IMPROVEMENT OF MEASUREMENT ACCURACY OF LINE-FOCUS-BEAM ACOUSTIC MICROSCOPE SYSTEM

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ABSTRACT

This paper describes accurate velocity measurements of leaky surface acoustic waves (LSAWs) on the water/sample boundary with the line-focus-beam (LFB) acoustic microscope system. Some serious problems, such as temperature stabilization and mechanical precision, are experimentally discussed from the point of view of measurement accuracy. It is essential to stabilize the temperature around the system because acoustic properties of water, used as a reference medium, depend on its temperature. The system is installed in a temperature-controlled room with 23±0.1 °C. The mechanical precision of the z-stage used in the system is also important. Influence of the movement errors on measurements is investigated by comparing the measured LSAW velocities with data obtained by the optical method. Experimental procedures to avoid the influence are established for accurate measurements. The relative accuracy is improved at 225 MHz to be better than ±0.005% at a chosen single point, and ±0.01% over a scanning area of 75 mm x 75 mm.

1. INTRODUCTION

The line-focus-beam (LFB) acoustic microscope system [1] can measure propagation characteristics of leaky surface acoustic waves (LSAWs) on the water/sample boundary. The measured results, especially phase velocities, can provide useful information in analyzing elastic or other related characteristics of solid materials. The LFB acoustic microscope with various distinctive features has been expected as a unique powerful technique for quantitative material characterization. The measurement accuracy must be investigated sufficiently before starting actual applications, in which reliable evaluation of materials is required. In general, accuracy can be classified into relative and absolute accuracy. The relative accuracy rather than the absolute accuracy is of greater importance for measurements of velocity changes among specimens and for inhomogeneity detection on specimens. Accuracy depends mainly on two factors, viz., the measurement environment, such as temperature stability around the whole measurement system, and the precision of the mechanical stages used in the system.

In this paper, detailed discussion, associated with the temperature stability and mechanical precision, is made at a frequency of 225 MHz with an LFB acoustic lens of 1.0-mm radius, and experimental procedures are established for reliable measurements.

In this study, we take a 4-inch wafer of (111) Gadolinium Gallium Garnet (GGG) with LSAW propagation in the $[\bar{1}\,\bar{1}\,2]$ direction as a standard specimen.

2. MEASUREMENT SYSTEM

Details of the measurement principle and the system were described in our previous paper. A block diagram of the LFB system is shown in Fig. 1. The system consists of an LFB acoustic lens, a pulse mode measurement system, mechanical stages, a wave memorizer, and a computer. An LFB sapphire lens of 1.0 mm in radius is used in this study. In this measurement method, a V(z) curve plays a very important role. A V(z) curve is a transducer output as a function of the relative distance between the LFB lens and a sample surface. V(z) curves are recorded into a wave memorizer synchronized with movement of the z-stage (a) driven by a stepping motor. A typical V(z) curve for a GGG wafer is shown in Fig. 2. As seen in this curve, several dips appear with a certain periodicity owing to interference of the two components of #0 and #1

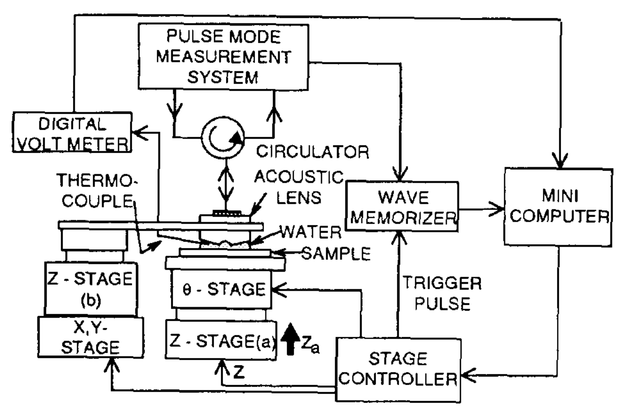

Fig. 1 Block diagram of the LFB acoustic microscope system.

