DIRECTIONAL ACOUSTIC MICROSCOPE WITH ELECTRICAL REFERENCE SIGNALS

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INTRODUCTION

The acoustic microscopes have been expected to be widely used in the fields of biological science, material characterization, nondestructive evaluation and others. For the quantitative measurements, several types of scanning acoustic interference microscope (SAIM) have been developed so far, to measure the velocity distributions in thin materials and/or topological profiles on the solid surfaces in imaging systems including SAIMs, a point-focus-beam has been employed for high resolution. On the other hand, with the nonscanning reflection acoustic microscope, a line-focus-beam has been introduced for the quantitative measurement of acoustic properties including anisotropy on various solid surfaces. A measurement system for the anisotropic materials have been successfully established with high accuracy. However, the line-focus-beam usually has a line width wider than 1 mm, so that the results obtained by the system show the mean values over the line width. A directional scanning acoustic microscope has been already proposed, which reveals elastic anisotropy with high spatial resolution. In that acoustic microscope, however, directly reflected waves from the sample is necessary to interfere with re-radiated leaky surface waves on the sample for the $V(z)$ curve establishment. If only the leaky surface waves can be excited and detected with perfect elimination of the directly reflected waves from the sample, the shapes of $V(z)$ curves can be preferentially controlled by mixing the received signals with the electrical reference signal. Recently, "Ultrasonic Micro-Spectroscopy (UMS)" has been expected for the development of a new field in material science and technology.

In this paper, a new directional point-focus-beam acoustic microscope with a variable phase shifter is demonstrated for the UMS system with which both quantitative measurement of surface wave velocity and two-dimensional imaging can be made including the angular dependence on a small area of the samples. The construction of the system and some experiments on the imaging and $V(z)$ curve measurement are described. Anisotropic measurements of leaky SAW velocity for a Y-cut LiNbO$_3$ wafer and images obtained for Mn-Zn ferrite ceramics are demonstrated in the frequency range between 60 and 200 MHz.
CONSTRUCTION OF THE SYSTEM

Figure 1 shows a block diagram of the directional acoustic interference microscope system for two-dimensional imaging and V(z) curve measurement. In this system, the focused acoustic pulse signal radiated by a transducer (transmitter) is reflected at the sample surface and received by another transducer (receiver). The received signal is mixed with the electrical reference signal through the variable phase shifter and the variable attenuator so that acoustic image contrast can be desirably controlled. This system can be said to be a modified system of the scanning acoustic interference microscope (SAIM) for the reflection mode. The cross-correlation signal between the received and the reference signal is obtained as the V(z) signal so that both the amplitude and the phase information can be detected.

Acoustical images can be displayed on the CRT by the conventional electronic techniques, as the acoustic beam is scanned in the X and Y directions synchronously with the raster scan of the CRT. In the V(z) curve measurements, the received output signals are observed as a function of moving distance z when the sample is moved along Z axis toward the acoustic transducers by a Z-stage controller. In this system, with the digitally controlled variable phase shifter newly introduced in the reference signal line, the phase difference between the received and the reference signal can be varied in association with the variation of distance between the acoustic transducer and the sample. The correlation output signals are taken into a computer through the A/D converter, and are recorded on the X-Y recorder. The dip interval Δz of V(z) curve is determined by the FFT analysis and then the leaky SAW velocity \( v_{\text{leaw}} \) of sample is calculated. For the directional measurements, the sample stage can be rotated around Z axis.

In this system, the phase variation \( \phi_p \) of reference signal is controlled to be proportional to the variation \( \delta z \) of distance z between the transducer and the sample. The relation between \( \phi_p \) and \( \delta z \) is expressed as,

\[
\phi_p = 2k_p \delta z
\]

where the proportional constant \( k_p \) is the equivalent wave number. The phase velocity \( v_{\text{leaw}} \) of leaky SAW can be determined from the dip interval \( \Delta z \) of V(z) curve by the similar manner as the conventional V(z) measurement. Using the equivalent wave number \( k_p \), the dip interval \( \Delta z \) is given approximately by the following equation,

\[
\Delta z = v_p / 2f (k_p / k_p - \cos \theta_{\text{leaw}})
\]

where \( \theta_{\text{leaw}} = \sin^{-1} (v_p / v_{\text{leaw}}) \) is the critical angle of leaky SAW, \( v_p \) and \( k_p \) is the longitudinal velocity and the wave number of coupling liquid respectively, \( f \) is the acoustic frequency. Equation (1) can be represented also in terms of \( v_{\text{leaw}} \) as

\[
v_{\text{leaw}} = v_p / [1 - (R_k - v_p / 2f \Delta z)^2]^{1/2}
\]

where \( R_k = k_p / k_{\text{leaw}} \) is the equivalent wave number ratio. Equation (2) shows that in case of \( R_k > \cos \theta_{\text{leaw}} \), the changing rate of \( \Delta z \) against \( v_{\text{leaw}} \) is increased as \( R_k \) is decreased, while in case of \( R_k < \cos \theta_{\text{leaw}} \), the changing rate of \( \Delta z \) against \( v_{\text{leaw}} \) is decreased with reversed sign as \( R_k \) is decreased.

Figure 2 shows the normalized dip interval \( f \Delta z \) as a function of \( v_{\text{leaw}} \) where a parameter is \( R_k \). The curve of \( R_k = 0 \) corresponds to the case of