SHALLOW BULK ACOUSTIC WAVE DEVICES

INVITED PAPER

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ABSTRACT

A brief overview of shallow bulk acoustic wave generation, propagation, and properties is presented. It is shown how the effect is manifested in doubly rotated crystal plates, and how certain features of device performance may be inferred from pre-existing calculations for bulk wave plates.

Introduction

Interdigital electrodes produce, in general, both surface acoustic waves (SAWs) and bulk acoustic waves (BAWs). When the BAW beam energy emitted is largely along a direction contained in the substrate surface, the waves are referred to as shallow bulk acoustic waves (SBAWs) or as surface-skimming bulk waves (SSBWs). The development and application of this species of acoustic wave is largely due to the efforts of Kagiwada[1-5] in the US and to Lewis[6-10] in the UK. Theoretical treatments have been given by Jhunjhunwala, et al.[11] and Lee.[12]

Because they are generated in the same fashion as SAWs, namely, by interdigital transducer (IDT) arrays, and because they propagate near to the surface where they can be detected, SBAWs can claim the same advantages as SAWs in most device applications. That is, the advantages of planar construction; frequency response dependent only on IDT dimensions and not on crystal geometry; time- or frequency- domain signal processing capacity, etc. On the other hand, because most of the beam energy is below, rather than within a wavelength or two of the surface, there is low susceptibility to surface contamination and defects, and so potentially, aging effects may be smaller than for SAW devices.

Forces Produced by IDT Arrays

The types of waves produced by IDT arrays can be determined if the distribution of the piezoelectric forces is known. This, in turn, follows from the electric field distribution and the substrate material and orientation. The piezoelectric portion of the mechanical stress relation is

$$T_{ij} = -e_{kji} E_k \quad . \tag{1}$$

The mechanical force-densities F_j are equal to the stress gradients:

$$F_j = -e_{kji} E_{k,i} \quad . \tag{2}$$

Taking as an example a rotated-Y-cut of quartz of orientation $(YX\ell)\theta$, with an IDT array along X_1, the electric field gradients peak sharply at the electrode finger edges,[13] and are $E_{1,1}$ (Largest) and $E_{2,2}$ plus both $E_{2,1}$ and $E_{1,2}$. The rotated piezoelectric constants that are non-zero, are e'_{111} ($=e_{111}$), e'_{122}, e'_{133}, e'_{123}, e'_{213}, e'_{212}, e'_{313}, and e'_{312}. Therefore $E_{1,1}$ produces X_1-directed forces, but no forces along X_2 or X_3. $E_{2,2}$ likewise generates X_1 forces. The weaker gradients $E_{2,1}$ and $E_{1,2}$ both produce X_1 and X_2 forces. The X_1 and X_2 forces lead to SAWs.

If the IDT array is rotated so that the finger edges are parallel to the X_1 axis and propagation takes place along X_3, then E_1 vanishes, along with the gradients $E_{2,1}$ and $E_{3,1}$. The gradients $E_{2,2}$; $E_{2,3}$; $E_{3,2}$; and $E_{3,3}$ all produce forces directed along X_1 but no other component of force. SAW propagation cannot take place but an SH-type of BAW propagates, and this is the SBAW that has been investigated to date.

This wave is analogous to a thickness mode BAW propagating in a plate of orientation $(YX\ell)$ $\theta \pm 90^\circ$, as pointed out by Lewis.[8] This is exactly the situation that exists with respect to the contour mode cuts CT and DT, when compared to their thickness mode counterparts, the AT and BT cuts. Because of this situation one may very simply carry over calculations made for thickness mode plates[14] to get an approximate idea of the corresponding SBAW behavior.

Consider the curves given in Figure 1. At top is given the frequency constants N for the longitudinal (P-wave), fast shear (SV-wave) and slow shear (SH-wave) waves in rotated-Y-cut quartz. These are labeled the "a", "b", and "c" modes, respectively. In the center are the effective piezoelectric coupling factors, $|k|$, and at bottom are the first order temperature coefficients of frequency, T_f, of these plate modes. By changing the abscissa θ to $\theta \pm 90^\circ$ (keeping the new value in the range $-90^\circ \leq \theta \leq +90^\circ$), one obtains the corresponding quantities for the SBAW modes in question.

Doubly Rotated SBAW Plates

In Figure 2 are given N, $|k|$, and T_f for plates of orientation $(YXw\ell)$ $\phi=24^\circ/\theta$. The physical situation is depicted in Figure 3, where the doubly rotated BAW plate is shown with its corresponding SBAW plate of orientation $(YXw\ell)$ $\phi=24^\circ/(\theta \pm 90^\circ)$. It is seen that the bulk wave calculations for generally oriented plates may be carried over to determine approximately the properties of a SBAW plate by appropriate change in the angle θ. The angle ϕ is unchanged. More general cases suggest themselves, as for example, propagation at an angle ψ from the X_2'' axis. By properly considering the corresponding BAW cut, and the piezoelectric forces produced, pre-existing information can be used to deduce the approximate behavior of the SBAW device.

