PERFORMANCE OF CONCAVE TRANSDUCERS IN ACOUSTIC MICROSCOPY

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ABSTRACT

Performance of scanning reflection acoustic microscope system using concave transducers has been investigated numerically and experimentally. V(z) characteristics which contains information of leaky surface acoustic waves (LSAWs) at the water/sample boundary is useful to analyze the performance of the system. In this paper, numerical analyses of V(z) curves are made through the transfer function of the system using a concave transducer based on the field theory, taking a fused quartz as a typical sample. The experiments are performed at a frequency of 375 MHz. It is revealed that the amplitude response of V(z) curve contains a rapid periodic variation in the defocus region, which is not directly related to the propagation properties of LSAW, while the phase response of V(z) curve depends strongly on the propagation properties of LSAW.

1. INTRODUCTION

In the acoustic microscope system, focusing devices are most important to obtain convergent acoustic beams. In the conventional system, an acoustic lens has been widely employed [1]. A concave transducer has been proposed by Chubachi as an alternative to be applied in the acoustic microscope system [2]. The basic focusing characteristics of concave transducer and its applicability in acoustic microscopy have been reported at about 200 MHz [3]-[5]. Recently, a new copolymer concave transducer has been developed for broadband characteristics up to 500 MHz with a high conversion efficiency [6]. The performance of the acoustic microscope system with the concave transducer in reflection mode has not been satisfactorily clarified, although a preliminary study on V(z) characteristics obtained with concave transducer has been made through a ray-optical approach by Bertoni and Somekh [7].

In this paper, the performance of the scanning reflection acoustic microscope system using a concave transducer is investigated through V(z) characteristics numerically and experimentally on the basis of field theory.

2. NUMERICAL CONSIDERATIONS

2.1 V(z) CHARACTERISTICS

Figure 1 shows the cross-sectional geometry of a concave transducer and coordinate system to calculate the V(z) curve, in which R_L and α_m are the radius of curvature and half-aperture angle for concave surface, respectively. In the figure, r_1, r_2 and r_3 coordinates are positioned on the concave surface, focal plane, and sample plane, respectively. By using the similar analysis based on field theory for the acoustic line-focus beam lens developed in reference [8], the V(z) for concave transducer is represented as follows:

$$V(z)=2\pi\int_0^\infty \{U_2^+(k_r)\}^2 R(k_r)\exp(j2k_z z)k_r dk_r \quad (1)$$

The quantity $\{U_2^+(k_r)\}^2$ is the transfer function in the reflection mode, which is determined uniquely by the dimensions of the concave transducer and operating frequency. The function $R(k_r)$ is the reflectance function which reflects the acoustic information of solid sample being considered. The

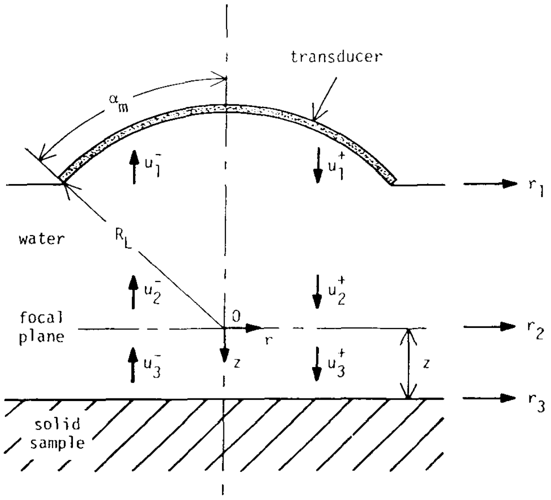

Fig.1 Cross-sectional geometry of concave transducer and coordinate system to calculate V(z) curve.

