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Electro-optic mapping systems of electric-field using CW laser diodes

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Abstract

Two novel systems are proposed to perform the electro-optic (EO) mapping of the electric-field strength close to electrode structure using CW laser diodes. By these systems, mappings of both static (DC) and high-frequency electric-field can be obtained. For the static field, the field is chopped to increase the sensitivity performance. For the high-frequency field, an intensity modulation laser, instead of a pulse laser, is used to perform the mapping measurement in frequency domain, instead of in time domain. This approach greatly simplifies the system. An experiment set-up using a vertical cavity surface emitted laser diode (VCSEL) of a wavelength 850 nm and its mapping results for a coplanar waveguide (CPW) with the signal frequency around 1 GHz are reported.

Keywords: Electric field measurement; Electro-optic mapping; Laser diode; VCSEL

1. Introduction

External electro-optic (EO) probing technique has been a very useful tool for the characterization of high-speed devices and circuits [1]. It has many advantages, such as broadband, non-contact, and less invasiveness. The physical basis of EO probing technique is the linear EO effect called Pockels effect, which is that presence of an electric field on an EO crystal can cause a change of the refractive indices of the crystal. This change can alter the polarization state of an optical probing beam that propagates through the crystal.

In most reported EO probing system, an ultra-fast pulse laser is used as an optical probing source to sample the waveform and it can perform the s-parameter measurement up to a frequency of 700 GHz [2]. On the other hand, a real-time probing method by using a continuous wave (CW) laser was also proposed [3]. This system also can perform the waveform measurement under several GHz. For the above EO probing systems, they are all dedicated to the time domain measurement. Recently, the EO probing technique is extended to obtain the mapping of electric-field strength close to metal structure of a device under test (DUT) [4]. This kind of EO mapping technique has many applications, such as characterization of micro-antennas and antenna arrays, verification of electromagnetic compatibility (EMC), and failure diagnosis of microelectronic integrated circuits. Therefore, it may play an increasingly important role for the future design and fabrication of high-speed and high-integrated circuits.

So far, in most EO mapping measurements, pulse-type lasers are utilized. Their measurement frequency is usually higher than several GHz and it is difficult to perform the measurement below this frequency because of the requirement for the longer optical delay line. However, for whole frequency range in all kind applications, it is necessary to have another method to cover this frequency range. Furthermore, for the mapping measurement, the electric field signal is usually a single frequency; therefore, a frequency domain measurement technique is adequate. This kind of approach can be greatly simpler than that of the

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traditional measurement in the time domain, which uses a sophisticated pulse-type laser as the probing source.

In this paper, two novel systems are proposed to perform the EO mapping measurements using CW laser diodes in frequency domain. By these systems, mappings of both static (DC) and high-frequency electric-field can be obtained. For the static field measurement, we use a CW laser diode as the probing light source and use the chopping field signal to increase the sensitivity. An experimental system using a CW laser diode is built and employed to map directional electric-field strength close to a metal plate with an L-shape slit pattern on it. For the high-frequency field, a CW intensity modulation laser, instead of a pulse laser, is used to perform the mapping measurement in frequency domain, instead of in time domain. This approach greatly simplifies the system. Furthermore, this approach can be easily applied to the three-dimensional electric-field vector mapping by using the multi-beam probing technique as described in our previous work [5]. A similar approach using two optically mixing lasers has been reported before [6]. However, in this method, a beating frequency of two narrow line-width solid-state CW lasers was mixed with the microwave frequency of DUT to convert the high frequency signal of DUT from GHz to MHz. Therefore, the above mixing method is also dedicated to the waveform measurement in time domain.

