DIRECTIONAL POINT-FOCUS-BEAM ACOUSTIC MICROSCOPE SYSTEM

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ABSTRACT

A practical system of directional point-focus beam (PFB) acoustic microscope with two functions of imaging and quantitative measurements is developed based on our previous study. Construction and performance of the system are described in this paper. The system is demonstrated for investigation of a polycrystalline sample of Mn-Zn ferrite with an average grain size of 100 µm using two directional PFB devices. Directional acoustic images are obtained at 225 MHz and 375 MHz in several different propagation directions of leaky surface acoustic waves (LSAWs). Measurements of LSAW velocity, including the angular dependence in some grains of the sample, are performed according to the procedure of V(z) curve analysis. Anisotropic elastic properties of each grain are characterized both in imaging and in quantitative measurements.

1. INTRODUCTION

In acoustic microscopy, there are two functions of imaging and quantitative measurements for material analyses. Acoustic images are obtained with a point-focus-beam (PFB) acoustic microscope providing high spatial resolution. Quantitative measurements through the V(z) curve analysis are made with a line-focus-beam (LFB) acoustic microscope, with perfect directionality, providing the capability of detecting material anisotropy, though the system is not suitable for imaging. The conventional PFB acoustic microscope system, however, presents a serious problem for users that the system may not be applicable for extracting true information of anisotropic materials from the obtained images, because of lack of the directionality. The introduction of LFB acoustic microscopy triggered development of directional acoustic microscopy with two functions of imaging and quantitative measurements combined effectively. Recently, such a microscope has been demonstrated at 200 MHz range by introducing a directional PFB device with a simple rectangular transducer instead of a circular transducer, by limiting excitation of leaky surface waves (LSAWs) within a narrow angle, employing two systems of PFB and LFB microscopes [1-2].

In this paper, a practical system of directional PFB acoustic microscope is constructed based on our previous study. Two directional PFB devices operating at 225 MHz and 375 MHz are designed by taking into account the acoustic fields and the effect of the beam steering of LSAWs due to material anisotropy on the transducer output. The system is demonstrated for characterization of a polycrystalline sample of Mn-Zn ferrite with an average grain size of 100 µm.

2. CONSTRUCTION OF THE SYSTEM

Figure 1 shows a block diagram of a directional acoustic microscope system developed here. The mechanical system is composed of a fast scanner for scanning an acoustic device along the x axis direction, an automatic Z-stage for movement along the z axis direction, an automatic XY-stage for translating the sample stage along the x and y axes, respectively, and then a manual XY-stage and a rotation stage introduced for this directional microscope system. The central beam axis of acoustic device can be exactly aligned with the axis of the rotation stage by the automatic XY-stage located at the lowest position. The manual XY-stage on the rotation stage can be used to select an area on the sample surface illuminated by a focused acoustic beam. We can make imaging and quantitative measurements on chosen areas as a function of LSAW propagation direction. Figure 2 is a photograph of the mechanical system. A two-axis (XY) goniometer and a manual Z-stage are also set for sample adjustment.

The electrical system is composed of the transmitter and receiver, control unit, A/D converter and memory, display unit, and mini-computer. An RF pulse signal from the transmitter is converted to an ultrasonic signal by an ultrasonic transducer, and focused ultrasonic waves are irradiated on the sample. Ultrasonic waves reflected from the sample are converted to electrical signals by the same ultrasonic transducer. The signals are amplified and detected as amplitude and phase signals in the receiver, and converted to video signals for two dimensional imaging or V(z) curve measurements. This system can be operated both in amplitude and phase modes. By using the phase mode, we can easily make the sample alignment with respect to the scanning plane.

Operating procedures to obtain directional images are as follows: First, the axis of the rotation stage is completely aligned with the axis of the acoustic device and the sample is moved to a desired position, and then the acoustic beam illuminates an observation area on the sample. After an image is recorded, the sample is automatically returned to the original position, and the center of acoustic beam is located at the center of the imaging area. So, various acoustic images in different LSAW propagation directions can be obtained by rotating the sample around the z axis.

