Focus Adjustment System for a Fast-Scanning and Phase-Sensitive Laser Probe for Radio Frequency Surface and Bulk Acoustic Wave Devices

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***Abstract*-This paper describes a focus adjustment system particularly designed for the fast-mechanical-scanning and phase-sensitive laser probe for radio frequency (RF) surface and bulk acoustic wave (SAW/BAW) devices. When high spatial resolution is necessary for the observation, one needs an objective lens of large magnifying power with extremely shallow focal depth. Then a tiny inclination of a measurement device may cause severe defocus resulting in blurred images. We installed the focus adjustment system in the laser probe, and showed that even there is the inclination, high quality information of the wave field can be acquired without slowing down the scanning speed. The laser probe with the focus adjustment function is applied to the characterization of RF SAW devices operated in 2 GHz range. It is shown the spatial resolution better than 0.5 μm is obtainable.**

***INDEX TERMS* – FOCUS ADJUSTMENT, LASER PROBE, SURFACE ACOUSTIC WAVE, BULK ACOUSTIC WAVE**

I. INTRODUCTION

A variety of laser probing systems have been developed as one of the effective diagnosis tools for sophisticated radio frequency (RF) surface and bulk acoustic wave (SAW/BAW) devices [1]-[7].

Recently, the authors have developed a phase-sensitive laser probe system [8] based on the Sagnac interferometer [9] shown in Fig. 1, which is capable of selective detection of RF vertical vibration. Due to the reciprocity of the Sagnac loop composed of two polarizing beam splitters (PBSs) and two static mirrors, the system exhibits a high-pass characteristic, and makes the measurement very insusceptible to low-frequency vibrations. This feature allows us to apply a fast mechanical scan to the interferometric measurement without badly sacrificing the signal-to-noise ratio and spatial resolution. Thus combining the Sagnac interferometry with the fast mechanical scanning technique, we can capture high quality and high-resolution two dimensional (2D) images of SAW/BAW field patterns in 10-20 min. [8]

For the diagnosis of RF SAW devices, it is essential to use an objective lens of large magnifying power to achieve spatial resolution better than electrode widths in SAW devices. For example, the electrode line width of interdigital transducers (IDTs) used in RF SAW devices is about 0.5 μm for an operation range of 2 GHz.

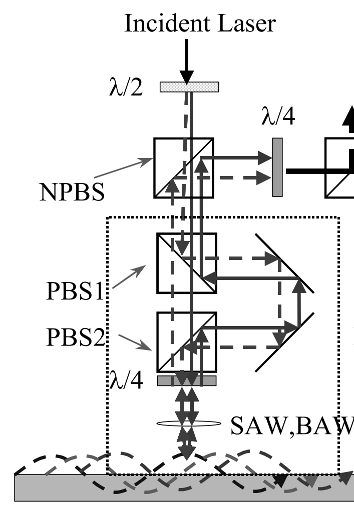


Fig. 1 Sagnac interferometer for detecting vertical vibration

Fig. 2 shows the optical image of a SAW device consisting of the electrodes of 0.5 μm line width, which is created from the output of a photo diode (PD) attached to the interferometer shown in Fig. 1. It is seen from the figure that when a 50× objective lens (Olympus LMPLFLN50×) is employed, the IDT fingers are hardly distinguishable according to insufficient spatial resolution. An objective lens with higher magnifying power may offer better spatial resolution. Since the interferometer makes up a confocal optical system [10], the spatial resolution may be slightly better than a half of the spot size. However, use of such a lens also results in an extremely shallow focal depth. For

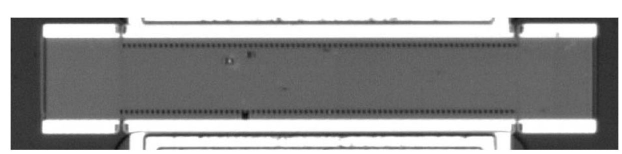


Fig. 2 Optical image taken by the 2D mechanical scan with 50× objective lens

example, the spot size and focal depth are about 1 and 6 μm, respectively, when a 100× objective lens (LMPLFLN100×) is applied to the present system. This means that only a tiny inclination of a device under test (DUT) causes severe defocus during the 2D mechanical scan and results in partially blurred images. Because of the fast and continuous mechanical scan with the maximum sampling speed of 25 kS/s, it is just not realistic to install in situ automatic focusing in the present system.

