DESIGN DATA FOR MICROWAVE ACOUSTIC SURFACE WAVE DEVICES

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Abstract: Sufficient quantitative information for the realization of optimum microwave frequency acoustic surface wave devices will be presented. Propagation losses, beam steering losses and diffraction losses will be listed for materials of technological importance. Figures of merit will be defined and computed.

As with any engineering problem, the design of microwave acoustic surface wave devices requires quantitative knowledge of all the parameters which can affect optimum performance. The object of this paper is to summarize the various sources contributing to device insertion loss and to indicate the design tradeoffs which can and must be made for the realization of long-time-delay, wide-bandwidth, microwave frequency acoustic surface wave signal processing devices. In addition, quantitative information to aid design, including figures of merit, will be provided for popular single crystalline materials and orientations.

A summary of the sources of delay line insertion loss is given in Table 1. Propagation loss[1] is a combination of scattering by thermally excited elastic waves (the unavoidable lower loss limit for any given crystal), scattering by crystalline and surface polish defects (with care these can be made negligible well up into the microwave frequency region), and energy lost to air adjacent to the surface. This latter term can be completely eliminated by vacuum encapsulating devices. Geometrical factors introduce two additional sources of loss: beam steering[2] and diffraction[3]. Beam steering losses, previously described in detail[1,2], occur in all anisotropic crystalline media (required for low propagation losses) when the surface wave phase and group velocities do not lie in the same direction. Only for specific (pure mode) crystalline orientations do these vectors coincide; consequently, there is no beam steering loss. Surface wave diffraction losses always occur and are analogous to those arising from the diffraction of light from a slit. Both cases produce Fresnel-like intensity profiles in the near region and eventually, significant beam spreading. A schematic representation of propagation loss as well as beam steering and diffraction effects is given in Figure 1. This figure also serves to define the angular parameters necessary for the quantitative description of both beam steering and diffraction.

For practical devices, the desirable propagation direction, θ, for a transducer pair is usually that for which the power flow angle, ϕ, is zero (no beam steering). In actual practice, however, slight deviations from the desired orientation ($\phi \neq \theta$) always result as illustrated in Figure 1. A direct measure of the seriousness of this effect is $\partial\phi/\partial\theta$, the slope of the power flow angle curve. In the anisotropic media with which we are dealing this same parameter can also be used to estimate the extent of beam spreading[4]. Depending on the value of $\partial\phi/\partial\theta$, diffraction may be dramatically increased or retarded in contrast to the analagous case for light diffraction in an isotropic medium. Within limits, proper choice of surface wave orientation results in the ability to trade off beam steering against diffraction losses. For example, materials such as YZ $LiNbO_3$ and ZY $LiTaO_3$, having $\partial\phi/\partial\theta \approx -1$, suffer from a minimum amount of diffraction but considerable beam steering. Orientations which have a small power flow angle slope approach the amount of diffraction expected for an isotropic case and are without beam steering problems. Materials having large positive slopes such as 111-Cut 110-propagating $Bi_{12}GeO_{20}$ and Y X quartz have beam spreading much greater than the isotropic case as well as serious beam steering problems.

A summary of data illustrating these tradeoffs for many popular materials is given in Table 2. Here we have reduced the raw data to the delay time available before 3 dB of insertion loss arises from beam steering or diffraction. For the beam steering calculations, transducer widths were assumed to be 0.2 mm with 0.1° misalignment from the exact direction of θ yielding $\phi = 0$. For the diffraction calculations transducers were assumed 40 wavelengths wide with a frequency of 1 GHz. A frequency assumption is, of course, necessary since the amount of diffraction depends on the ratio of the distance travelled in wavelengths to the transducer width in wavelengths. The parameter $\partial\phi/\partial\mu$ given in Table 2 also influences beam steering[1,2]. It describes the effect of a misorientation of the perpendicular to the crystalline surface in direct analogy with $\partial\phi/\partial\theta$ for a misorientation in the plane of the plate.

Other important information is also contained in Table 2. For example, both the surface wave velocity and the surface wave coupling parameter, $\Delta v/v$, developed by Campbell and Jones[5] are given. In addition, measurements made by the laser deflection technique[1,6] of surface wave attenuation at 1 GHz are also given. Although we have emphasized geometric losses up to this point, quick reference to the 3 dB propagation loss time delay indicates attenuation is the dominant loss mechanism at microwave frequencies. This would not be the case at 100 - 200 MHz.

Ideally, a perfect material would have very long 3 dB propagation loss, beam steering loss, and diffraction loss time delays as well as a high value of $\Delta v/v$. We have already seen that it is physically impossible to have simultaneously long values of both beam steering loss and diffraction loss time delays. Here, tradeoff for each given design requirement is a necessity. It might be noted that both beam steering and diffraction losses can be minimized by using wide transducers which unfortunately increases the conduction loss[7,8] listed under the third loss category in Table 1. This is especially true at higher frequencies. In practice, then, parameters do not occur together to yield a maximally good material. Thus it is best to consider each design on an individual basis. However, as a general guide to useful microwave frequency surface wave materials and orientations we have defined two figures of merit. The first is the product of the time delays available considering propagation losses, beam steering losses, and diffraction losses. This quantity is then multiplied by $(\Delta v/v)^2$ to account for coupling efficiency. The second figure of merit gives additional weight to low velocity materials since a given time delay can be accomplished in less space.

The most significant facts to be learned from Table 2 are summarized as follows. Y-Cut, Z-propagating[9] $LiNbO_3$ is superior when low diffraction is the foremost requirement. The 41.5^o rotated-cut, X-propagating[10] orientation of $LiNbO_3$ yields the best combination of low beam steering, moderate diffraction and high coupling. 001-cut, 110-propagating $Bi_{12}GeO_{20}$ is superior for long time delays in a short space.

Since all sources contributing to delay line insertion loss are now well understood and easily measurable using, for example, the laser deflection[1,6] technique it is possible to completely characterize surface wave devices. This has been done for two YZ $LiNbO_3$ delay lines, with the results used to predict the ratio of acoustic power generated on one device to that generated on the other under identical incident power conditions. These results are summarized in Table 3. Direct comparison of the light deflected from each of the two surface waves yielded a surface-wave power ratio of 1.50 dB. This is in excellent agreement with the value given in Table 3 which also serves to illustrate the relative magnitudes of the effects described in this paper.

In summary, sufficient quantitative data has been presented for the realization of optimum microwave frequency acoustic surface wave devices. Whereas at lower frequencies solution of the transducer design problem[8] was the major breakthrough, at microwave frequencies diffraction and beam steering losses become ever more important and propagation loss, negligible at lower frequencies, becomes the dominant loss mechanism.

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