Restricted aperture acoustic microscope lens for Rayleigh wave imaging

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The performance of an acoustic microscope lens is reported that permits both Rayleigh wave velocity measurement of anisotropic media as well as raster-scanned imaging. The lens surface is spherical and uses a circular p-wave transducer; however, an acoustic absorbing layer is applied to the spherical surface in order to limit the angular range over which Rayleigh waves are launched. When operated at 50 MHz, a lens having a slot-like aperture of 0.8 mm width permits measurement of $V_R(\theta)$ of y-cut quartz with a maximum error of less than 2%. The same system employed in imaging provides spatial resolution of about one wavelength in a direction parallel to the axis of the slot and between two and three wavelengths in the perpendicular direction.

A novel acoustic lens has been developed that permits quantitative measurement of Rayleigh wave velocity V_R as well as imaging in raster-scanned applications.

Kushibiki and Chubachi[1] developed and demonstrated a line focus acoustic-microscope lens that permits the accurate determination of Rayleigh wave velocity as a function of angle in anisotropic crystals as deduced from the behavior of transducer voltage as a function of focal distance $V(z)$. The precision of the V_R determination can be attributed to the essentially one-dimensional character of the surface wave excitations which results in a uniform spacing between minima in $V(z)$ or, equivalently, a sharp peak in the Fourier spectrum of the function $V(z)$ from which the aperiodic geometric component $V_g(z)$ has been subtracted. The sharp spectral peak defines the Rayleigh velocity with little ambiguity. The one-dimensional character of this system, however, does not facilitate the formation of raster-scanned images.

Chou *et al.*[2] developed an alternate scheme involving a spherical lens but driven by a shear wave transducer as a means of providing, by mode conversion at the lens surface, a preferential direction along which Rayleigh waves are excited. This system was used to demonstrate enhanced contrast in raster-scanned imaging applications.

In an effort to realize both quantitative Rayleigh wave measurements and scanned image capability in the same acoustic microscope lens, a conventional spherical microscope objective insonified by a p-wave transducer with a bow tie shaped electrode was proposed[3] and later constructed and tested.[4] The results were disappointing in that the spectrum of $V(z)$ exhibited double peaks at several angles suggesting simultaneous excitation of several Rayleigh waves along different directions. Such behavior can result from diffraction in the buffer rod giving rise to an ancillary Rayleigh wave in a direction perpendicular to the bow tie axis. To summarize, the $V_R(\theta)$ measured did not agree well with the accepted values for y-cut quartz; however, it did show significant variation with angle θ, and did show the proper crystallographic symmetry. Moreover, the images formed by scanning demonstrated some variation in resolving power along different directions in structured samples and greater con-

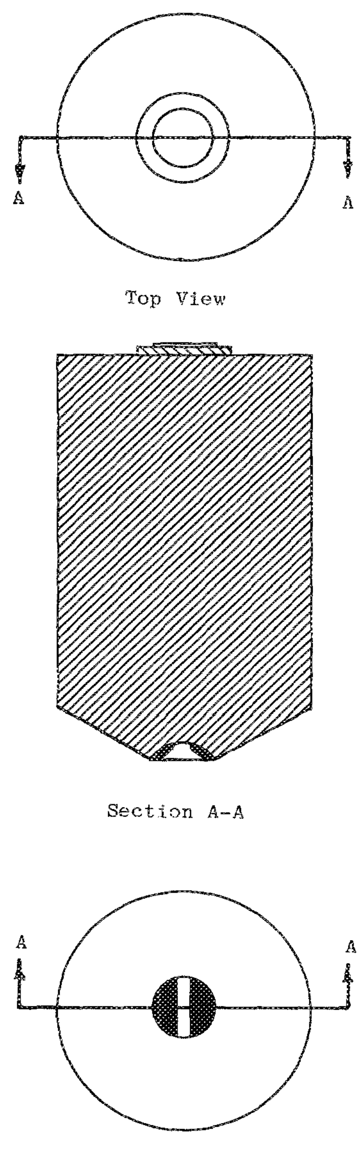

FIG. 1. Cross-sectional view of the restricted-aperture acoustic microscope lens in which the acoustic absorbing material is shown in black. The reported results made use of a 50 MHz transducer, an aperture width of 0.8 mm, and water couplant.