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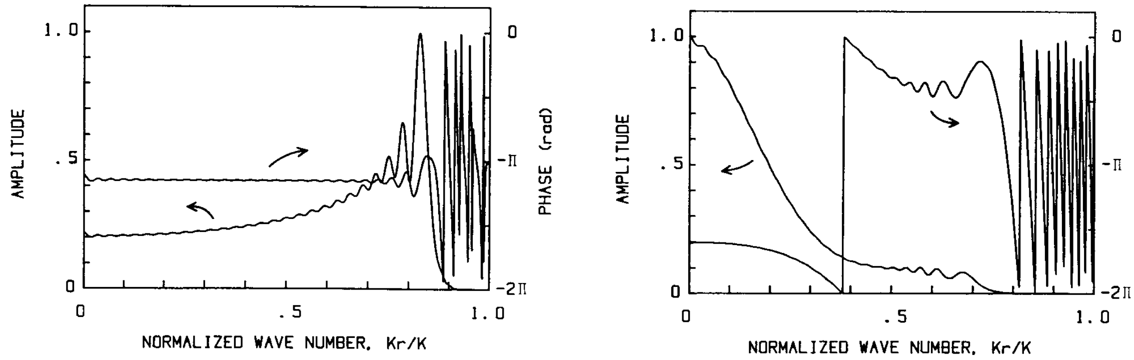


(a) concave transducer

(b) acoustic lens

Fig.2 Calculated transfer functions for the systems using a concave transducer and an acoustic lens at 375 MHz.

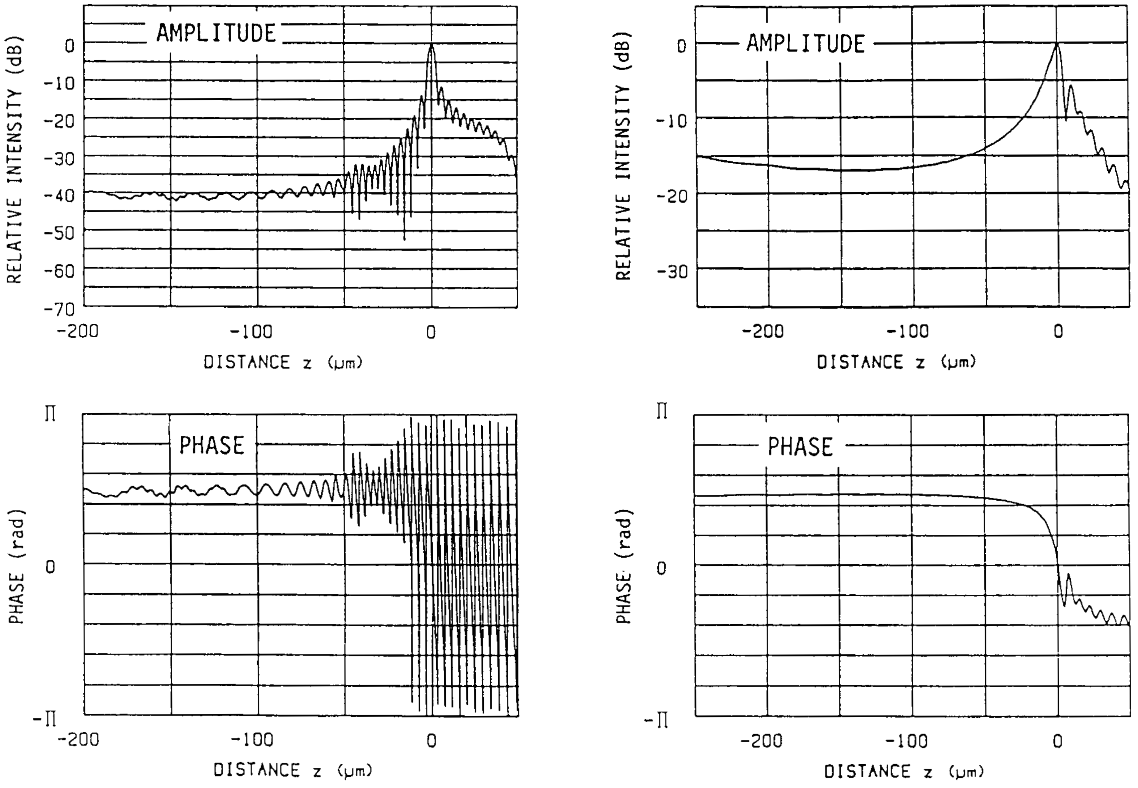
quantity k_r is the r-component of wavenumber k for longitudinal acoustic waves in water corresponding to the spatial frequency in the r direction, and k_z is the z-component of wavenumber k defined as $k_z=(k^2-k_r^2)^{1/2}$.

