Acoustic material signature from frequency analysis

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An alternative approach to obtain the acoustic material signature in scanning acoustic microscopy as the periodicity of the output voltage in the frequency domain \( V(f) \) is suggested. Certain advantages of this technique over the conventional \( V(z) \) approach are demonstrated through experimental results.

The most unique feature that distinguishes acoustic microscopy from all other types of microscopy is the origin of the contrast in the mechanical properties of the specimen. Scanning acoustic microscopes with water couplant have been used with great success in the reflection mode of operation since the late seventies. The excellent contrast of these devices is somewhat surprising since the reflection coefficient of most solids in water is not a particularly sensitive measure of material properties. For instance, the reflection coefficient from such different materials as copper, steel, and nickel are 93.2\%, 93.5\%, and 94.1\%, respectively, i.e., almost the same. Therefore, when the transducer is focused at the surface of the specimen and only specular reflection is generated, the acoustic contrast is very weak and even very different materials are difficult to distinguish. On the other hand, when the transducer is focused below the surface, the contrast becomes much stronger due to an interferometric effect, providing that the aperture angle is sufficiently high to generate Rayleigh-type surface waves on the specimen.

Figure 1 shows the geometrical configuration of reflection-type acoustic microscopy. Certain rays (B) generate leaky surface waves which interfere with the specularly reflected one (A), thereby resulting in strong contrast between points of constructive and destructive interference. The output voltage \( V \) of the microscope is very sensitive to the vertical position \( z \) of the lens, which strongly affects the relative phase between the two principal components. It was found that the characteristic periodicity of \( V(z) \), which is often called the “material signature,” gives quantitative information on the Rayleigh wave velocity of the specimen. Several authors have explained the observed more-or-less periodic oscillations of \( V(z) \) using either ray theory or Fourier decomposition techniques.\(^1\)\(^{10}\) According to the more rigorous latter approach, the output of the transducer can be written as \(^9\)

\[
V(z) = \int_{0}^{2\pi} \int_{0}^{\alpha} R(\theta,\phi) P(\theta) \times \exp(i2kz \cos \theta) \cos \theta \sin \theta \, d\theta \, d\phi,
\]

where \( R(\theta,\phi) \) is the reflectivity of the sample, \( P(\theta) \) is the pupil function of the acoustical transducer, and \( \alpha \) is the viewing angle of the focusing lens. \( \theta \) and \( \phi \) denote the polar and azimuthal angles, respectively, and \( k \) is the wave number in the coupling liquid.

Naturally, the defocusing \( (z) \) is measured in terms of the acoustic wavelength in the couplant, therefore it always appears in product with frequency \( (f) \). Only \( V(zf) \) can be regarded as a more-or-less system-independent material parameter, while \( V(z) \) is simply a particular cross section of \( V(zf) \) at a certain frequency. In a similar way, we can consider \( V(f) \), i.e., the cross section of \( V(zf) \) at a certain defocusing depth. As an example, Fig. 2 shows the detected signal amplitude from glass as a two-dimensional distribution over the \( z = -1.0 \) mm and \( f = 20-40 \) MHz range. Figures 3 and 4 show typical \( V(z) \) and \( V(f) \) curves from glass at \( f = 30 \) MHz and \( z = -1.0 \) mm, respectively.

The interchangeability of \( z \) and \( f \) in obtaining the material signature of the specimen gives us an option to analyze the frequency spectrum of the received signal rather than its \( z \) dependence. The suggested \( V(f) \) technique can be used in acoustical imaging to optimize the contrast by purely electronic means. As an example, Fig. 5 shows the acoustic micrographs of an aluminum-stainless-steel inertia friction weld at three different frequencies (the aluminum is on the left side with the characteristic flash of extruded material). The very different contrasts of these pictures can be readily explained with the help of Fig. 6 showing the measured \( V(f) \) curves over the two bonded parts at \( z = -1.52 \) mm defocusing. At 32.2 MHz the aluminum part appears to be much brighter than the stainless-steel one, while at 34.5 MHz it is the other way around. As for the evaluation of the solid-state bond itself, an intermediate

![FIG. 1. Geometrical configuration of reflection-type acoustic microscopy.](image-url)
frequency of approximately 33.5 MHz offers the best contrast. At the intersection point of the two \( V(f) \) curves, the counterparts are of the same brightness. This particular intersection point is below the average level, which indicates more- or less destructive interference between the specular and surface wave components. The bond line shows up brighter than the base materials since the attenuated surface wave component results in a higher interference signal. At other frequencies, of course, negative interface contrast can be produced as well.

Besides being a high-resolution imaging device, the acoustic microscope is also a unique quantitative tool to measure certain elastic properties of the specimen on a...
Correlation between the photoreflectance impurity peak in semi-insulating GaAs and the bulk acceptor concentration

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We have measured the strength of the first-derivative peak observed below the band gap in photoreflectance spectra of semi-insulating GaAs and found that it is correlated with the bulk residual acceptor concentration. The apparent energy separation of the impurity peak is not fixed, but varies from sample to sample.

Recently, Pikhtin et al.\textsuperscript{1} reported observing a photoreflectance (PR) spectrum on a bulk GaAs sample which included a first derivative peak slightly below the third derivative band-gap structure. This peak was attributed to an impurity state, although its polarity (donor or acceptor) was undetermined. However, the energy separation (35 meV) led them to speculate that the impurity might be the acceptor resulting from Si occupying an As site.

Similar features have been seen in PR spectra on bulk GaAs wafers in our laboratory. By relating the intensity of the impurity peak to the background acceptor concentration as determined from multiple-wavelength IR absorption measurements\textsuperscript{2} for a sequence of samples, we have been able to remove the ambiguity in the sign of the impurity and establish that it is an acceptor.

Five liquid encapsulated Czochralski (LEC) semi-insulating GaAs substrates from four commercial suppliers (see Table I) were selected with the aim of achieving a reasonably wide range of background acceptor concentrations. The acceptor concentrations were then measured using our infrared absorption mapping system. This system raster scans the wafer through a $1 \times 1$ mm$^2$ beam from a highly stable 50-W tungsten-halogen lamp. The chopped beam is detected with a thermoelectrically cooled

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