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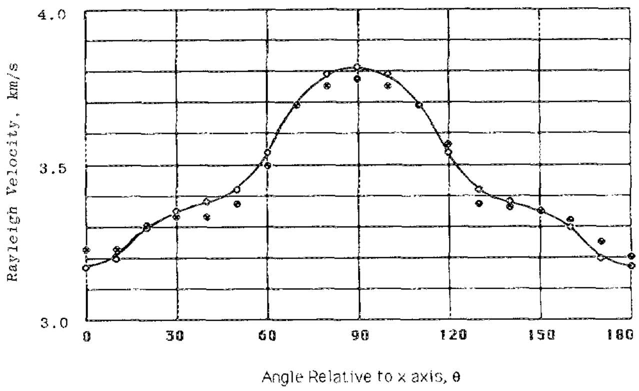

FIG. 2. Comparison between accepted Rayleigh wave velocity values $V_R(\theta)$ (solid curve connecting open circles) and measured values (solid circles) derived from $V(z)$ data obtained with the 50 MHz slot microscope lens from a y-cut quartz sample.

trast in the grain structure of metalographic samples as compared with lenses using normal circular transducers.

The present work involves a spherical lens insonified by a circular transducer but occluded at the spherical lens surface with an acoustic absorber to provide a rectangular or slot-like aperture as illustrated in Fig. 1. The object here is to excite Rayleigh waves over a limited range of angles but to eliminate the undesirable side lobes associated with diffraction in the buffer rod. The $V(z)$ data were reduced using the relation $|V'(z)| = [|V(z)|^2 - |V_g(z)|^2]/|V_g(z)|$, and the resultant Fourier spectrum of $|V'(z)|$ was obtained by means of a fast Fourier transform. The $V_R(\theta)$ data so obtained for y-cut quartz at 50 MHz are illustrated in Fig. 2. The agreement is seen to be quite good: the largest error is less than 2%. The spectra at all angles show single sharply peaked maxima unlike what is observed using the bow tie lens system.

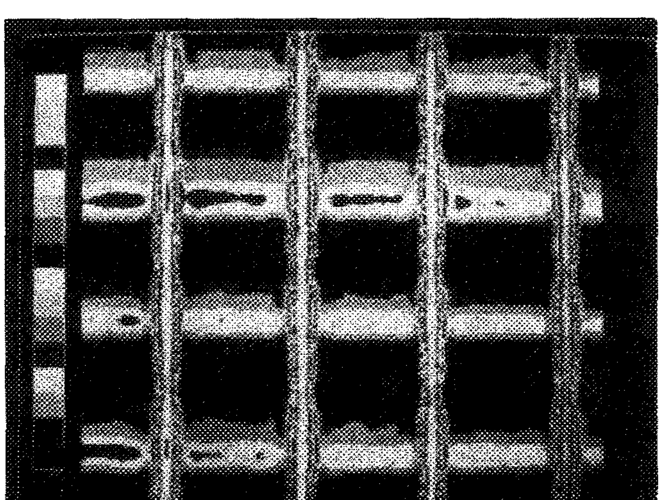

FIG. 3. Image of a nickel photoetched rectangular grid having a pitch of 100 lines per inch produced by raster scanning of the slot lens over a square field of 1024 μm edge dimension. The wide dimension of the slot is parallel to the horizontal axis x. The width of the nickel strips is approximately 35 μm.