To solve this problem, we propose a simple but most effective focus adjustment technique particularly suitable for the present laser probe system. That is, the adjustment is performed by measuring the surface inclination in advance, followed by data acquisition by adjusting the height of the object lens in synchronization with the mechanical scan.

The developed focus adjustment system was installed to the present laser probe employing the Sagnac interferometer, by which a ZnO/diamond SAW resonator filter operating at 2.4 GHz and an SH-type SAW device with 0.5 μm line width were characterized. The whole system successfully visualized the field pattern on the vibrating surface of these two DUTs. At a specified frequency point, high-resolution 2D images with 1675 × 425 and 1150 × 250 pixels width were obtained in 20 and 6 minutes, respectively.

The result suggested that the proposed focus adjustment system could be most effective in the diagnosis of RF SAW/BAW devices in 2 GHz range.

II. Laser Probe System

Fig. 3 shows the setup of the laser probe system. An optical output of the Sagnac interferometer is sensed by a high-speed photo detector (PD), down-converted to an intermediate frequency (IF) and finally detected by an RF lock-in amplifier.

The measurement with the fast mechanical scanning is performed by the following procedure. The translation stage moves continuously along the longitudinal (x) direction between the specified starting and ending points. The high-precision linear scale attached to the stage outputs two-phase pulse trains every 40 nm movement. Then output signals of the RF lock-in amplifier are acquired by the data-logger in synchronization with the pulse trains. After one x scan is completed, the stage returns to the original position, moving simultaneously along the lateral (y) direction at a given step. This process is repeated until the 2D scan is completed. For adjusting the sampling interval, the N-divider circuit was inserted between the linear-scale output and the data-logger.

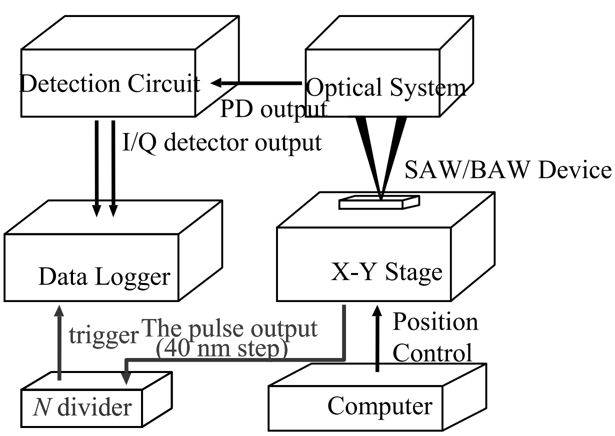


Fig. 3 Setup of Laser Probe System

The focus adjustment is performed by the following procedure. First, the objective lens is manually adjusted into focus at three different points on a surface of a DUT, and the lens heights and their corresponding device positions are recorded. The present system allows us to monitor the laser spot by a CCD camera through a dichroic mirror installed coaxially in the microscope tube with the objective lens.

If the surface is assumed to be flat enough, the relation between the lens height h and surface position (x, y) is modeled as

$$h=c_1x+c_2y+c_3, \qquad (1)$$

where the coefficients c_i (i=1,2,3) are readily determined from the recorded data.

Then, during the measurement with fast mechanical scanning, h is adjusted continuously by Eq. (1) in accordance with the position (x, y). The stepping motor is used for the vertical translation of the object lens, and h is monitored by a laser displacement sensor with the resolution of 0.2 μm. In practice, the lens height should be adjusted monotonically to avoid problems occurring with the mechanical backlash.

III. Measured Example

The effectiveness of this focus adjustment system was examined by using a two-port SAW resonator filter employing the SiO_2/IDT/ZnO/diamond structure [11].

