Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 214-216 **PB-3-1**

Measurement of Longitudinal Electric Field on Coplanar Transmission Lines by Electrooptic Sampling

Taro Itatani, Tadashi Nakagawa, Kimihiro Ohta, and Yoshinobu Sugiyama
Electrotechnical Laboratory
1-1-4 Umezono Tsukuba-shi, Ibaraki, 305 Japan
+81-298-58-5130

Fumihisa Kano
Oyama National College of Technology
771,Ohaza-Nakakuki Oyama-shi,Tochigi 323 Japan
+81-285-22-3344

We measured, for the first time, longitudinal electric field at the wavefront of electrical pulses on a coplanar transmission line(CTL) by electrooptic(EO) sampling. The longitudinal electric field is a short pulse, and it becomes wider and smaller as it propagates along a CTL. The strength of the longitudinal electric field varies strongly with the relative position between two conductors. The influence of the longitudinal electric field for the output signal of EO sampling is also discussed.

I. INTRODUCTION

There has been rapid progress in short pulse lasers. As an application of the short pulse laser, electrooptic(EO) sampling method has been proposed as a promising technique to measure high frequency electrical signals[1]. Measurement of electrical pulses on a coplanar transmission line(CTL) with a rise time as short as 0.3ps has been reported. For these short pulses on a CTL, it is expected that the TEM mode approximation, which is usually assumed for the signal analysis of EO samplings, becomes significantly inaccurate. TEM mode approximation implies that the longitudinal electric field can be neglected . The dispersion relation and the attenuation have been analyzed[2] in such a high frequency region without assuming TEM waveform, and appearance of longitudinal electric field has been discussed[2]. However, the exact waveform of the longitudinal electric field in time domain has not been studied theoretically and experimentally.

In this paper, we report the measurement of the longitudinal electric field on a CTL for the first time. It was found that the longitudinal electric field appears only at the wave front. It was also found that the peak strength of the longitudinal electric field is comparable to the transverse electric field for electrical pulses whose rise time is less than 1 ps.

II. EXPERIMENTAL

The CTL for the experiment was made on an unintentionally doped semi-insulating GaAs substrate. The metal conductors were made of Au, and they were 20μm wide and 200nm thick. The line separation was 20μm and the gap of the photoconductive switch was 10μm.

The EO sampling system for the experiment is based on a colliding pulse mode-locked(CPM) dye laser. The EO sampling system is shown in Fig. 1. The laser provides 80fs optical pulse train(λ=620nm) at a repetition rate of 94.2MHz. The output power was 10 mW and the laser beam was divided into a pump beam for the photoconductive switch and a probe beam. The device under test is depicted in Fig. 2. The probe beam goes through the EO crystal(250x300x50μm) and is reflected at the bottom by a dielectric mirror deposited on the crystal. We prepared two kinds of EO probes. One probe was made of $LiNbO_3$ whose z axis is perpendicular to the surface of the device under test. Although this configuration gives poor sensitivity, it gives the sensitivity only to the x axis component of the electric field. Transverse and longitudinal electric field were measured by rotating this probe crystal by 90 degrees. The other probe was made of $LiTaO_3$ whose x axis is perpendicular to the surface of the sample. This configuration has sensitivity to both the direction of y axis and z axis, though it has larger sensitivity than the configuration mentioned before. The output signal is the superposition of the transverse component and the longitudinal component. The reflected beam through a compensator which compensate static retardation, was decomposed into two polarizing components, and they were detected by two slow Si photodetectors. The electrical output signal was processed by a lock-in amplifier. The sampling point was set at the distance of 100, 150, or 200 μm from the center of the photoconductive switch.

