

Reciprocal conversion of shear body and surface acoustic waves on periodically perturbed solid state surface

Yu. V. Gulyayev, T. N. Kurach, and V. P. Plesskii

Institute of Radio Engineering and Electronics, USSR Academy of Sciences

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We show that a pure shear body acoustic wave normally incident on a periodically uneven piezoelectric surface may be effectively converted into two pure shear surface electroacoustic waves, and a surface wave incident on a periodic structure may be effectively reconverted into a body shear wave.

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One of the more important problems of acoustoelectronics is the development of acoustoelectronic devices based on surface acoustic waves (SAW) operating in the SHF region. The engineering difficulties which this presents are sufficiently formidable to be considered fundamental. One of the difficulties is construction of opposed-pin transducers of submicron dimensions which requires the use of electron and x-ray lithography. Another, even more serious difficulty is attributed to the fact that the Rayleigh SAWs normally used propagate in the near-surface crystal layer with a depth of the order of a wavelength (in the SHF range—fraction of a micron), which suffers badly in the process of buffing. Therefore, lattice attenuation of Rayleigh SAWs in the SHF range is substantially greater than attenuation of the corresponding body waves due to additional scattering by surface defects. The latter difficulty may be surmounted by means of pure shear surface electroacoustic waves (SSEAW) in piezoelectrics.^[1,2] Actually, these waves penetrate much deeper (to a depth of the order of tens and hundreds wavelengths) and the surface defects influence them considerably less. However, techniques for the excitation and reception of these waves used heretofore (opposed-pin and wedge-shaped transducers) are hardly effective because of their large penetration of depth in a crystal.

A method of excitation of Rayleigh SAWs proposed earlier^[3] is based on the

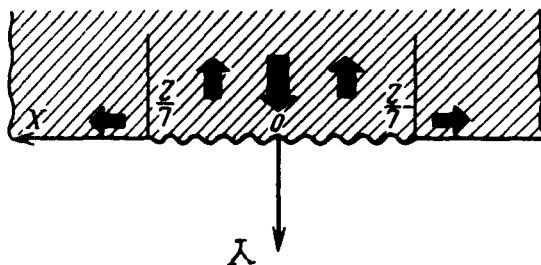


FIG. 1.

conversion of body acoustic waves into surface Rayleigh waves by a periodic system of trenches on a crystal surface. In this work we shall show that such a conversion system is particularly effective for pure shear surface acoustic waves and, allowing for the aforementioned properties of SSEAW, it may, in principle, extend the acoustoelectronic SAW devices into the SHF range.

For the sake of definiteness, we shall consider a type C_{6v} crystal with a hexagonal axis (oz -axis) parallel to an xz -surface along which a periodic perturbation in the form of "inertial loading" $\Delta m(x) = m_0 + 2m_1 \cos Qx$ occurs; for example, a metal layer that is periodically inhomogeneous with respect to thickness ($\Lambda = 2\pi/Q$ —structure period, see Fig. 1). We shall consider two situations: (1) when a mechanically-displaced along the oz -axis SSEAW, incident on the surface in the ox direction, is converted into a body shear wave ("reception") and (2) when a mechanically-displaced along the oz -axis body shear wave emerges from the crystal volume onto the structure and is converted into two SSEAWs traveling in two opposite directions along the ox axis ("excitation"). We shall seek a solution of the standard equations of piezoacoustics for mechanical displacements u and potentials ϕ in a region of periodically-perturbed surface in the form of the Bloch functions, $u, \phi \sim e^{i\delta x} f(x, y)$ ($f(x, y)$ is a function periodic along the ox -axis with the period Λ), representing them as a sum of harmonics $e^{i(\delta + nQ)x}$. We are interested in a region near the resonance ($\delta \ll Q$) and if we retain only three waves (two surface and one body⁽⁴⁾) using the impedance boundary conditions,⁽⁵⁾ we get the following expression for δ :

$$\delta = \pm \frac{1}{A} \sqrt{(B \Delta k)^2 - 2 B \Delta k \frac{\alpha_1^2 Q}{i \frac{k}{Q} + \alpha_0}} \quad (1)$$