Doubly rotated cuts of quartz, and possibly other materials, are coming into use because of their desirable temperature behavior and their compensation of certain mechanical and thermal stress effects that have their basis in nonlinear elasticity.[14] The corresponding SBAW cuts may also possess these very desirable attributes. For doubly rotated cuts in general, all three modes (a, b, and c) are excitable. This is seen in Figure 4, which gives a mode spectrograph of a doubly rotated quartz plate of orientation $(YXw\ell)\phi=10^\circ/\theta=+34^\circ$. One can see clearly the presence of all three SBAW modes. The measured excitation strengths, propagation velocities, and temperature coefficients agree well with those obtained from the BAW calculations for a plate with $\phi=10^\circ$, $\theta=-56^\circ$, as given in Table I.

References

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TABLE I. SHALLOW BULK ACOUSTIC MODE PROPERTIES

$\phi = 10^\circ$; $\theta = +34^\circ (-56^\circ)$; Z-PROPAGATION			
	MODE c	MODE b	MODE a
N (m/s)	1873	2521	3177
$T_f (10^{-6}/K)$	-56.0	-20.2	-94.6
(k) %	0.78	3.77	1.04
f (MHz)	185.3	249.4	314.3

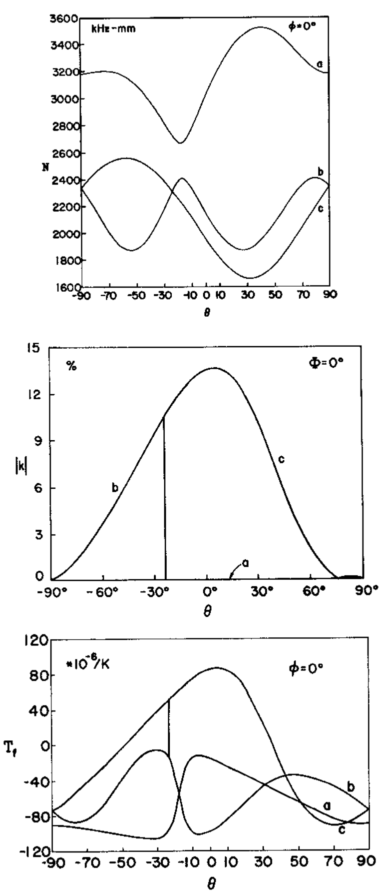

FIGURE 1. SINGLY ROTATED PLATE PARAMETERS; QUARTZ ORIENTATION (YXℓ)Θ.

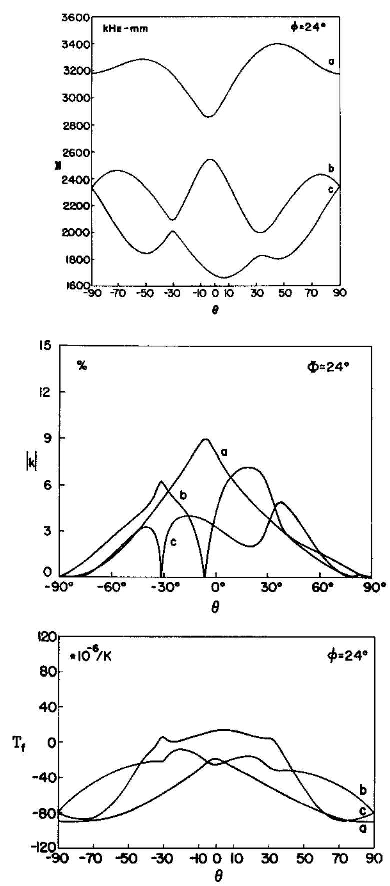

FIGURE 2. DOUBLY ROTATED PLATE PARAMETERS; QUARTZ ORIENTATION (YXwℓ)Ø=24°/Θ.