In V(z) curve measurements, the fast scan is stopped, and the output voltage of the transducer is recorded by changing the distance between the acoustic lens and the sample surface. The obtained V(z) data are analyzed according to the procedure of V(z) curve analysis [3] established for the LFB acoustic microscope, to obtain the acoustic properties of LSAW velocity and attenuation.

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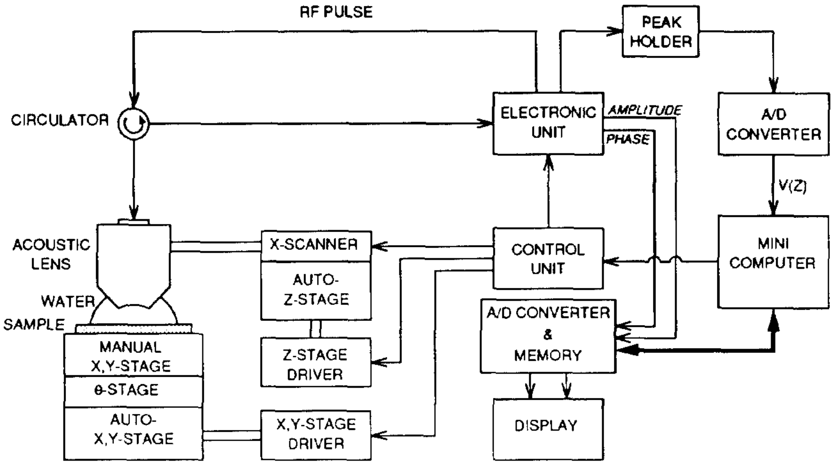


Fig. 1 Block diagram of directional PFB acoustic microscope system.

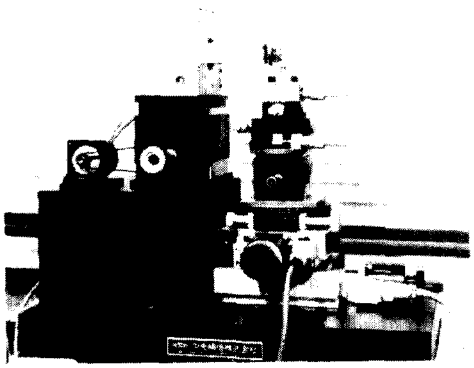


Fig. 2 Photograph of mechanical system of directional acoustic microscope.

3. EXPERIMENTS

Two kinds of directional PFB acoustic devices with the rectangular transducers were fabricated around the center frequencies of 225 MHz and 375 MHz on the flat end surfaces of PFB acoustic lenses. The configuration and device parameters are given in Fig. 3 and Table 1, respectively.

The 3 dB widths of acoustic beam along the x axis direction in Fig. 3 at the focal plane are measured to be 6 μm for the 225 MHz device and 4 μm for the 375 MHz device, respectively. These values are comparable to the acoustic wavelengths in water, respectively. The beam widths along the y axis direction are broaden to be 9 μm at 225 MHz and 6 μm at 375 MHz due to the wave diffraction effect. A polycrystalline sample of Mn-Zn ferrite with average grain size of 100 μm was taken for experiments.

3.1 Images and contrast variations

The contrasts of acoustic image vary with the defocus distance in complicated manner. Figure 4 (a) - (d) show directional acoustic images observed on the sample for the different LSAW propagation directions at 225 MHz at the defocus distance of $z = -40$ μm. In the system, the larger output voltage of the transducer is displayed brightly in imaging. In these pictures, it is found that the contrast of the images vary with the LSAW propagation direction, due to different crystalline orientations among the anisotropic grains. The grain A shows larger contrast variation depending upon the LSAW propagation direction, while the grain B and C show less constant variations. These variations can be explained by V(z) curves obtained for each grain surface.

