Restricted aperture acoustic microscope lens for Rayleigh wave imaging

D. A. Davids, P. Y. Wu, and D. Chizhik

Institute for Imaging Sciences, Polytechnic University, Brooklyn, New York 11201

(Received 21 November 1988; accepted for publication 7 February 1989)

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 $\gamma$-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 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. 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 insenitized by a p-wave transducer with a bow tie shaped electrode was proposed and later constructed and tested. 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 $\gamma$-cut quartz; however, it did show significant variation with angle $\theta$, 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-

![Top View](image1.png)

![Section A-A](image2.png)

![Bottom View](image3.png)

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.
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.

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 $\mu$m edge dimension. The wide dimension of the slot is parallel to the horizontal axis $x$. The width of the nickel strips is approximately 35 $\mu$m.

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. (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 $\mu$m. 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 $\lambda_f$ 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.

This work was supported by the National Science Foundation under grant No. ECS 8414081, and by a Research Fellowship from the Air Force Office of Scientific Research, Bolling AFB DC.