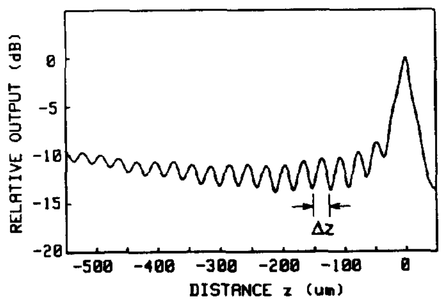

Fig. 2 Typical V(z) curve for (111) GGG with [$\bar{1}\bar{1}$ 2] propagation.

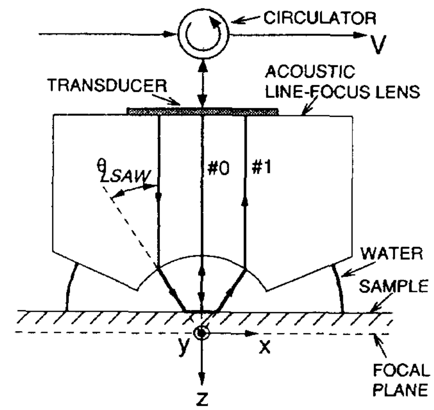

Fig. 3 Cross-sectional geometry of acoustic LFB lens showing construction mechanism of V(z) curve.

in Fig. 3, showing a cross-sectional geometry of the LFB lens. The LSAW velocity is determined with the dip interval Δz using the following equation,

$$V_{lsaw} = \frac{V_W}{\sqrt{1 - (1 - V_W/2f\Delta z)^2}} \quad ... (1)$$

where V_W is the longitudinal wave velocity in water and f is the acoustic frequency. V_W is obtained from the temperature measured with the thermocouple inserted into the water couplant, as shown in Fig. 1, by using the data reported by Greenspan et al. [2]. As shown in this equation, the measurement accuracy depends on the accuracy of V_W and Δz.

2.1 Measurement Environment

Measurements are affected by the environment conditions, especially the temperature stability around the system. Because the measurements are performed with reference to the acoustic properties of water used as acoustic coupling liquid, which are completely determined as a function of temperature. It is a basic requirement for accurate measurements to keep the temperature of water couplant constant. The system is, therefore, installed in the temperature-controlled room with 23±0.1 °C. Furthermore, various kinds of efforts have been made by introducing air-suspension unit to suppress some vibration problems of the mechanical system and a chamber box of acrylic resin covering the whole mechanical system to resolve some environment disturbance due to wind blowing from the air-conditioner unit.

2.2 Mechanical Precision

Measured V(z) curves go through the V(z) curve analysis to determine dip interval Δz. Since the V(z) curve analysis is well-established on the basis of the measurement principle for velocity measurements, an error arising in this analysis is negligible. Thus, the accuracy of Δz depends on how accurately a V(z) curve can be recorded. Here, a movement error can be defined to discuss the accuracy as the following equation,

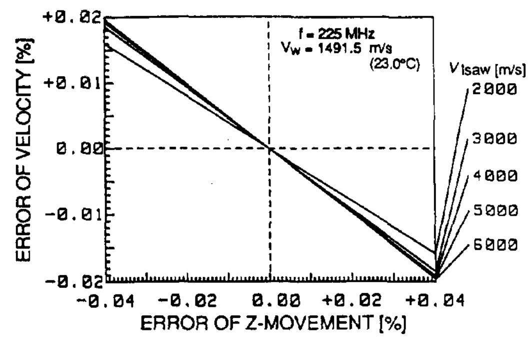

Fig. 4 Calculated results of influence of mechanical errors on LSAW velocity measurements.

$$\delta z = z_a - z \quad ... (2)$$

where z_a is an actual moving distance and z is an instructed distance determined by the number of pulses for the stepping motor.

Let us suppose a case that a z-stage moves up more than an instructed distance, that is, it has a positive movement error ($\delta z>0$). With such z-stage, a V(z) curve is recorded by being compressed along the z axis. As a result, the error in Δz has a negative value, which gives rise to a negative error in measured LSAW velocity. On the other hand, with a z-stage having a negative movement error, a V(z) curve is recorded by being extended along the z axis and the error in Δz has a positive value. Figure 4 shows a calculated result of the influence on LSAW velocity measurements for various velocities. This shows that if required relative accuracy is ±0.01%, the movement error must be within ±0.02%.

