A CALIBRATION METHOD OF THE LFB ACOUSTIC MICROSCOPE SYSTEM USING ISOTROPIC STANDARD SPECIMENS

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ABSTRACT

Absolute accuracy of the line-focus-beam (LFB) acoustic microscope system is investigated for measurements of the leaky surface acoustic wave (LSAW) velocity and attenuation, and a method of system calibration is proposed. In order to discuss the accuracy, it is necessary to introduce a standard specimen whose bulk acoustic properties, viz., the independent elastic constants and density, are measured with high accuracy. Three synthetic silica glass substrates from different manufacturers are taken as isotropic standard specimens. The LSAW propagation characteristics, measured at a frequency of 225 MHz, are compared with the calculated results using the measured bulk acoustic properties.

1. INTRODUCTION

Line-focus-beam (LFB) acoustic microscopy [1] is recognized as a very useful and unique method of quantitative material characterization. Characterization is made by measuring the propagation characteristics, viz., velocity and attenuation, of leaky surface acoustic waves (LSAWs), excited on the boundary between the specimen and the liquid coupling, through V(z) curve analysis. A variety of applications have been extensively and successfully developed to resolve material problems in science and industry [2-6]. Absolute accuracy is, at present, the most important research topic from the technological point of view, for such applications as absolute measurements of the velocity and attenuation, and as determinations of the elastic constants of bulk and thin-film materials [3, 4]. It is also necessary to develop a method of system calibration since different measured values can result from different systems/devices operating at the same frequency.

This paper presents an idea for discussing absolute accuracy of the LFB acoustic microscopy system using isotropic standard specimens and proposes a method for system calibration.

2. CONCEPT OF SYSTEM CALIBRATION

Figure 1 illustrates schematically the concept of a calibration method for the LFB system for studying an isotropic standard specimen having the three independent physical constants of the longitudinal wave velocity V_l, shear wave velocity V_s, and density ρ. The theoretical values of the velocity, V_{lsaw}, and normalized attenuation factor, α_{lsaw}, calculated from the actually measured bulk velocities and density, provide a standard for calibration and are compared with the experimental values obtained by the LFB acoustic microscopy system.

Here, three homogeneous and optically polished substrates of ultrasonically low-loss synthetic silica glasses of T-4040 (Toshiba Ceramics Co.), J-ES (Japan Quartz Glass Co.), and C-7940 (Corning Co.) being approximately 3 mm thick, were taken as isotropic standard specimens for the demonstration.

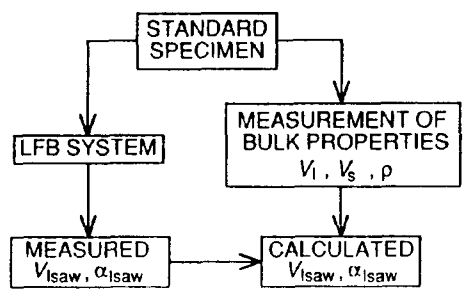

Fig. 1. A concept of calibration of the LFB system.

3. MEASUREMENTS OF BULK PROPERTIES

Measurements of the bulk acoustic properties were made first. Longitudinal and shear wave velocities were measured by the pulse interference method using an RF pulse signal, while densities were measured by a conventional method based on Archimedes' principle by weighing the specimens both in air and in distilled water.

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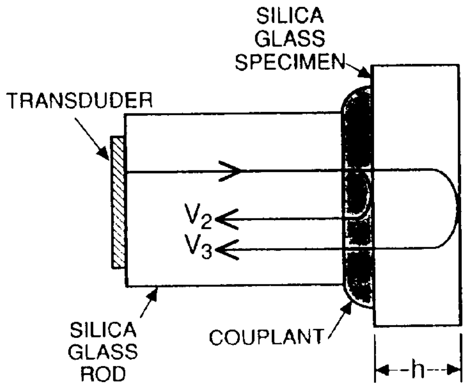

Fig. 2. Experimental arrangement of velocity measurements by the pulse interference method.