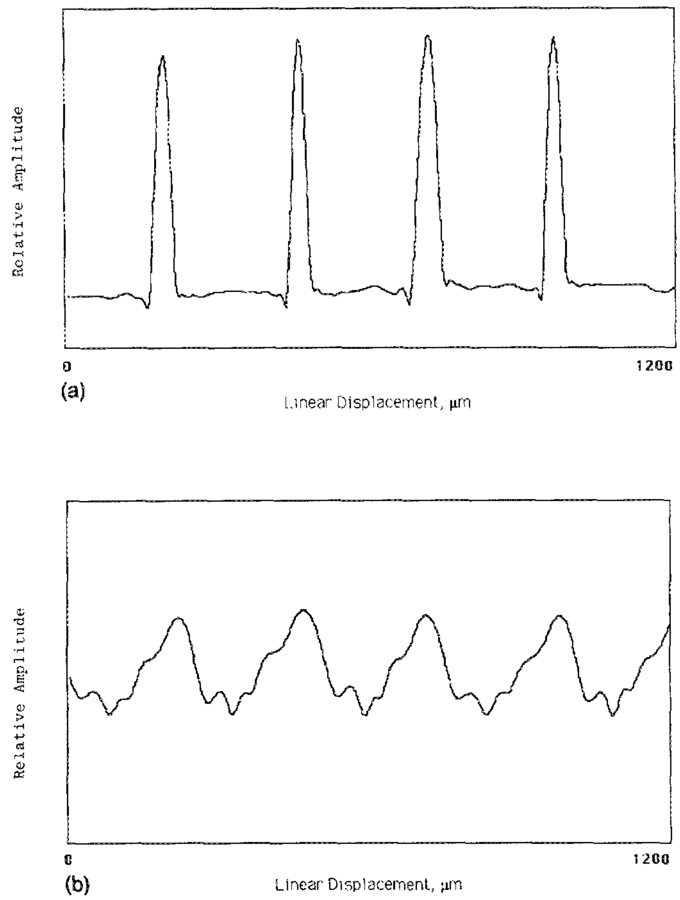

FIG. 4. Results of line scans over the object of Fig. 3. The centers of the x and y scans coincide with the center of the scanned image. It may be observed that the resolution perpendicular to the slot is approximately between one-half and one-third of the resolution parallel to the slot which is consistent with the effects of diffraction in the couplant. 4(a) results from a line scan along a direction parallel to the slot axis x, while (b) is along the perpendicular direction y.

Imaging behavior is illustrated in Fig. 3 in which a 100 lpi pitch rectangular grid is raster scanned over a square field of 1024 μm. It is noteworthy that the spatial resolution along the x and y directions is inequivalent. As expected, the resolution perpendicular to the slot is significantly lower than that along the slot as expected from the diffraction of a uniformly illuminated rectangular aperture. The effect is better quantified in the linear scans shown in Fig. 4. Here the analog transducer voltage is quantized on a range of 2048 levels as opposed to the 16 level quantization of the "false color" representation used in the image of Fig. 3. Analysis of the linear plots reveals that the spatial resolution along the slot axis is on the order of one wavelength in the coupling fluid λ_f and approximately $2.5\lambda_f$ in the perpendicular direction.

The performance of an acoustic microscope lens has been demonstrated that enables both Rayleigh velocity measurement of single-crystal samples and raster-scanned image formation. The spatial resolution is observed to have a degree of anisotropy owing to diffraction caused by the rectangular aperture. It appears that the angular resolution of measured Rayleigh wave velocity and resolution anisotropy may be traded off by adjustment of the aperture width, thus an optimum configuration may be determined for imaging of, for example, polycrystalline samples of anisotropic media.

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[1]J. Kushibiki and N. Chubachi, IEEE Trans. Sonics Ultrason. **SU-32**, 189 (1984)
[2]C-H Chou, B. T. Khuri-Yakub, and K. K. Liang, Proc. 1987 IEEE Ultrason. Symposium **2**, 813 (1987)
[3]D. A. Davids and H. L. Bertoni, Proc. 1986 IEEE Ultrason. Symp. **2**, 735 (1986)
[4]D. A. Davids, D. Chizhik, and H. L. Bertoni, IEEE 1988 Ultrason. Symp. Abstracts **53** (1988).