2.2 CALCULATED RESULTS AND DISCUSSIONS

A V(z) curve to be obtained with the system using a concave transducer is numerically calculated, taking fused quartz as a typical sample material. For the comparison, a V(z) curve to be obtained with the system using an acoustic lens is also calculated. The following device parameters are chosen in the calculations:
radius of curvature of concave surface; R_L=0.5 mm,
half-aperture angle of concave surface; α_m=60°,
and acoustic frequency; f=375 MHz.

Figure 2 (a) and (b) show the transfer functions $\{U_2^+(k_r)\}^2$ calculated numerically for the systems using a concave transducer and an acoustic lens, respectively, as a function of the normalized wavenumber k_r/k. In the calculations, wave diffraction, propagation loss of acoustic waves, and effect of the acoustic matching layer are taken into consideration. The transfer functions for both systems have the normalized wavenumber components up to 0.9. This is due to the fact that the half-aperture angle α_m of the concave surface is limited to be 60° which corresponds to normalized wavenumber of 0.86. In the case of the system using an acoustic lens, the amplitude of the transfer function has the maximum at a normalized wavenumber k_r/k=0 corresponding to the normal incidence of acoustic waves, and decreases monotonously with increase of k_r/k. In the case of the system using a concave transducer, the amplitude has almost uniform distribution and increases gradually with k_r/k. On the other hand, differences between the phase variations for both the systems cannot be seen.

V(z) curves reflecting the characteristics of the system with an acoustic focusing device are numerically analyzed by two components, namely, amplitude and phase. First, an ideal sample reflector is taken for the calculation, where no leaky surface acoustic waves can be excited. Figure 3 (a) and (b) show calculated results using the values given by the transfer functions in Fig.2. The phase shown in Fig.3 is that of the V(z) curve with the phase change exp(j2kz) due to the change in separation between the focusing device and the reflector extracted out. In the case of the system using an acoustic lens as shown in Fig.3(b), the amplitude decreases quickly with -z of distance and becomes almost constant, while the phase in the negative z region keeps almost constant except for the vicinity of focal point. This is, as well known, due to the fact the acoustic waves propagating along z-axis contribute effectively to the transducer responses in the negative z region. On the other hand, in the case of the system using a concave transducer as shown in Fig.3(a), the amplitude decreases with rapid vibrations of periodicity of around 4 μm. The phase changes with the same periodicity as that of the amplitude with respect to -z, and its variations become small. Thus, the characteristic response for the system using a concave transducer is quite different from that for the system using an acoustic lens.



(a) concave transducer

(b) acoustic lens

Fig.3 Calculated V(z) curves for an ideal sample reflector at 375 MHz.

Next, V(z) curves obtained with the system using each focusing device are numerically calculated, taking fused quartz as a sample material. Figure 4 shows the calculated reflectance function R(k_r) on the water/fused-quartz boundary as a function of normalized wavenumber k_r/k. Figure 5 (a) and (b) show the calculated V(z) curves. In Fig.5, the phase is also shown as that of the V(z) curve with the removed phase change of exp(j2kz). In the V(z) curve for the system using an acoustic lens, both the amplitude and the phase in the negative z region vary with a periodicity around 20 μm, and exhibit a simple variation. This can be explained by interference of two wave components; a directly reflected wave component propagating along z-axis and leaky surface acoustic wave (LSAW) component excited on the water/fused-quartz boundary. In the V(z) curve for the system using a concave transducer, on the other hand, the amplitude presents apparently complex variation in a region between z=0 μm and z=-75 μm. This is due to the superimpose of the