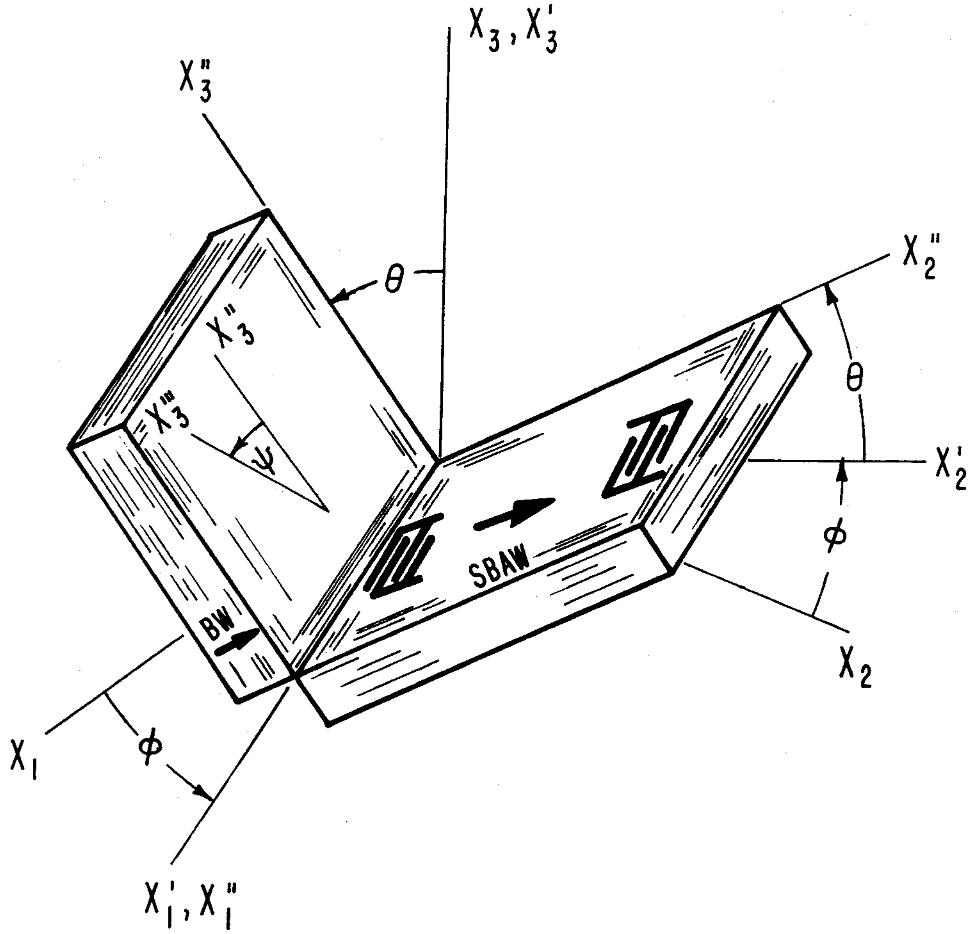

FIGURE 3. DOUBLY ROTATED CRYSTAL PLATES FOR BAW AND SBAW APPLICATION.

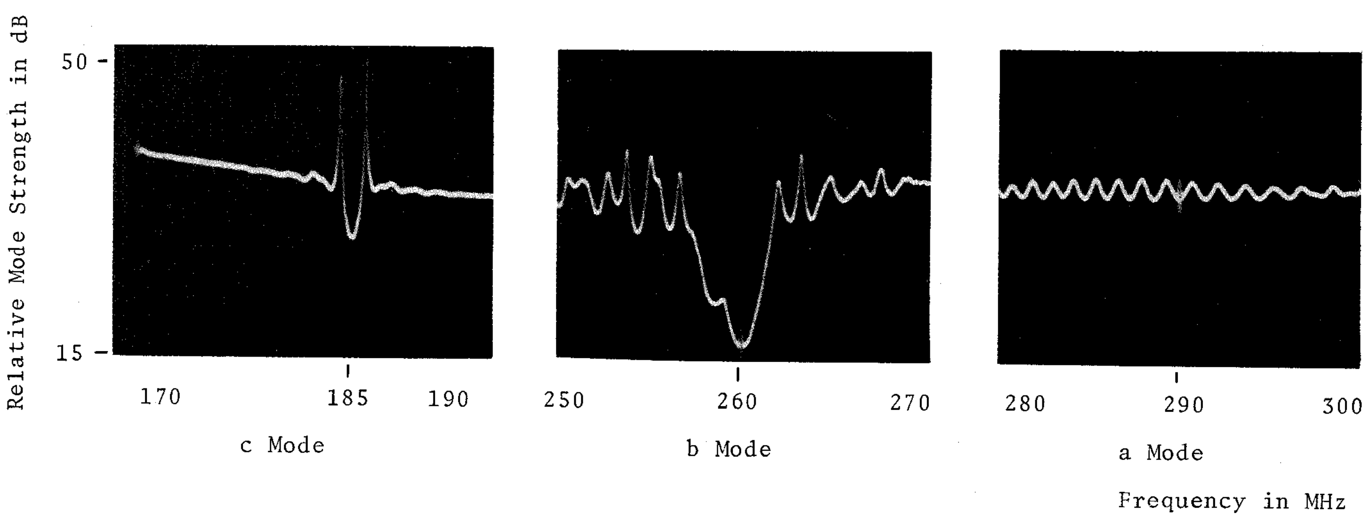

FIGURE 4. SBAW MODE SPECTROGRAPH OF DOUBLY ROTATED QUARTZ PLATE.