3. MEASUREMENTS

3.1 Reproducibility

To make reliable measurements, it is important to know how precisely the z-stage moves. Figure 5 shows the positioning error of the z-stage in the LFB system measured by a laser interferometer. It is found out that the movement error defined previously, which is represented by the inclination of the curve, changes depending on z. Since the movement distance for a V(z) curve at 225 MHz is limited to be as short as 620 μm by the LFB lens, it is important to select a characterization region for V(z) curves.

To investigate the influence of this movement error, experiments were made with a GGG wafer in the following way. First, a V(z) curve was recorded at a certain region of z. Then the position of the LFB lens was moved up with the z-stage (b) by 200 μm, and the z-stage (a) was moved up by the same distance. After that, a V(z) curve was recorded again. By repeating this process, V(z) curves over the whole movable region of the z-stage could be obtained. The results of LSAW velocities through the V(z) curve analysis are shown in Fig. 6, where data are given at the focal points for each V(z) curve. It can be observed that measured velocities changed depending on mechanical regions, with the maximum difference of 0.09%. We experienced for another type of z-stages with the maximum difference of 0.4% or worse. This is a very serious problem in the system for quantitative material characterization. Although it is of fundamental importance to obtain greater z-stage precision, the influence of the movement error has to be taken into account by any means. So there must be some procedures to avoid the influence of this problem. For this purpose, it is effective to use the same region of the z-stage. Even in a case that samples have different thicknesses, this can be realized by adjusting the position of the lens with the z-stage (b).

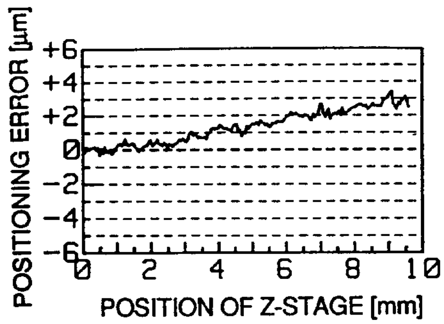

Fig. 5 Positioning errors of z-stage measured by laser interferometer.

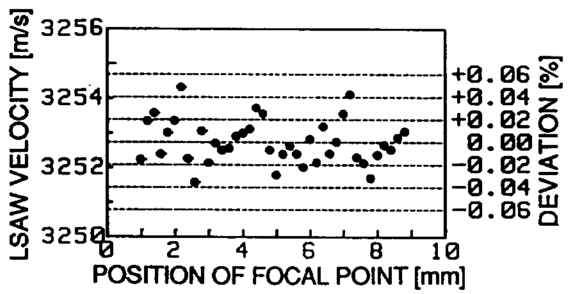

Fig. 6 Measured results of LSAW velocities for different regions of z-stage.

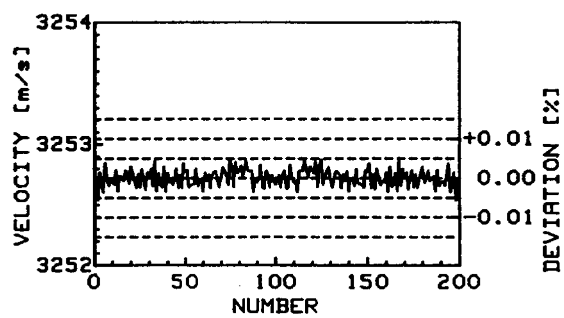

Fig. 7 Results of 200 time-repeated velocity measurements for the same region of z-stage.

To investigate the reproducibility obtained as a result of the stable temperature and the procedure mentioned above, V(z) curve measurements at 225 MHz were repeated 200 times at a single point on the GGG wafer. The z-stage position of z = 3.5 mm was used. The result is shown in Fig. 7. Changes in temperature were within 0.02 °C during the experiments for which it took about one hour. It is observed that changes in measured LSAW velocities were so small that the standard deviation was 0.07 m/s, corresponding to 0.0022%. By taking twice the standard deviation, the relative accuracy can be estimated to be better than ±0.005%.