Taking the typical grains marked in Fig. 4, the V(z) curves have been measured in the four different directions of LSAW propagation of $\theta = 0°, 30°, 60°$, and $90°$. The V(z) curves for the grain A are shown in Fig. 5. In this figure, the output voltage at the defocus distance of $z = -40$ μm increases as θ increases from 0° to 90°. Comparing the four curves, it is easily understood that the output voltage differences among the four curves at the defocus distance of $z = -40$ μm directly correspond to the constant variations appearing in Fig. 4 (a)-(d). The dip interval Δz in V(z) curves can be related to the LSAW velocity as follows:

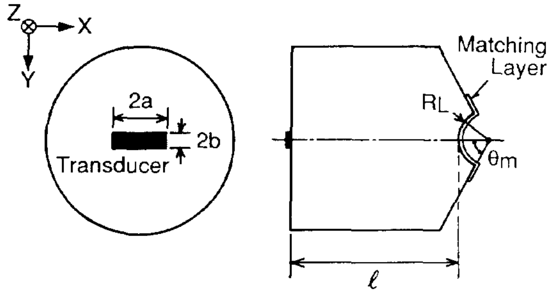


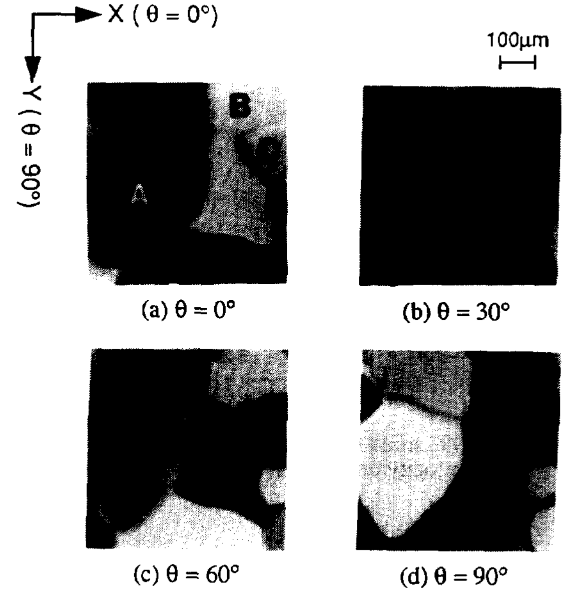
Fig. 3 Configuration of the directional PFB acoustic device with rectangular transducer.

Table 1. Dimensions of directional PFB devices for experiments.

Center frequency	f (MHz)	225	375
Rod length	ℓ (mm)	5.5	2.3
Radius of curvature	R_L (mm)	1.0	0.5
Aperture half angle	θm	60°	60°
Transducer size	2a	1.73	0.865
	2b	0.5	0.25
Matching layer		As-S-Se film	

$$\Delta z = \frac{v_W}{2f\,(\,1 - \cos\theta_{lsaw}\,)}$$

where $\theta_{lsaw} = \sin^{-1}(v_W / v_{lsaw})$. θ_{lsaw} is the LSAW critical angle between the water and sample, v_W the longitudinal velocity in water, v_{lsaw} the LSAW velocity on the water/sample interface, and f the acoustic frequency. A larger dip interval in



(a) θ = 0° (b) θ = 30°

(c) θ = 60° (d) θ = 90°

Fig. 4 Acoustic images of Mn-Zn ferrite with average grain size of 100 μm obtained at 225 MHz in different LSAW propagation directions (defocus z = - 40 μm).