2. Descriptions of two mapping systems

The proposed static field mapping system is shown in Fig. 1. This system is the same as that in our previous work except one optical probing beam, a computer-control motorized X–Y stage, and the hardware for automatic data acquisition [7]. The function generator output the square wave signal to the DUT to produce an AC electric-field, which can be viewed as the static field being chopped at the frequency of the square wave signal. Then the chopping field EO modulates the laser retardation at this frequency. Using a polarizer, a compensator, and an analyzer, the retardation modulation can be converted to the intensity modulation. Consequently, the intensity difference between two output laser beams from the analyzer is proportional to the modulated electric field strength. The photodetector pair converts the difference of optical intensity to electric signal and then feeds into the lock-in amplifier. Another signal with the same frequency as the output but fixed amplitude is used as the reference signal for the amplifier. The EO probe tip has the total internal reflection (TIR) geometry to avoid reflecting loss in the beam intensity. The beam propagation path in the tip and their side view are shown in Fig. 2, where the principal axes of the EO crystal are also shown. The blunt angle between the inclined surface and horizontal is 120°. The EO crystal material is $LiTaO_3$ and its thickness and bottom area are 120 μm and 200 μm × 200 μm, respectively. In our previous work [8], it has been discussed that this kind of beam propagating path in the TIR tip can be set to be sensitive only to the electric field along the z-direction of the principal axes of the crystal. To obtain the other tangential x-direction field, we can rotate the DUT by 90° or change the linear polarization direction of the probing laser beam to detect rotational modulation as

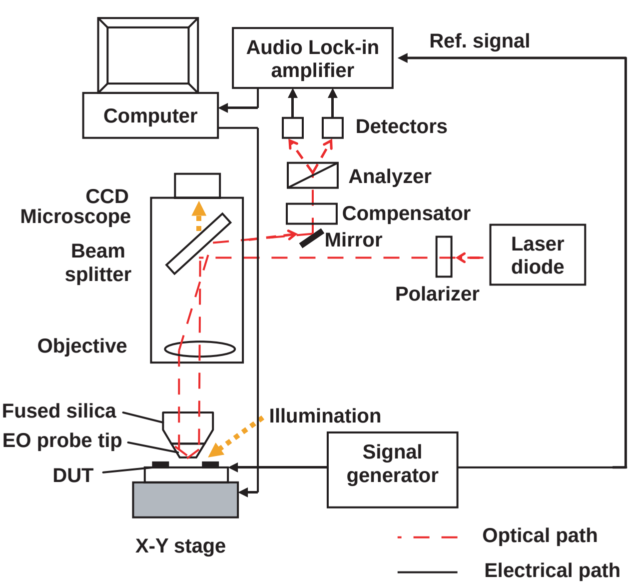

Fig. 1. The experimental set-up of the static electric-field mapping system.

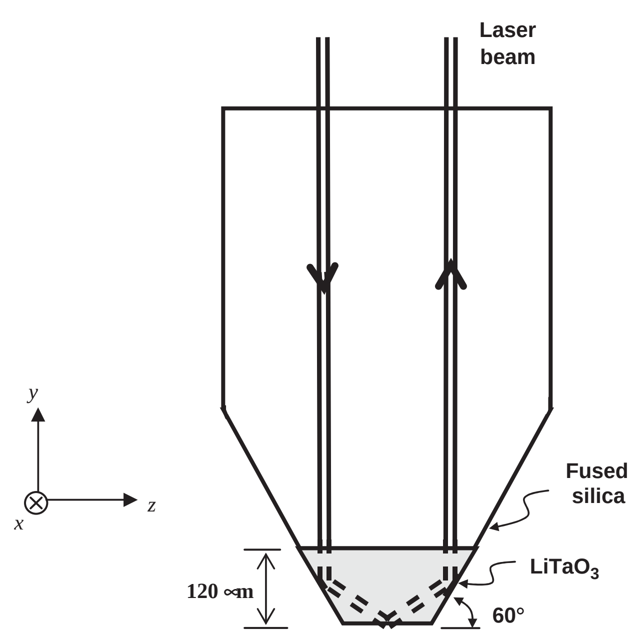

Fig. 2. The propagation path and the side view of the TIR EO probe tip.