Fig. 4 shows the structure of the device. Two Al IDTs and two reflectors with the line width of 1.0 μm are sandwiched in between SiO_2 and ZnO layers, and the resonance frequency is about 2.4 GHz.

Prior to the measurement, the inclination of the DUT sample was estimated by the manual focus adjustment. The variation of the lens heights among three points was more

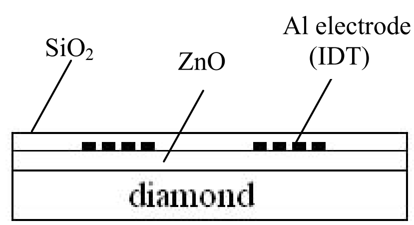
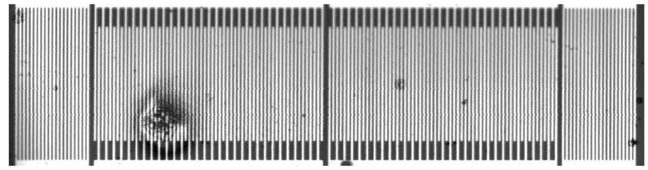
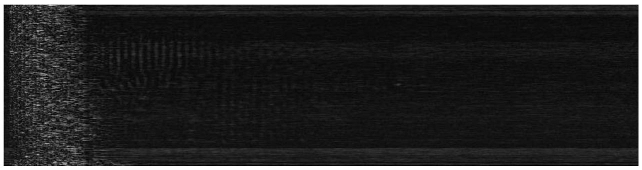


Fig.4 Schematic diagrams of SiO_2/IDT/ZnO/diamond

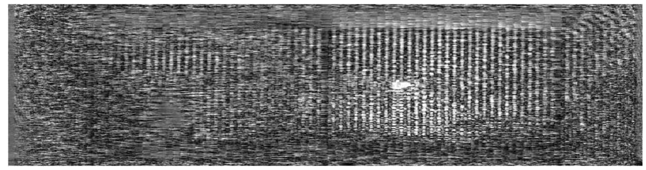
(a) Optical image without focus adjustment



(b) Optical image with focus adjustment

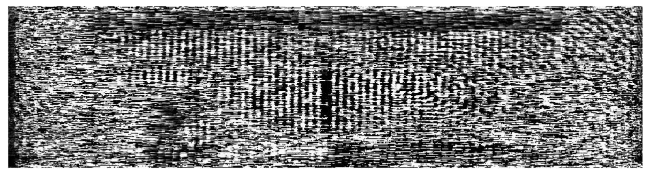


(c) Amplitude image without focus adjustment



(d) Amplitude image with focus adjustment

(e) Phase image without focus adjustment



(f) Phase image with focus adjustment

Fig.5 Optical image and measured field distribution of the ZnO/diamond SAW device

than 20 μm. This indicated the inclination of the DUT surface is about 3^o.

Figs. 5(a) and (b) compare the optical images of the surface taken by the PD without and with the focus adjustment. The comparison clearly shows that (1) the inclination causes a severe problem in the confocal system, (2) the effect of the inclination is successfully compensated by the present focus adjustment technique and (3) the whole device surface comes into focus.

Figs. 5(c)-(f) compare the images created from the laser probe output taken by the same PD without and with the focus adjustment. In the measurement, the operation frequency was set at 2.435 GHz. It is seen that only when the focus adjustment is applied, the SAW energy concentration near the IDT on the right is made clearly visible. For this measurement, the RF input power was set at 13 dBm. It took about 20 min. to scan 1675×570 ($x\times y$) points with 0.2μm step.

Fig. 6 shows another example. A SAW device fabricated on a 5^oYX-$LiNbO_3$ substrate [12] is used as a DUT. An Al IDT with the line width of 0.5 μm is covered by a SiO_2 layer.

Fig. 6 (a) and (b) compare the optical images of the surface taken by the PD without and with the focus adjustment. In Fig. 6 (a), part of the electrodes on the left is clearly visible. This suggests that the spatial resolution could be better than 0.5 μm when the 100× objective lens is employed. However, other part is blurry due to defocus. On the other hand, the whole device surface comes into focus when the focus adjustment is applied.