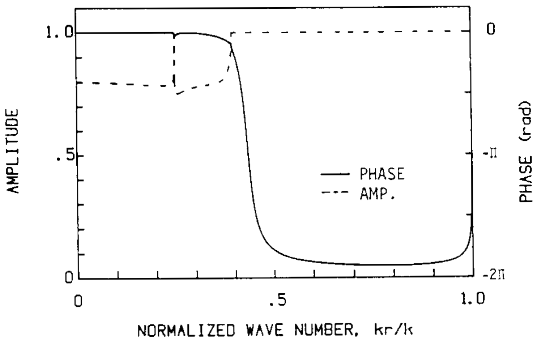
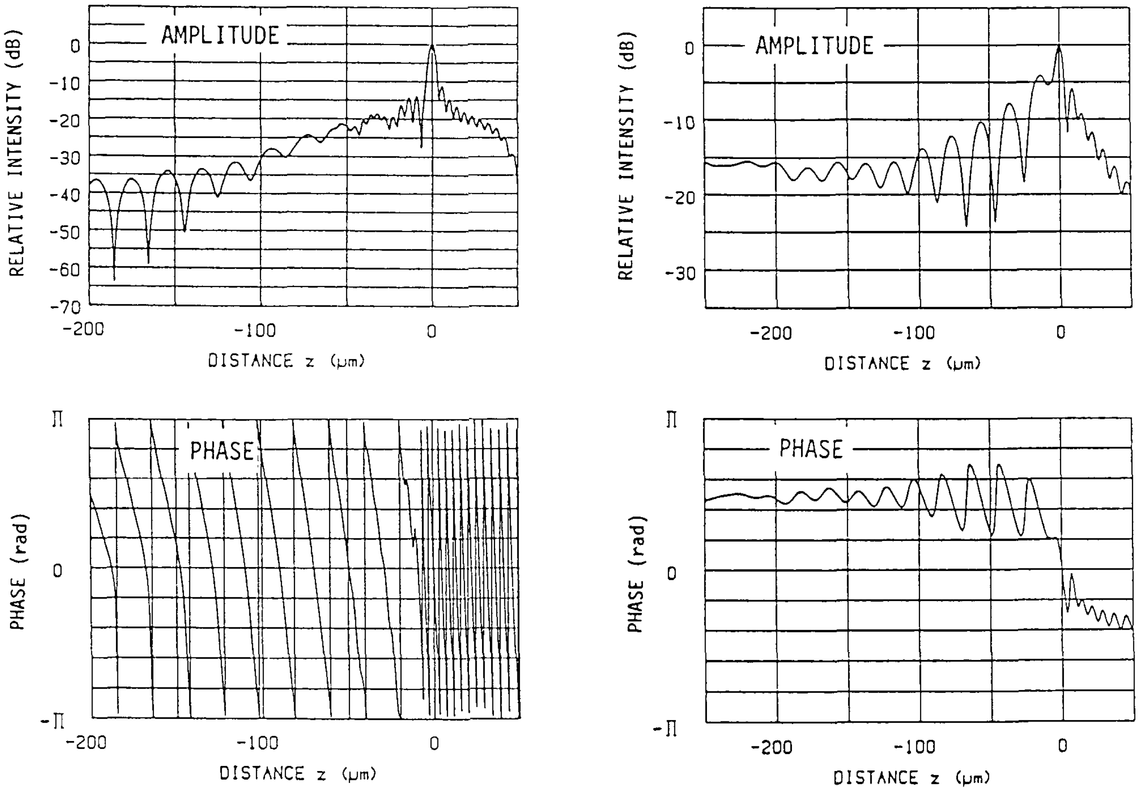


Fig.4 Calculated reflectance function on water/fused-quartz boundary.



(a) concave transducer

(b) acoustic lens

Fig.5 Calculated V(z) curves for fused quartz sample material at 375 MHz.

variations having different periodicities of about 4 µm associated with the characteristic response for the system itself and about 20 µm associated with the LSAW. In a region between z=-75 µm and z=-200 µm, the amplitude presents a simple variation only with a periodicity of about 20 µm associated with the LSAW. The phase in the negative z region, as a whole, presents a periodic change of about 20 µm associated with the LSAW. In the focal region, additional small changes of the phase associated with the characteristic response for the system itself appears. Thus, the V(z) curve for the system using a concave transducer shows apparently complex shape of amplitude and change of phase, as compared with that for the system using an acoustic lens. Especially, the amplitude response contains a rapid periodic variation in the defocus region which is not directly related to the propagation properties of LSAW, while the phase response depends strongly on the propagation properties of LSAW.