3.2 Two-Dimensional Measurements

Besides the temperature stability and the movement error, the straightness in the z-stage movement is also a serious problem for two-dimensional velocity measurements on a sample surface. An illustration is drawn over in Fig. 8 for explanation. This z-stage is supposed to have an undesirable straightness, but no error at the center, x=0. In this case, even if the sample is homogeneous, measured velocities become higher at the left side and slower at the right side. The slanting angle θ, defined in Fig. 8, was measured for the z-stage in the system as a function of z by a laser autocollimator. The result is shown in Fig. 9. It is observed that the slanting angle varies with z. Figure 10 (a) shows the typical results of velocity measurements as a function of x position on the GGG wafer. It can be seen that the slanting of the stage affected on the result, and this should be corrected. The region of the z-stage actually used for the V(z) curve analysis was from 3.53 mm to 4.06 mm, where the average inclination of the curve with respect to x-axis in

Fig. 9 was +0.512x10^{-5} rad/mm. Figure 10 (b) shows the velocities corrected by using this value. The maximum difference became as small as 0.008%. This means that this correction is a proper procedure and it is also confirmed that the GGG wafer is suitable for a standard specimen with sufficient elastic homogeneity. This correction can be easily extended to a two-dimensional case. With this correction procedure and the reproducibility determined previously, it can be estimated that the relative accuracy in two-dimensional measurements is better than ±0.01%.

4. CONCLUSION

To carry out accurate measurements with the LFB acoustic microscope system, some requirements have been discussed in details. The temperature stabilization and establishment of the experimental procedures have improved the relative accuracy of our system to better than ±0.005% at a chosen single point, and ±0.01% over a scanning area of 75 mm x 75 mm. The LFB system has been practically applied to resolve problems in the scientific and industrial fields [3-5].

Furthermore, a calibration method for the LFB system has been proposed [6] and this will certainly improve absolute accuracy for applications such as determination of the elastic constants of bulk and thin-film materials.

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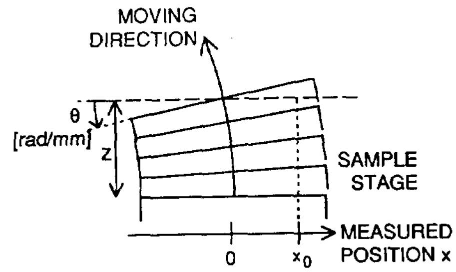

Fig. 8 Illustration of undesirable straightness of the z-stage movement with slanting angle θ.

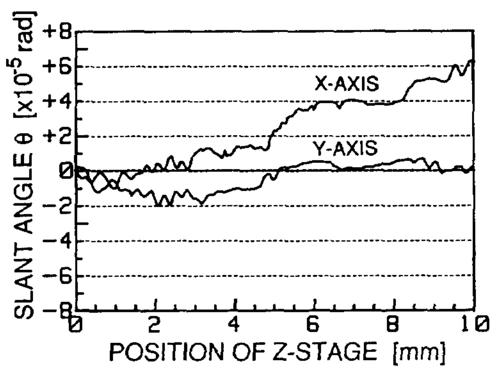

Fig. 9 Slant angle θ of z-stage with respect to x and y axes of the mechanical system, measured by laser autocollimator.

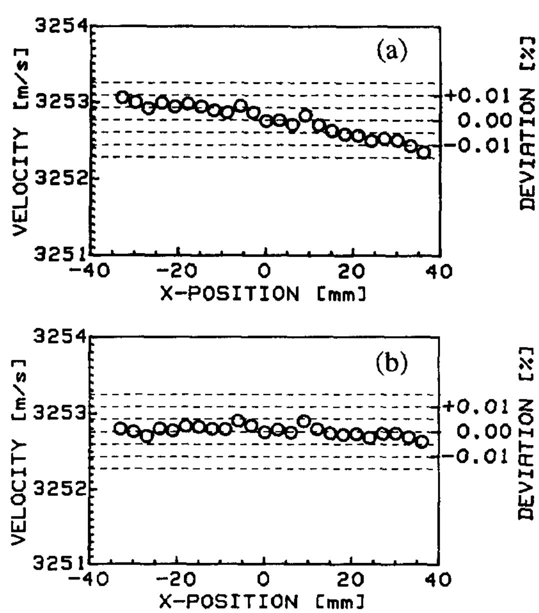

Fig.10 LSAW velocity variation measured along x axis of the mechanical system.
(a) without correction. (b) with correction.