Figs. 6 (c)-(f) compare the images created from the laser probe output taken by the same PD without and with the focus adjustment. In the measurement, the operation frequency is at 1.866 GHz, and the electromagnetic feed through is removed by the wavenumber domain processing [13, 14]. The images apparently show how the present focus adjustment is effectively working. It is only Figs. 6 (d) and (f) that show the SAW energy confinement around the center of the IDT. In addition, the energy leakage is even made visible along the bus-bars and both outsides of the reflectors. For this measurement, the RF input power was set at 13 dBm. It took about 6 min. to scan 1150×250 ($x\times y$) points with 0.2μm step.

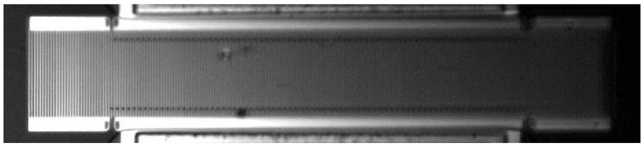
The results practically demonstrated the effectiveness of the present focus adjustment system; even when the focus depth of objective lenses (with large magnifying power) is shallow, the effect of defocusing problem can be avoided and high spatial resolution is obtainable on the entire surface of the DUTs.

Although not discussed in detail, it is confirmed that the system is also applicable to the diagnosis of RF devices based on BAWs.

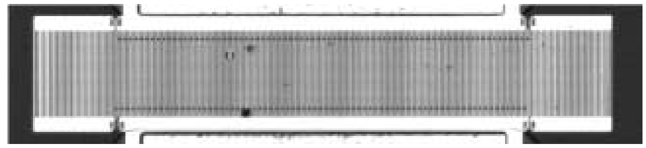
IV. CONCLUSION

This paper proposed a focus adjustment technique particularly suitable for the fast-mechanical-scanning and phase-sensitive laser probe for RF SAW/BAW devices.

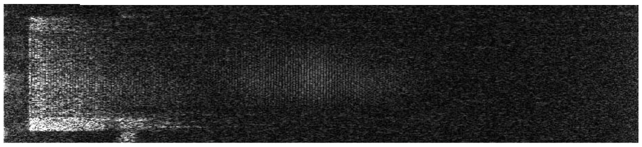
To overcome the influence of a tiny inclination of the DUT surface, the system based on the proposed technique was installed in the present laser probe using the Sagnac interferometer. This makes it possible to use an objective lens of large magnifying power to achieve high spatial resolution. In fact, it was shown that the spatial resolution



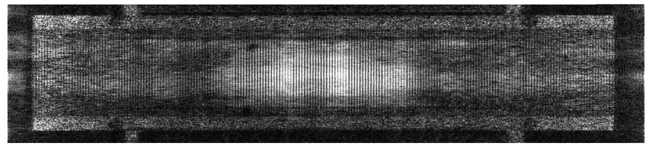
(a) Optical image without focus adjustment



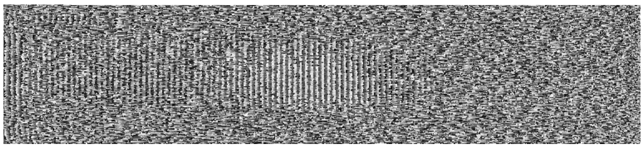
(b) Optical image with focus adjustment



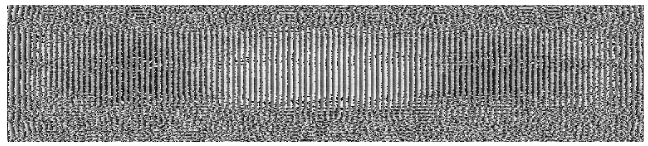
(c) Amplitude image without focus adjustment



(d) Amplitude image with focus adjustment



(e) Phase image without focus adjustment



(f) Phase image with focus adjustment

Fig.6 Optical image and measured field distribution of the SAW device with 0.5 μm Al electrodes.

better than 0.5 μm was obtainable on the entire surface of a SAW device, employing the 100× objective lens.

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