3. EXPERIMENTS

Experiments are carried out for the demonstration of V(z) curves for the systems using a concave transducer as well as an acoustic lens for a fused quartz sample material in order to verify the validity of the numerical considerations described above.

Figure 6 shows a block diagram of V(z) curve measurement system, which is basically the same system of the line focus beam acoustic microscope for material characterization [9]. In particular, this system can simultaneously measure the amplitude and the phase of the RF burst pulse signals.

Figure 7 (a) and (b) illustrate basic configurations and dimensions for a concave transducer and an acoustic lens, respectively. The device parameters are as follows: radius of curvature of concave surface; R_L=0.5 mm, half-aperture angle; α_m=60°, and acoustic frequency; f=375 MHz. The concave transducer is constructed as follows: First, on the concave surface formed on one end of a Z-cut sapphire solid rod, a ZnO piezoelectric film transducer is fabricated to radiate and detect acoustic longitudinal waves. Next, on this concave surface, a chalcogenide glass film is deposited as a quarter-wavelength acoustic matching layer for efficiently transmitting acoustic waves across the interface of the ZnO film and water [10].

Experimentally measured V(z) curves for fused quartz sample at a frequency of 375 MHz are shown in Fig. 8 (a) and (b) for the systems using a concave transducer and an acoustic lens, respectively. In Fig.8, the phase is also shown as that of the V(z) curve with the removed phase change of exp(j2kz). It can be easily seen that experimental V(z) curves agree well with the calculated V(z) curves shown in Fig.4 over the whole range of the shapes of the amplitude as well as changes of the phase. This agreement proves the validity of the discussions for the performance of the concave transducer described above.

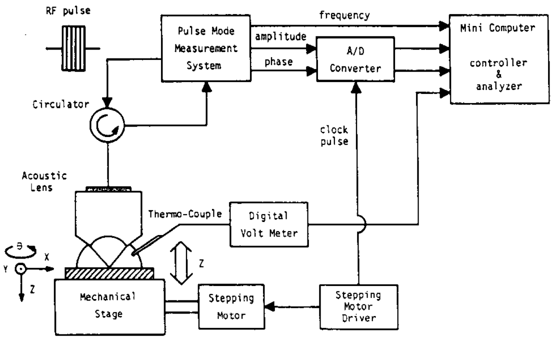
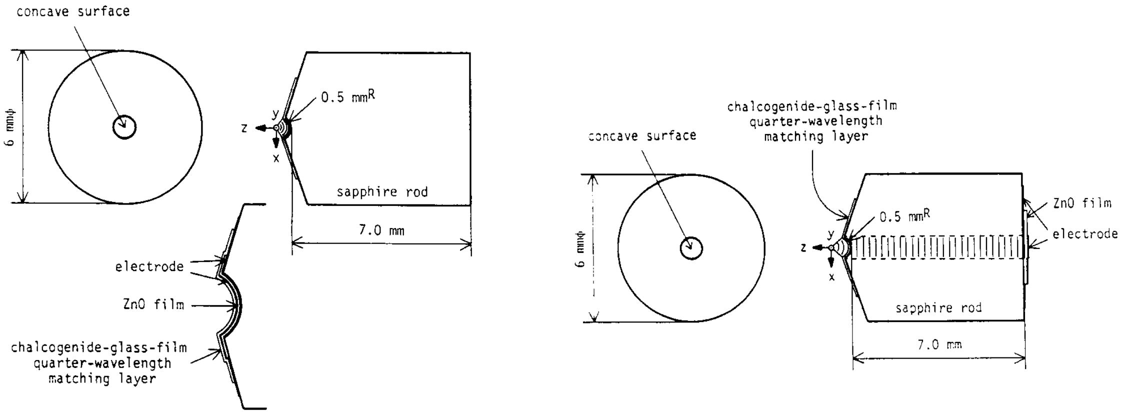


Fig.6 Block diagram of V(z) curve measurement system.