620nm, 10mW, 80fs

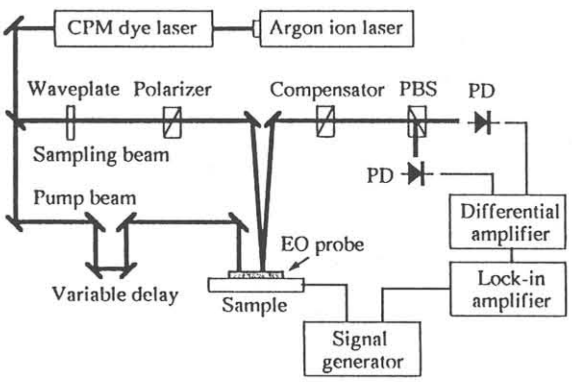

Fig.1 The EO sampling system based on a CPM dye laser

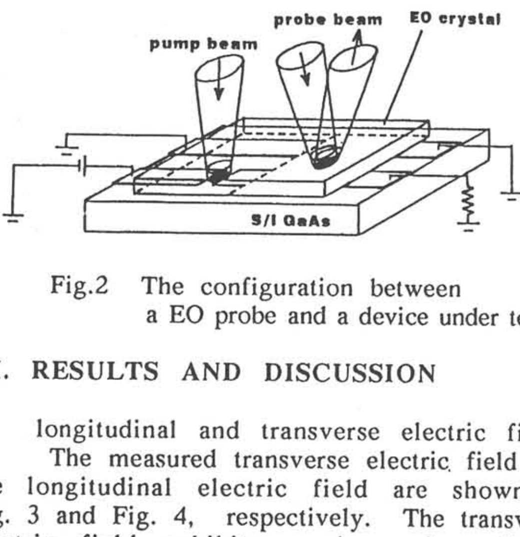

Fig.2 The configuration between a EO probe and a device under test

III. RESULTS AND DISCUSSION

(i) longitudinal and transverse electric field

The measured transverse electric field and the longitudinal electric field are shown in Fig. 3 and Fig. 4, respectively. The transverse electric field exhibits a sharp rise without any undershoot or overshoot. The 10-90% rise time is 0.7, 1.0, 1.2 ps for three sampling points. The longitudinal electric field is a short pulse. The pulse becomes wider and lower as it propagates along the CTL. The pulse widths for three sampling points are 0.7, 1.0, and 1.3 ps, and are almost the same to the respective rise time of the transverse electric field. This implies that the propagating electrical signal is no longer a simple TEM mode.

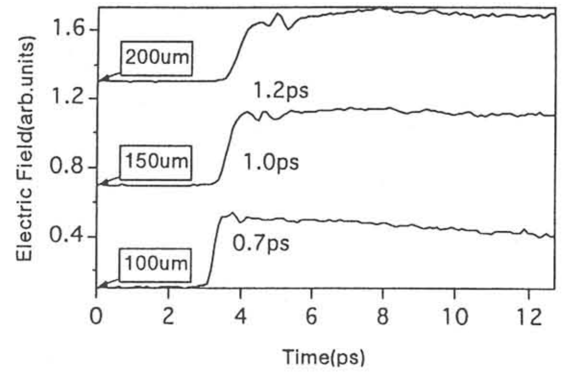

Fig.3 The transverse electric field measured by the EO sampling system

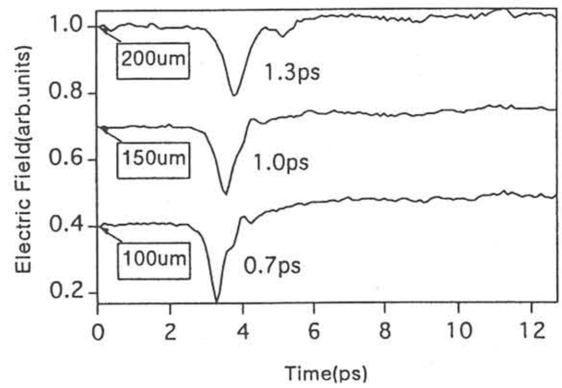

Fig.4 The longitudinal electric field measured by the EO sampling system

(ii) effect of longitudinal electric field for EO signals

In the case EO crystal is $LiNbO_3$ or $LiTaO_3$, the probe crystal is conventionally set to be most sensitive to the expected electric field component such as transverse direction or perpendicular direction. The measured waveform obtained by using the probe crystal of $LiTaO_3$ whose x axis is perpendicular to the surface is shown in Fig. 5. This configuration is most sensitive to the transverse electric field. The output signal has an undershoot due to the longitudinal electric field whose waveform is a pulse. These experiments show that this conventional crystal orientation, together with a probe crystal which has sensitivity to the longitudinal electric field, results in inaccurate pulse profile measurement, hence inaccurate estimation of rise time and wrong calibration of the signal level when the probe crystal has sensitivity to the longitudinal electric field. There is also substantial influence of static longitudinal electric field when the photoconductive switch is close to the sampling point.

