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Magnetic Near-Field Mappings over Fine Circuits by Fiber-Edge Magneto-Optic Probe

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1. Introduction

The problems of EMC/EMI in electronic equipment are becoming more serious as operation speed and complexity increase in digital circuit systems. Recently, it is highly desired to prevent the problems in the early stages of design and packaging of electronic components [1]. To meet such a trend, it is considered indispensable to evaluate a correlation between electromagnetic near-field and far-field and to find out hidden EMI sources. Hence, the electromagnetic near-field probing technique with high-spatial resolution and wide-bandwidth is needed toward optimum designs of electronic systems.

Electromagnetic near-field probes that utilize optical measurement techniques have attracted considerable attention these days [2-6]. Because those can be microminiaturized and do not require electrodes as part of a probe, one can make the probe invasiveness minimal. Recently, rapid progress concerning magneto-optic (MO) probing that utilizes the MO effect to detect a magnetic field has been brought about by Yamazaki et al. [5][6]. By means of the fiber-edge magneto-optic (FEMO) probing technique, 10 μm-class spatial resolution [5] and 10 GHz-class measurable bandwidth [6] were reported. The former was realized by using a MO crystal of a 20 μm thickness, which showed the effectiveness of thinner crystal on higher spatial resolution. On the other hand, control of magnetization process in a MO crystal to an external magnetic field brought about the latter. In general MO probing, the Faraday effect caused by a domain wall displacement (DWD) phenomenon is utilized to detect a magnetic field optically. In this case, while high-sensitivity can be realized, because of slow magnetization process, measurable bandwidth is several hundreds MHz at most [7]. To break the bandwidth limitation of the DWD-based probing, the probing that employs the Faraday effect caused by a rotation magnetization (RM) phenomenon was planned and was successfully applied to GHz-order magnetic near-field mappings over a microstrip line band pass filter [6]. In the RM-based probe, a MO crystal is glued onto an optical fiber facet so that its easy magnetization axis is perpendicular to the optical probe beam [6].

In this paper, we report on evaluation results of the RM-based FEMO probe with a MO crystal of an around 10 μm thickness. It was found that the probe had spatial resolution enough to distinguish a field generated from each line of a 10 μm-scale circuit and measurable bandwidth of around 2.5 GHz. Moreover, applying this probe, a magnetic near-field over a fine circuit was successfully mapped at 1 GHz.

2. Experimental Setup

Fig. 1 shows a schematic diagram of a probing system. It consists of the FEMO probe head and its optical system [3, 5, 6]. The MO crystal we used was Bi-substituted rare-earth iron garnet (BiRIG). Its size was 270 μm^2 in an area and 11 μm in a thickness. To satisfy the configuration described above, the crystal was formed by conventional cut and polish techniques from an original crystal. Such an extremely thin MO crystal was glued at an edge of a single mode optical fiber. The system detects a field element perpendicular to a surface of a device under test (DUT) in the configuration shown in Fig. 1 [3][5].

Fine meander circuits with a 10 or 20 μm line width/ space were selected as DUTs for near-field mappings.

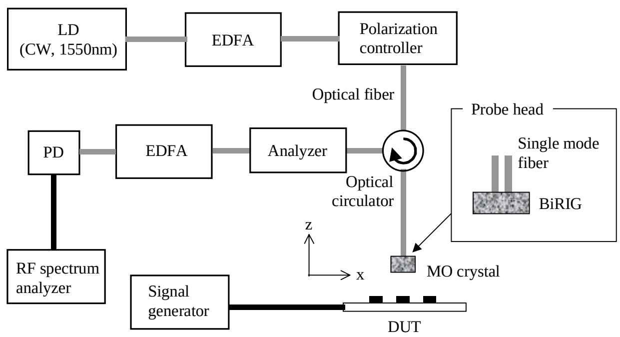

Fig. 1 Schematic diagram of the FEMO probing system. The bottom surface of a MO crystal is high-reflection-coated. LD: laser diode, EDFA: Er-doped fiber amplifier, PD: photodetector.

3. Results

First, we measured a frequency characteristic of the probe. The probe head was set at a height of 3 μm over a surface of a general microstrip line and a RF signal of 15 dBm was injected into it. Fig. 2 shows a measured result. It was confirmed that the range where the undulation stays within 3 dB extended to 2.5 GHz. However, according to Ref. 6, the probe bandwidth where the undulation stays within 3 dB is 10 GHz, which is broader. We speculate that a discrepancy between both results from the difference of domain structures in MO crystals. In the future, we plan to examine its origin in detail.

