Development of terahertz pulse time-domain reflectometry system for transmission line failure analysis

T. Okada, S. Nishina, T. Ataka, M. Hashimoto, A. Irisawa, and M. Imamura

ADVANTEST Corporation, 48-2 Matsubara, Kamiayashi, Aoba-ku, Sendai, Miyagi 989-3124, Japan

***Abstract*—A time-domain reflectometry (TDR) unit is developed that scans for faults in transmission lines with high spatial resolution by transmitting a terahertz wave pulse down the transmission line and measuring the reflected wave. Photoconductive switches illuminated by femtosecond laser pulses are used for generating and detecting wideband electrical pulses. By this method, failure points in transmission lines can be identified at a resolution surpassing that of conventional electrical TDR.**

I. INTRODUCTION

IN recent years, electronic devices such as mobile phones have required smaller sizes and higher speeds, and attention has been focused on system in a package (SiP) technology, which makes it possible to achieve size reductions by stacking multiple elements in three dimensions. SiP enables high integration densities through the manufacturing of semiconductor chips by individually optimized processes and wiring the separate chips in the package via interposers. Si interposers that have through-silicon vias (TSVs) play an important role in realizing higher integration density in the vertical direction. One issue with this type of SiP is ensuring the reliability of the high-density wiring and the TSV connections in the interposers.[1]

Although TDR is used as a technique for analyzing the locations of broken wiring and TSV faults inside interposers, the TDR units that are commercially available in current oscilloscopes have a rise time (T_r) of around 10 ps. Since the propagation velocity in general resin substrates is around 150 µm/ps, the spatial resolution is limited to around 600 µm, which corresponds to a T_r / fall time (T_f) ratio of 1/3. However, since the wiring via pitch in future high-density interposers will become as small as 50 µm, accurate identification of fault locations will be difficult. In addition, there is the problem of improving the spatial resolution by increasing the signal bandwidth in TDR instruments.

We have developed a terahertz (THz)-TDR system that uses the same system configuration as the time-domain spectroscopy (TDS) terahertz wave spectroscopy technique. The developed system generates THz pulses and records the time waveform to detect faults in electrical transmission lines with high resolution. In this manuscript, we describe the operating principles and characteristics of the instrument, and we present measurement examples.

II. EXPERIMENTS

This system generates and detects electrical pulses by illuminating photoconductive switches (PCS) with femtosecond laser pulses instead of using conventional electrical circuits. The extremely short pulse signals of this method contain an ultra-wideband signal extending up to the sub-terahertz band, which greatly increases the measurement bandwidth. By performing TDR measurement using this signal, the locations of faults within interposers can be identified up to a maximum wiring length of 300 mm ($\epsilon_{\mathrm{eff}} = 3$) for an SiP. Furthermore, in digital systems with high transmission speeds, signal integrity becomes problematic because a digital signal cannot be received correctly if the waveform becomes distorted while passing through a signal line. This analysis system is also capable of evaluating transmission line bandwidth by using an ultra-wideband time-domain transmission (TDT) measurement function with the emission and detection technique using PCSs to examine the distorted waveform.

Figure 1 shows a schematic diagram of the THz pulse emitter and detector probe[2]. A transmission line is fabricated and a PCS emitter and PCS detector are arranged on a low-temperature-grown GaAs substrate. The THz pulses generated by the PCS emitter are sent to the transmission line device in the device under test (DUT) such as an interposer, and the reflected waves from fault points such as opens and shorts are detected by the PCS detector. The PCS components are each illuminated by separate femtosecond laser pulses, and we employ a THz sampling method that controls the timing between the femtosecond laser pulses at the two units during this measurement. We thus constructed a measurement system that acquires the waveform with a high throughput of 8 ms per measurement.

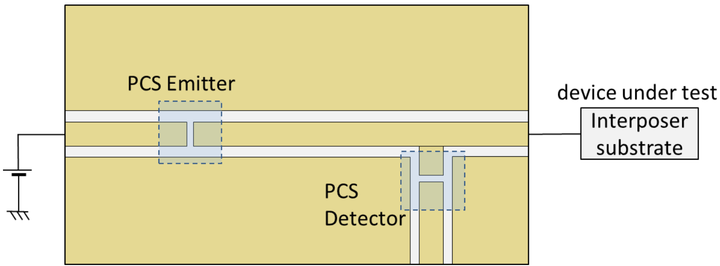

Fig. 1 Schematic diagram of THz-TDS probe [2]

III. RESULTS

Figure 2 shows an example of a THz pulse waveform captured by the PCS detector in the probe with the output from the THz-TDR probe terminated.