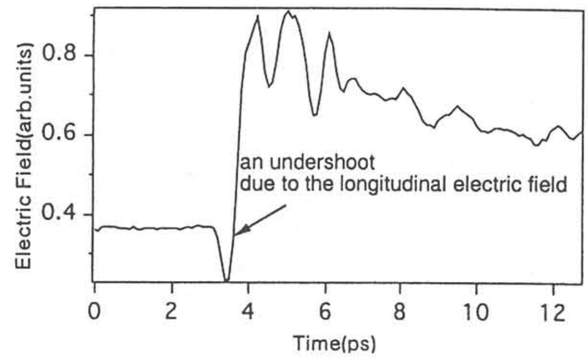

Fig.5 The EO signal using $LiTaO_3$ X plate. The output signal is a superposition of the longitudinal and transverse electric field

(iii) Position dependence of longitudinal electric field

The output signals using the EO probe of $LiTaO_3$ are shown in Fig. 6. The probe was set to be most sensitive to the transverse electric field and also has slight sensitivity to the longitudinal electric field due to the EO coefficient of r_{22}. The measurements were done at three points(on the signal line, at the mid point between two lines, and on the ground line) at the distance of 150mm from the photoconductive switch to avoid static longitudinal electric field. The measured signals show different characteristics of waveform. The 10%-90% rise time became longer as the sampling point moved toward the ground line. The rise time are 0.5 ps on the signal line, 0.8 ps at the mid point and 1.3 ps on the ground line. The output signal on the signal line has short rise time due to the small undershoot from the longitudinal electric field at the wavefront. On the other hand, we cannot observe undershoot for the output signal on the ground line. It was shown that the strength of the longitudinal electric field depends on the transverse position. It will be important to know the

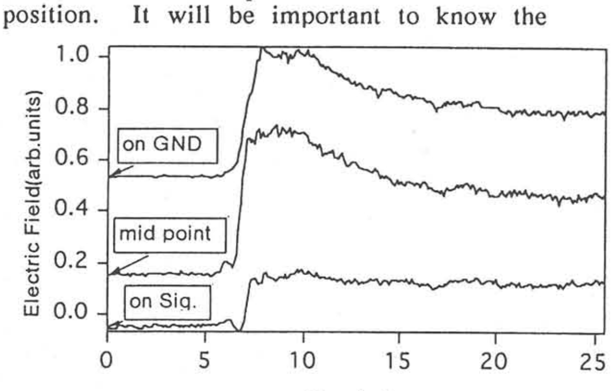

Fig.6 Position dependence of the longitudinal electric field

spatial distribution of longitudinal electric field at the wavefront for the estimation of the radiation loss.

IV. CONCLUSION

We measured, for the first time, the longitudinal electric field at the wavefront on a CTL by EO sampling. It was shown experimentally that the electrical waveform signals are no longer expressed by a simple TEM mode because of the significant appearance of the longitudinal electric field. The longitudinal electric field was a short pulse and its pulsewidth corresponds to the rise time of the transverse electric field which represents the voltage of the signal line at the TEM approximation. The strength of the longitudinal electric field varies spatially and was strongest on the signal line.

We also observed an undershoot of the EO signal due to the longitudinal electric field caused by the small EO coefficient r_{22} at the configuration of high sensitivity. This EO signal mixing was caused not only by the dynamic longitudinal electric field due to the non-TEM wave but also by the static longitudinal electric field which could not be ignored when the sampling point was near to the photoconductive switch. EO signal mixing is inevitable for the configuration of high sensitivity using a 3m symmetry crystal such as $LiNbO_3$ or $LiTaO_3$, which has a large EO coefficient. We cannot estimate exactly the pulsewidth and the rise time of short electrical pulses without considering EO signal mixing. More experimental and theoretical work which do not assume TEM mode approximation will be necessary for the complete understanding of EO sampling signal of THz frequency region.

REFERENCES

[1] J. A. Valdmanis, Appl. Phys. Lett. 26(1982) 211.

[2] M. Y. Frankel, IEEE Trans. Microwave Theory Technol. 39(1991) 910.