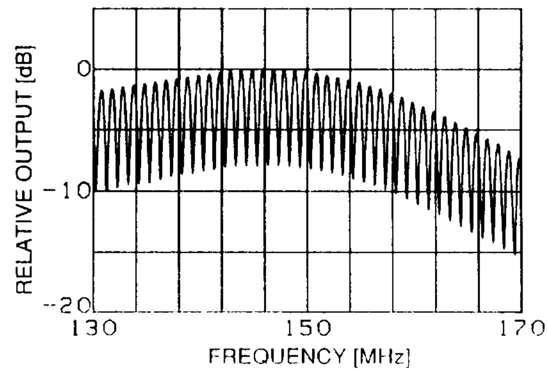

Fig. 3. Frequency response of interference output in longitudinal velocity measurements for synthetic silica glass (T-4040).

Two plane wave ultrasonic devices for velocity measurements were prepared, with a ZnO film transducer for longitudinal waves and an X-cut $LiNbO_3$ transducer for shear waves, on cylindrical buffer rods of synthetic silica glass (T-4040). Velocity measurements were carried out around 150 MHz for the longitudinal waves and around 100 MHz for the shear waves, as shown schematically in Fig. 2. RF pulsed plane waves emitted from the devices are incident on a specimen through a couplant. Partial reflection and transmission occur at the interface between couplant and specimen, and transmitted waves are reflected perfectly at the back surface. Two echoes of V_2 and V_3 reflected from the front and back surfaces of the specimen, respectively, were used for measurements. The RF pulse width was set to be long enough such that the two echoes can overlap and interfere. By gating out the interfered signal and sweeping the ultrasonic frequency, a series of interference maxima and minima can be recorded (see Fig. 3). The frequency interval Δf is related to the phase velocity V for specimen thickness h as $\Delta f=V/(2h)$. The thickness was measured by a digital micrometer with an error of ± 1 µm. In our measurements, the significant figures of determined velocity values are four digits, which is essentially determined by the thickness measurements. Coupling materials are distilled water for longitudinal waves and a thin layer of bonding material Salol for shear waves. For shear wave velocity measurements, corrections for phase shifts at the Salol bond must be made for accurate determinations of shear wave velocities.

Table I. Measured bulk acoustic properties of standard specimens.

Specimen	V_l (m/s)	V_s (m/s)	ρ (kg/m^3)
T-4040	5953	3757	2203.2
J-ES	5928	3762	2201.7
C-7940	5933	3764	2201.9

Figure 3 shows the typical frequency response of the interference output measured for a specimen of T-4040 synthetic silica glass. From this waveform, we can measure Δf=1.00283 MHz. With the measured thickness h=2.968 mm, the longitudinal wave velocity was determined to be V_l=5952.8 m/s. The velocities and densities measured for three specimens are shown in Table I. It is seen clearly from these measurements that these synthetic silica glasses have slightly different values in longitudinal and shear velocities, as well as in density. The T-4040 silica glass has significantly greater density and longitudinal velocity and slightly smaller shear velocity values than the two other specimens. The maximum differences of the velocities and densities are about 25 m/s (0.42%) for the longitudinal velocity, 7 m/s (0.19%) for the shear velocity, and 1.5 kg/m^3 (0.068%) for the density, respectively.

4. LSAW PROPAGATION CHARACTERISTICS

Next, in order to obtain the LSAW propagation characteristics, V(z) curve measurements were performed at 225 MHz by the LFB system having the LFB device used for the recent and practical applications [5, 6]. Experiments were repeated 50 times at the same central point on each specimen. Figure 4 shows one of the V(z) curves measured for the T-4040 specimen. According to the procedure of V(z) curve analysis, the LSAW velocity and normalized attenuation factor were determined to be 3432.7 m/s and 3.99×10^{-2}, respectively. For the 50 curves, the average velocity is obtained to be

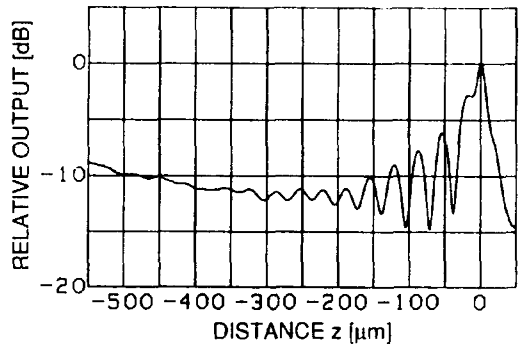

Fig. 4. V(z) curve measured at 225 MHz for synthetic silica glass (T-4040).

