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Implementation of Auto-focus Function to Laser Probe for RF Acoustic Wave Devices for Its Long Time Continuous Operation

高周波弾性波素子用レーザプローブの長時間連続運転を目的とした自動焦点機能の実装

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1. Introduction

The laser probe is well recognized as a versatile nondestructive diagnosis tool for RF SAW/BAW Devices [1]. The authors' group have developed a high-speed and phase-sensitive laser probe system using the Sagnac interferometer, and demonstrated its usefulness [2]. Recently, they also implemented frequency scanning function in the system [3]. Although this function enables us to give deep understandings how the field distribution changes with the frequency, it also demanded installation of the automatic focus adjustment system. This is because the defocus becomes obvious after continuous operation of the system for dozens of hours, necessary for the frequency scan.

This paper describes implementation of auto-focus mechanism to the laser probe system.

2. System Setup

Fig. 1 shows the optical configuration of the laser probe system. The Sagnac interferometer using a 635 nm laser and a CCD camera are attached coaxially to the common lens barrel, and their optical paths are separated by a dichroic mirror. A halogen light source is also given coaxially to illuminate the specimen surface for the CCD monitoring. The CCD camera can be also used to monitor the laser spot on a DUT surface. Since we use high magnification (100×) lens for high lateral resolution, tiny vertical misplacement causes significant defocusing. A stepping motor is used for the vertical translation of the lens barrel with the resolution of 0.2 μm. A tilt of the DUT surface is compensated by moving the lens barrel while XY-scanning [4].

Backlash in the vertical translation mechanism is a main origin of defocusing. Since the backlash is tiny, its impact is small for single XY-scan. However, it becomes apparent after multiple scans.

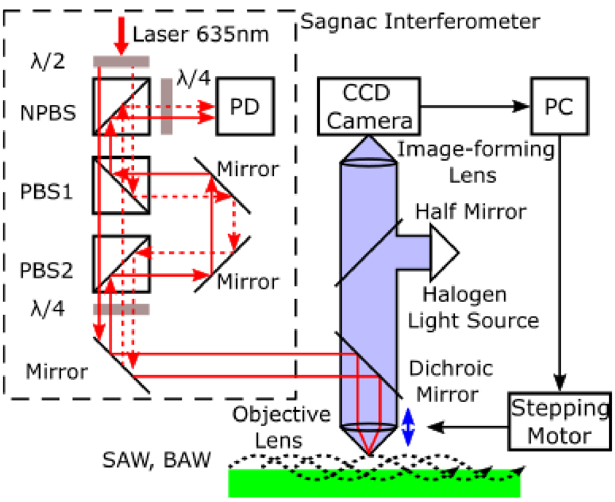

Fig.1 Optical setup

3. Auto-focus Function

3. 1. Evaluation Function of focusing

Since the CCD camera has already been installed in the current laser probe system, we use it for the focal position adjustment.

Fig. 2 shows the flow of employed image processing for monitoring the focusing condition. First, the RGB separated images (640×480 pixels) are captured by the CCD camera, and are clipped into 60×60 pixels near the center area to make it easy to extract the laser spot edge. Then, the sum of Energy of Laplacians (EOLs) as an evaluation function of focusing is calculated. The EOL for each image defined by

$$EOL = \sum_x \sum_y (f_{xx} + f_{yy})^2 \quad (1)$$

is known as one of criteria of image border sharpness [5]. In Eq. (1), the discrete Laplacian is calculated from the intensity of each pixel $f(x,y)$ by

$$f_{xx} + f_{yy} = -f(x-1,y) - f(x,y-1) + 4f(x,y) - f(x,y+1) - f(x+1,y). \quad (2)$$

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Since the sharper edge gives the larger EOL, auto-focus will be realized by seeking the lens height giving the maxima of EOL.

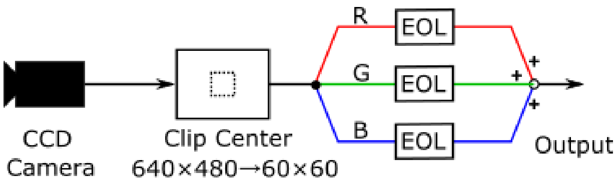


Fig.2 Image capture and evaluation of focusing

Fig.3 shows calculated EOLs of the images when white light is irradiated on a DUT. The horizontal axis is the lens height, and the lens barrel was lifted up every 0.2 μm step. Note that Δz=0 corresponds to the best focal position which was manually set based on the CCD image.

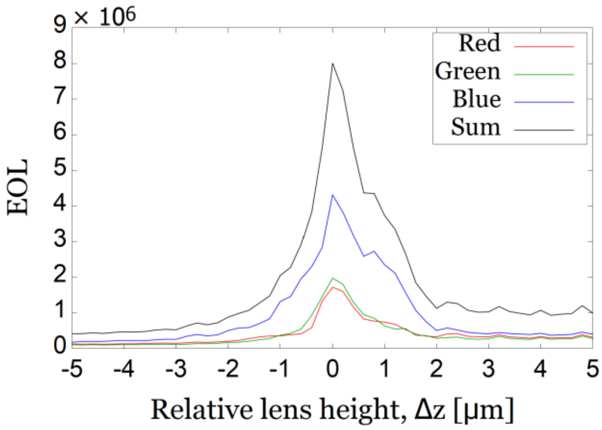


Fig.3 Evaluation function of focusing

From the figure, the evaluation function gives relatively steep unimodal curve and takes its maxima at Δz ~ 0. Thus, it is confirmed that the technique is applicable to auto-focusing.

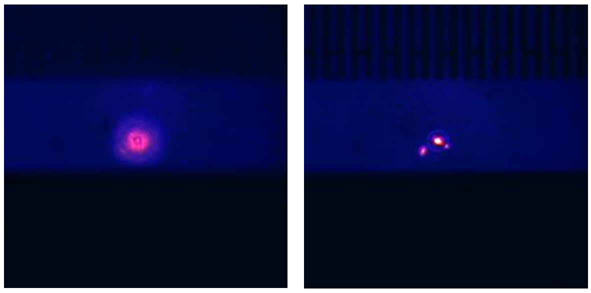
3. 2. Procedure of auto-focusing

The automatic focus adjustment is carried by the following procedure; (1) getting EOLs of every 2 μm step by moving the lens height between ±20 μm from the current position, (2) seeking the coarse position which gives the maximum of evaluation function of the calculated data, (3) moving the lens height to the position, and (4) reducing the moving range and step to ±2 μm and 0.2 μm, respectively, and repeat steps (1) to (3). It took about 30 seconds to complete this whole procedure.

The system software including this auto-focus function is realized under OpenCVsharp [6] of OpenCV wrapper for the .NET Framework platform.

4. Experiment

Fig. 4(a) shows the captured image when Δz=2.0 μm. **Fig. 4(b)** shows the captured image after the auto-focusing was applied. The auto-focused image is quite similar to the image at Δ z = 0. Satellite spots are also seen clearly. They are caused by multiple reflections of the laser beam in the optical system. From the above, it is confirmed that the implemented auto-focus function works properly.



(a) Before auto-focusing (b) After auto-focusing

Fig.4 Example of auto-focusing

5. Conclusion

This paper described implementation of auto-focus function in the high-speed laser probe system for RF SAW/BAW devices.

At first, we demonstrated that the evaluation function defined by the sum of EOLs of CCD camera captured images enables us to monitor the focusing condition. Then it was shown that the auto-focusing is realized by adjusting the lens height to take the evaluation function maxima. Using this implemented auto-focus function, defocusing occurs in long time measurement will be corrected properly.

Acknowledgment

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