Next, we report on results of near-field mappings. Fig. 3(b) shows a measured result of the x-z magnetic near-field

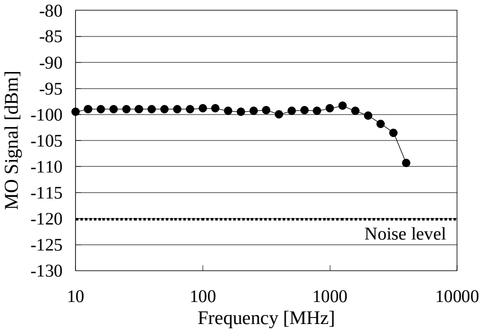

Fig. 2 Frequency characteristic of the FEMO probe.

mapping over a 10 μm-scale circuit in which a 10 MHz current flowed. The distance between the MO crystal bottom and the circuit was ranged from 3 μm to 15 μm. The measured result gives considerably well agreement with the simulated one shown in Fig. 3(a), which means that the probe can distinguish a field generated from each line of a 10 μm-scale meander circuit. Both results shown in Figs. 2 and 3 indicate that this probe has 10 μm-class spatial resolution as well as GHz-range measurable bandwidth.

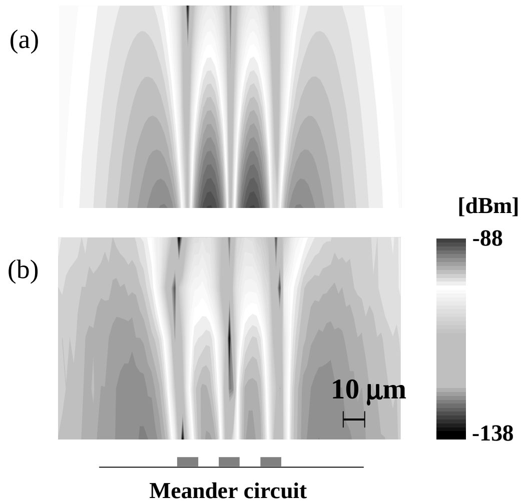

Fig. 3 Simulated (a) and measured (b) results of x-z mapping of magnetic near-field over a 10 μm-scale circuit. Measurement frequency was 10 MHz.

Furthermore, we performed x-y mappings at the meandering part of a 20 μm-scale circuit. Figs. 4(a) and 4(b) show mapping results at 10 MHz and 1 GHz, respectively. The crystal bottom was set at a height of 6 μm above the circuit. In case of 10 MHz, one can clearly find a magnetic field distribution corresponding to the circuit shape. In addition, strong field intensity is observed inside the meandering part, which is expected from electromagnetics. Compared with this mapping result, in case of 1 GHz, the field intensity becomes uniform and stronger at the circuit corner in the lower middle of the figure. It can be speculated that this phenomenon is associated with the current distribution in the circuit, probably standing wave. Its analysis is one of important subjects of future work.

These measured fine near-field mappings demonstrate the potential of the FEMO probing technique toward realization of an optimum circuit design.

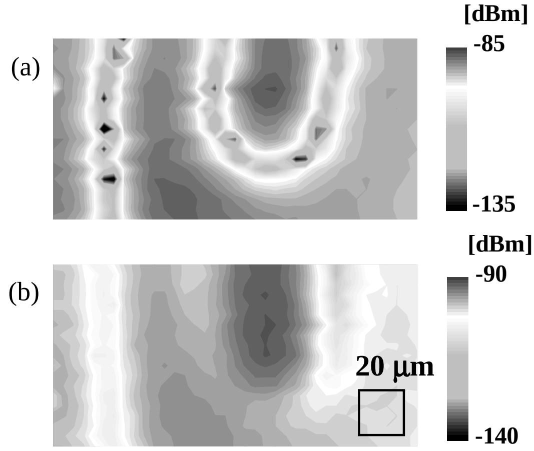

Fig. 4 X-y mappings of magnetic near-fields at the meandering part of a 20 μm-scale circuit. Measurement frequencies were 10 MHz (a) and 1 GHz (b).

4. Conclusions

For the purpose of realization of a magnetic near-field probe with low-invasiveness, high-spatial resolution, and wide-bandwidth, we fabricated the RM-based FEMO probe with a MO crystal of an about 10 μm thickness and evaluated its spatial resolution and measurable bandwidth. The evaluation results demonstrated that the probe that has 10 μm-class spatial resolution as well as GHz-range measurable bandwidth was accomplished. By applying this probe, a GHz-region magnetic near-field distribution over a fine circuit was successfully measured.

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