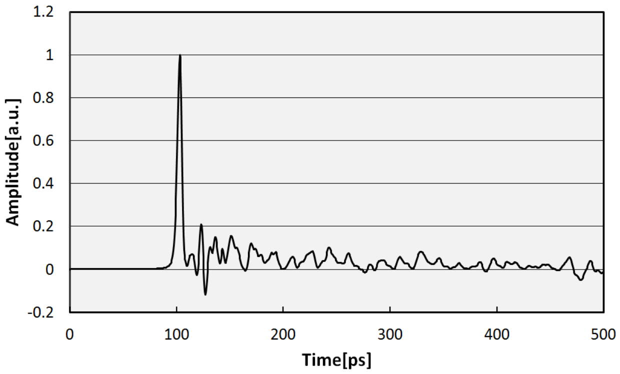

Fig. 2 Waveform example of the THz-TDR probe pulse

A waveform is obtained that has a pulse shape with a full width at half-maximum of under 6 ps. Furthermore, since the jitter is sufficiently small (<30 fs), the positions of fault locations can be measured with high spatial resolution. We measured the reflected wave from a transmission line by using this probe. Figure 3 shows the THz waveform reflectefrom an open end of a DUT. The open end was placed at distances of 3 mm, 5 mm, and 20 mm from the probe end. The reflected waveform clearly indicates the position corresponding to the distance from the probe tip to the open end. Furthermore, when the wiring fault is an open connection, the phase of the free-end reflection can be evaluated because it is reflected as-is.

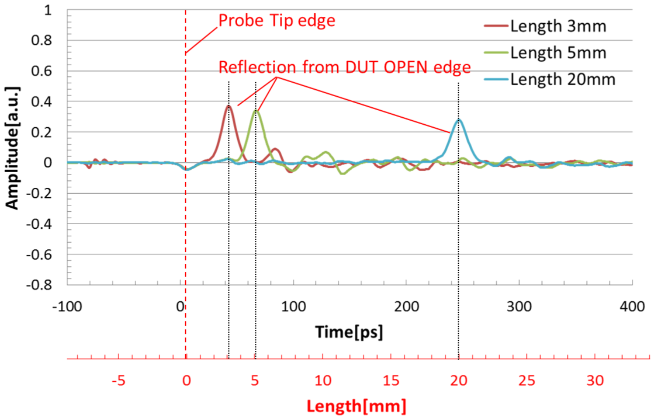

Fig. 3 Reflected waveform from an open end

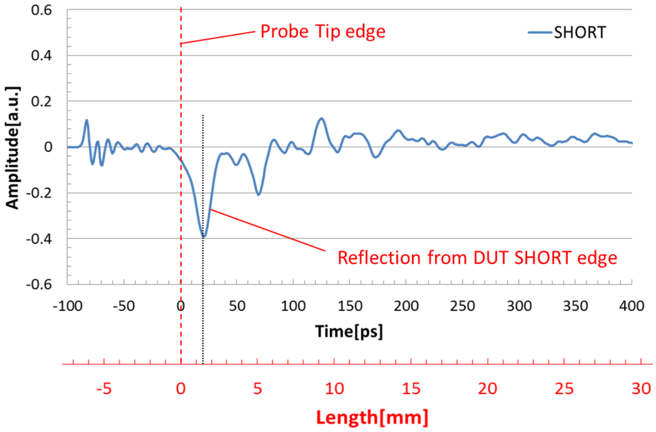

Fig. 4 Reflected pulse from a short end

Figure 4 shows the THz waveform reflected from a short end of a DUT. When the wiring fault is a short connection, the phase is inverted by π because of the fixed edge reflection, and a waveform with inverted phase is observed. In other words, since a positive pulse is observed if the fault mode is open and a negative pulse is observed if the fault mode is short, it is possible to perform short/open fault analysis.

SUMMARY

We developed a TDR instrument that uses a THz sampling method by controlling the timing of low-jitter femtosecond laser pulses from two units. This instrument can identify the locations of faults with high spatial resolution, and can be used in fault analysis for determining whether wiring fault locations in the DUT are open or short.

In this presentation, we also described the improved characteristics of the THz-TDR probe and we presented examples of fault analysis results for transmission lines using TDR measurement and examples of TDT measurement. In this way, we demonstrated the effectiveness of this method.

A TDR/TDT analysis instrument employing this method is planned for commercialization as the TS9000 (Terahertz TDR Option). This system supports measurement at a spatial resolution of 5 μm up to a maximum wiring length of 300 mm. It has a probe station that makes probing a DUT easy and software that has a fault location identification function able to be used with the same simple operations as the existing TDR analysis instruments and also supports branch signals.

REFERENCES

[1]. International technology road map for semiconductors 2011 edition, “Assembly and packaging”, ITRS.

[2]. US Patent, US5767955 “Short-width pulse generating apparatus for measure ement of reflection point”, Takeshi Konno, Takao Sakurai, Kouji Sasaki.