4. CONCLUSION

In this paper, the performance of the scanning reflection acoustic microscope system using a concave transducer has been analyzed numerically and experimentally on the basis of field theory. The transfer function for the system using a concave transducer is quite different from that using an acoustic lens, so that the V(z) curve for the concave transducer shows apparently complex shape and the phase changes, as compared with that for the acoustic lens. Especially, the amplitude response of V(z) curve obtained with the system using concave transducer gives rapid periodic variation which is not directly related to the propagation properties of LSAW, while the phase response of V(z) curve depends strongly on the propagation properties of LSAW in the defocus region. This characteristic performance has been successfully demonstrated by the system using a concave transducer with the radius of curvature of 0.5 mm at a frequency of 375 MHz.

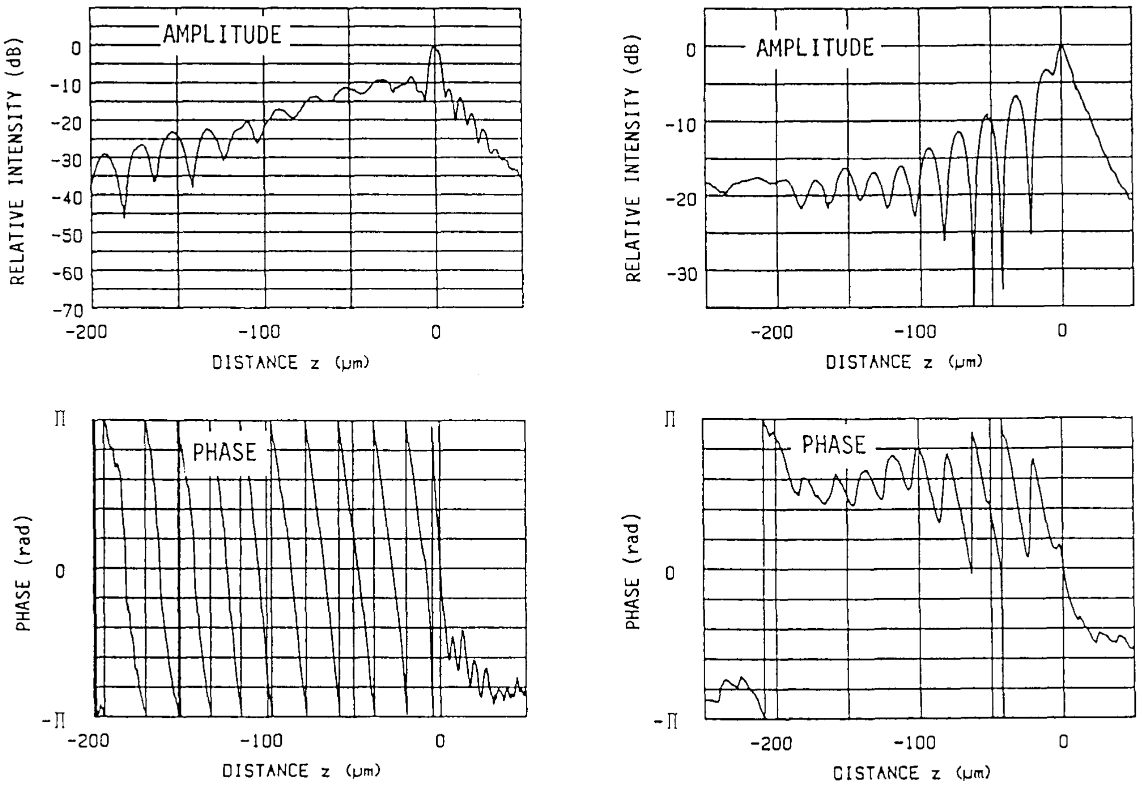
Recent developments on the copolymer concave transducer technology are expected to improve the performance of the acoustic microscope system using a concave transducer. The results described in this paper, therefore, should be ingeniously introduced to establish new methods or systems for interpreting and analyzing the acoustical images and/or the V(z) curves obtained with the acoustic microscope using a concave transducer.



(a) concave transducer

(b) acoustic lens

Fig.7 Configurations and dimensions of a concave transducer and an acoustic lens at 375 MHz.



(a) concave transducer

(b) acoustic lens

Fig.8 Measured V(z) curves for fused quarzt sample material at 375 MHz.

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