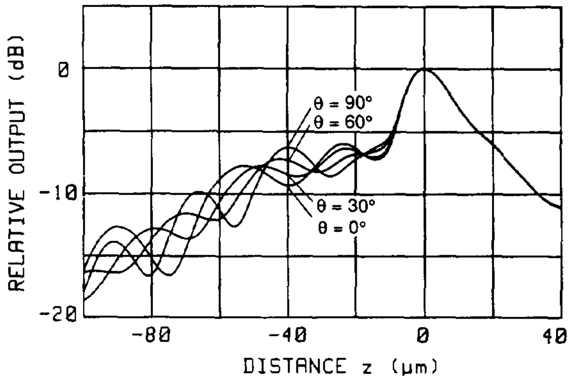


Fig. 5 V(z) curves measured at 225 MHz on grain A in different LSAW propagation directions.

the V(z) curve corresponds to a larger LSAW velocity. In Fig. 5, the dip intervals decrease as changing θ from 0° to 90°, because the corresponding LSAW velocities decrease.

In Fig. 6, four V(z) curves measured for the grain C are shown. The output voltage changes at the defocus distance of z = - 40 μm also correspond to the contrast variations appearing in Fig. 4.

Figure 7 shows directional acoustic images observed at 375 MHz at the defocus distance of z = - 24 μm on the same sample in the different LSAW propagation directions. The boundaries among grains are clearly displayed in comparison with the images obtained at 225 MHz, because the lateral resolution is increased.

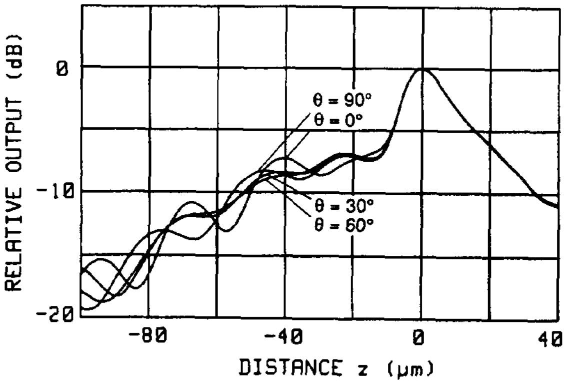
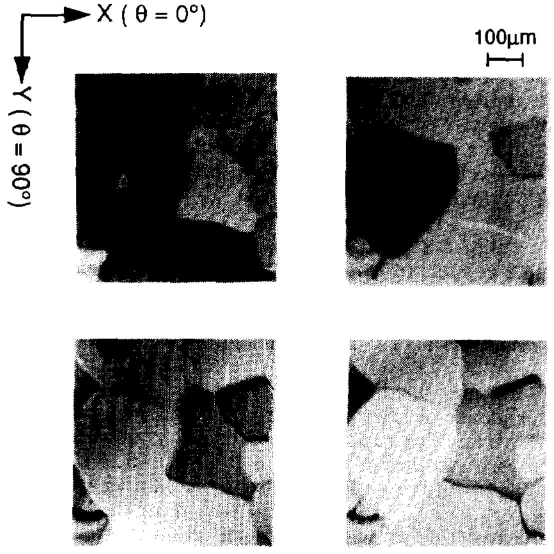


Fig. 6 V(z) curves measured at 225 MHz on grain C in different LSAW propagation directions.



(c) θ = 60° (d) θ ≈ 90°

Fig. 7 Acoustic images of the same ferrite sample as that shown in Fig. 4, obtained at 375 MHz in different LSAW propagation directions (defocus z = - 24 μm).

3.2 Anisotropy measurements of grain surfaces

For the grains studied in imaging, LSAW velocities were measured as a function of the rotation angle of a sample by the V(z) curve analysis, rotating the sample around the center of the grains. Taking into account the fact that the effect of the beam steering on the transducer output becomes more remarkable as the defocusing distance z increases [1], we made data analysis of V(z) curves in the limited defocus region near the focal point. Figure 8 shows the measured results of angular dependence of LSAW velocity on the grains of A, B, and C as marked in Fig. 4 at 225 MHz with the limited region from z = - 20 to - 80 μm. The directions of 0° and 90° in this figure correspond to the x- and y-axis directions taken in imaging, respectively. The

