

**NUMERICAL ANALYSIS OF ACOUSTIC WAVE GENERATION
IN ANISOTROPIC PIEZOELECTRIC MATERIALS**

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With the increasingly widespread use of surface acoustic wave (SAW) devices, particularly filters, modeling of wave propagation phenomena in anisotropic piezoelectric materials has become eminently important. However, almost all modeling activities have been concentrated on the simulation of the extrinsic device behaviour. We present an "Ab Initio" analysis - not a simple simulation - of wave effects without neglecting second order effects, like bulk wave generation, diffraction, interaction of surface waves and bulk waves. For that purpose we have developed a computer program for the solution of the fundamental partial differential equations (1) and (2) which describe wave propagation in arbitrary, anisotropic piezoelectric media [1].

$$c_{ijkl} \cdot \frac{\partial^2 u_k}{\partial x_l \partial x_i} - e_{kij} \cdot \frac{\partial^2 \varphi}{\partial x_k \partial x_i} = \rho \cdot \frac{\partial^2 u_j}{\partial t^2} \quad (1)$$

$$e_{ikl} \cdot \frac{\partial^2 u_k}{\partial x_l \partial x_i} - \epsilon_{ik} \cdot \frac{\partial^2 \varphi}{\partial x_k \partial x_i} = 0 \quad (2)$$

(1) are the equations of motion in three space dimensions ($j=1,2,3$) and (2) is the Poisson's equation under the quasi-static assumption with u_j , the mechanical displacement components, and φ , the electrostatic potential, as unknowns. c_{ijkl} denotes the elastic tensor, e_{kij} the piezoelectric tensor and ϵ the dielectric tensor. The index formalism in (1) and (2) conforms to the standard tensor notation as well as to Einstein's summation convention. The surface boundary conditions result from the fact that the force component as well as the electrical displacement component perpendicular to the surface have to vanish.

Some attempts have been made in the past to find a solution of these equations in two space dimensions but either the authors a priori postulate a wave approximation [3,4] or simulate an infinite periodic structure [2]. Our

method is different since we do not anticipate the solution in any way. We solve the fundamental equations in two space dimensions - in the sagittal plane - distinguishing two different applications: For a transient analysis we solve the coupled hyperbolic-elliptic system by a semi-implicit time integration scheme. If only the time-periodic solution is interesting first we eliminate the time dependency of the mechanical equations by a harmonic approach and then we solve the resulting system with the finite difference method. In both cases we use a novel form of boundary conditions for the quasi infinite domain to avoid reflection phenomena.

The input data for our program are the geometry of the transducer fingers, the substrate material and the Euler's angles of the crystal cut. The structure and the actual values of the material dependent tensors are stored in a database for most of the common materials. However, the analysis of new materials is merely a matter of specifying the tensor data. One major objective of our investigation is the quest for physical insight into SAW devices to enable the development of simple analytic formulas for device characterization and design. The power of our analysis method lies in the general applicability with respect to the different materials and crystal cuts and the not neglected interaction between surface and bulk waves. For that reason our computer program can be used for instance to optimize a crystal cut by minimizing the acoustic power radiation into the bulk. Because of the flexibility of our solution method the program could be extended to include non linearity effects.

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