3432.6 m/s with the maximum deviation of 0.9 m/s (0.026%), and the average normalized attenuation factor to be 4.00×10^{-2} with a maximum deviation of 3×10^{-4} (0.66%). These data guarantee the reproducibility of V(z) curve measurements by the present LFB system. Similar experiments were carried out for the other glasses. The data are tabulated in Table II. As expected from the variations of the measured velocities and densities shown in Table I, we found some slight differences among the measured LSAW propagation characteristics for the three glasses. Velocity experiments were further made to investigate elastic inhomogeneities on both the front and back surfaces of the specimens over an area of 5mm x 5mm, which included the region used for measurements of the bulk and LSAW properties. It was confirmed that these standard specimens had adequate homogeneities, on which no significant velocity variations were observed within the measurement errors of ±0.01%.

Calculations of the theoretical propagation characteristics were made by using the measured bulk velocities and densities for the glasses in Table I and, for distilled water, the longitudinal velocity of 1491.234 m/s and the density of 997.54 kg/m^3 at 23°C. The values are given in Table II as compared with the measured results. The theoretical calculations predict slightly different LSAW propagation characteristics for each specimen, reflecting the different measured bulk acoustic properties described above. The phase velocity of the C-7940 specimen is considerably greater than those of the other specimens, and the velocity of the T-4040 is almost as great as that of the J-ES. On the other hand, the normalized attenuation factor of the T-4040 is clearly lesser than those of the other specimens. It is seen in Table II that the experimental results for all the specimens are slightly greater than the calculated results. For example, the measured values of V_{lsaw}=3432.6 m/s and $\alpha_{lsaw}=4.00 \times 10^{-2}$ for the T-4040 specimen are different from the calculated values of V_{lsaw}=3421.2 m/s and $\alpha_{lsaw}=3.855 \times 10^{-2}$. The differences are +11.4 m/s (+0.33%) in velocity and +0.15 (+3.8%) in attenuation. It is interesting to note that nearly the same differences in velocity and in attenuation are observed between the experimental and theoretical values for all the specimens, and that the LSAW velocities and normalized attenuation factors vary reasonably depending upon the specimens, as predicted in the calculated results. The differences in velocity and attenuation for each specimen should be corrected for the calibration of this LFB system.

5. CONCLUDING REMARKS

We have proposed a calibration method for the LFB acoustic microscopy system, for quantitative material characterization, in which a standard is given by the theoretical LSAW propagation characteristics, viz., velocity and attenuation, of standard specimens calculated with the bulk acoustic properties measured with sufficient accuracy. The demonstration has been made satisfactorily, at 225 MHz, for isotropic standard specimens of synthetic silica glasses. All the materials, including nonpiezoelectric and piezoelectric materials could be ap-

Table II. Calculated and measured LSAW propagation characteristics of standard specimens.

	V_{lsaw} (m/s)			α_{lsaw}		
specimen	calculated	measured	difference (%)	calculated	measured	difference (%)
T-4040	3421.2	3432.6	+0.33	3.855×10^{-2}	4.00×10^{-2}	+3.8
J-ES	3421.7	3432.4	+0.31	3.891×10^{-2}	4.04×10^{-2}	+3.8
C-7940	3424.0	3436.7	+0.37	3.886×10^{-2}	4.02×10^{-2}	+3.5

propriate for the standard specimen if all the physical constants necessary for the theoretical calculations of the LSAW characteristics can be determined by accurate measurements. The following requirements should be applied for selecting the standard specimen: single crystals with less anisotropy and negligibly small acoustic loss at higher frequencies; materials with moderate LSAW velocity and attenuation to produce many continuous oscillations in the V(z) curve over the entire defocus region used for the V(z) curve analysis. From our experience, a gadolinium gallium garnet (GGG) single crystal, which belongs to the cubic system and has three independent elastic constant c_{11}, c_{12}, and c_{44}, will be one of the most suitable materials for the complete calibration. It is expected that the system calibration can be made with this standard specimen at any frequencies where the LFB system can be applied to material characterization.

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