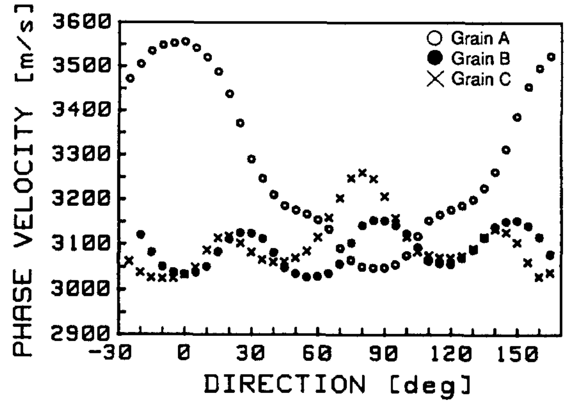


Fig. 8 Measured results of angular dependence of LSAW velocity on grain A, B, and C at 225 MHz.

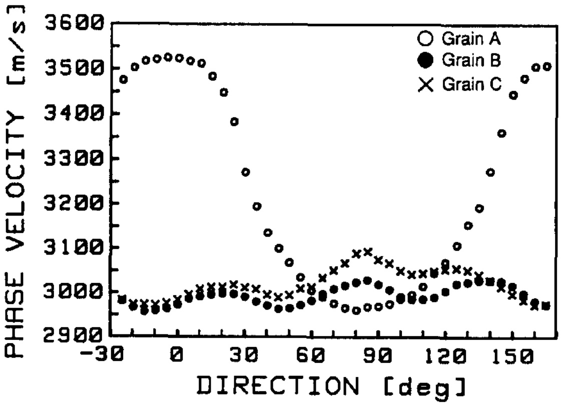


Fig. 9 Measured results of angular dependence of LSAW velocity on grain A, B, and C at 375 MHz.

angular dependences of LSAW velocity for every grain are different, because the grains have different crystalline orientations. The variations of LSAW velocity between 0° and 90° coincide with the above explanation from the variations of the dip interval in V(z) curves. The angular dependences of LSAW velocity on the grain A, B, and C indicate 180°, 60°, and 180° symmetry, respectively.

From the study with the LFB acoustic microscope for single crystals of Mn-Zn ferrite, it has been identified that the surfaces of grain A and B correspond to a (110) plane and a (111) plane, respectively, and the surface of grain C is estimated as a (110) plane with a little inclination angle.

Figure 9 shows the measured results of angular dependence of LSAW velocity on the grains of A, B, and C at 375 MHz. The region of defocusing distance for V(z) curve analysis was limited from $z = -12$ to -48 μm. Anisotropic properties of the grains are also detected reasonably, although the results are fairly different from those at 225 MHz. The values of LSAW velocity for the grain A are about 5 % in maximum smaller than those for 225 MHz in the LSAW propagation direction from $\theta = 30°$ to 140°. On the grains of B and C, LSAW velocities are also smaller than those for 225 MHz over the whole range of propagation direction. The velocities are measured here as the mean values around the limited excitation angles of LSAWs. Such different results might be allowable in directional PFB acoustic microscope, considering that the two devices have different responses for anisotropic property of material, including the effect of the beam steering.

4. CONCLUSION

A directional acoustic microscope system with two functions of imaging and quantitative measurements for material analyses has been constructed using a directional PFB acoustic device with a simple rectangular transducer. Experiments for a polycrystalline sample of Mn-Zn ferrite have been satisfactorily demonstrated at the frequencies of 225 MHz and 375 MHz. The directional images have been presented with significant contrast varying with the LSAW propagation directions. The anisotropic properties of each grain have been quantitatively measured with this system.

Further investigations should be made, in order to understand the detailed performance of the directional PFB acoustic microscope system, utilizing the function of the complex measurements of amplitude and phase involved in our system and developing the complex V(z) curve analysis and micro-defocus analysis to avoid the beam steering effect on the transducer output.

The directional PFB acoustic microscope developed here is expected to be a powerful system in the ultrasonic-micro-spectroscopy (UMS) technology for material analyses [4].

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