In MOSD1 and MOSD2, the THz emission signals from heavily doped areas in n-type in both areas A and B are smaller than that from MOSN due to the disconnection. In the case of MOSD3, the THz emission signals from heavily doped areas in n-type of A increase but that from B decrease by the disconnection between the electrode pad C and the area B, which suggests that the increase of the transient photocurrent from A flowing into the electrode pad enhances the THz emission. On the other hand, it can also be seen that there is little influence of the disconnections to the THz emission signals from heavily doped areas in p-type. These results suggest that the electrode pad enhances the THz emission efficiency by working as an antenna and the change of the THz emission images are useful for the localization of defects in circuits with the aid of numerical simulation of the THz emission waveforms from circuits.

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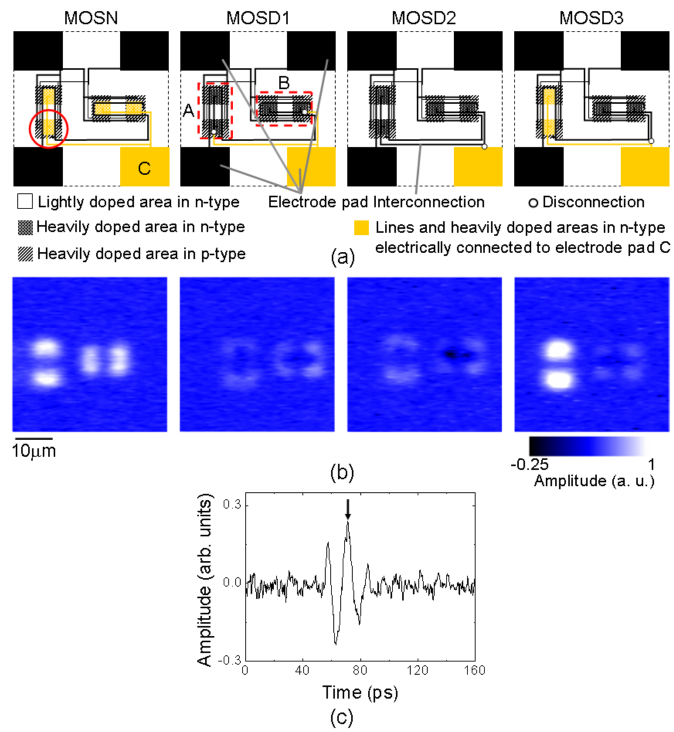

Fig. 4 (a) Illustrations of the normal circuit (MOSN) and the defective ones (MOSD1-MOSD3) with different disconnection positions. (b) The corresponding THz emission images. (c) The waveform of the THz emission measured by exciting the p-n junctions indicated by a large circle in MOSN.

References

[1] T. Kiwa, et al., "Laser terahertz-emission microscope for inspecting electrical faults in integrated circuits," Opt. Lett., vol. 28, 2004, pp. 2059-2061

[2] M. Yamashita, et al., "Imaging of large-scale integrated circuits using laser terahertz emission microscopy," Optics Express, vol. 13, 2005, pp. 114-120.

[3] M. Yamashita, et. al., "Non-contact measurement of MOSFET with zero bias voltage using the laser-THz emission microscope," Proc. of IRMMW-THz 2004, pp. 515-516.