In Eq. (1), $\Delta k = (\omega - \omega_r)/v_r$ (v_r is velocity of shear body wave, ω_r is resonant frequency at which the SSEAW length coincides with the structure period, ω is wave frequency), $k = \omega_r/v_r$; A and B are numbers of the order of K^{-2} , K^2 is the electromechanical coupling constant; $\alpha_0 = m_0 Q / \rho (k/Q)^2$, $\alpha_1 = m_1 Q / \rho (k/Q)^2$ (ρ is the crystal density)—are small perturbation parameters. We shall denote δ_0 to be a value of δ for which $\text{Im} \delta > 0$. In the case of incidence of a surface wave from the left onto a limited periodic structure of length L we should take into account both natural modes of the structure which correspond to the wave numbers $\pm \delta_0$. Using the boundary conditions at the structure ends $[0, L]$ $u_{(x=0)}^{(\rightarrow)} = u_0$, $u_{(x=L)}^{(\leftarrow)} = 0$ ($u(\rightarrow)$, $u(\leftarrow)$ are amplitudes of waves traveling to the right and left, respectively, u_0 is the amplitude of incident wave) for the case when we are near resonance, we get the following amplitude distri-

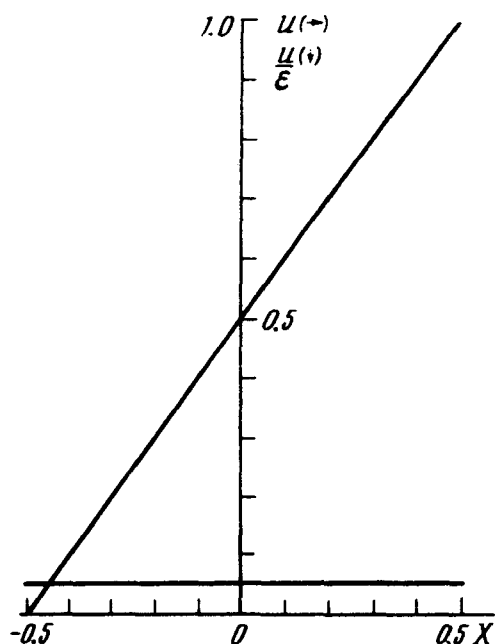


FIG. 2.

bution of an incident wave and of a wave entering the volume:

$$u^{(\rightarrow)} = \frac{F + iL^* \left(1 - \frac{x}{L}\right)}{F + iL^*} u_0, \quad (2)$$

$$u^{(\downarrow)} = -\frac{\alpha_1}{F + iL^*} u_0. \quad (3)$$

Above, $L^* = \alpha_1^2 QL / A$ is the effective lattice length, $F = (ik/Q) + \alpha_0$. As can be seen from Eqs. (2) and (3), the attenuation of an incident wave along the structure is linear near the resonance, and the amplitude of the entering wave is independent of coordinate x , i.e., the lattice generates a plane shear body acoustic wave which travels toward the surface along the normal. It may be shown that the most effective conversion of a surface wave into body wave is done by lattice with length $L^* = |F| \approx 1$. Moreover, the energy conversion coefficient is:

$$\eta = \frac{F'''}{|F| + F'''} \lesssim \frac{1}{2}. \quad (4)$$

We shall now consider the conversion of a shear body acoustic wave which emerges normally from the crystal volume onto the subject structure $[-L/2, L/2]$ into two SSEAWs traveling left and right. Using the boundary conditions $u^{(\rightarrow)}|_{x=-L/2} = u^{(\leftarrow)}|_{x=L/2} = 0$ under the conditions of resonance we get (Fig. 2):

$$u^{(\rightarrow)} = \frac{2i}{\alpha_1} \frac{k_0}{Q} \frac{iL^*}{F + iL^*} \left(\frac{1}{2} + \frac{x}{L} \right) u_0^{(\uparrow)}. \quad (5)$$

Clearly, the bulk of the energy in the incident body wave is converted to SSEAW

energy at $L^* = |F| \approx 1$, i.e., in the "excitation" mode a lattice of the same length as in the "reception" mode "works" most effectively. Moreover, the maximum coefficient of energy conversion to one of the two SSEAWs coincides with Eq. (4), i.e., practically all the energy of the incident body wave is converted to surface wave energy.

For the sake of evaluation, we shall consider a CdS crystal with a periodic metal structure deposited on its surface, such that at $\alpha_1 \approx 0.1$. Thus, the condition $L^* = |F| = 1$ yields the optimal lattice length $L_{\text{opt}} \approx 400 \text{ \AA}$ which is quite reasonable.

Thus, this calculation indicates that an effective (practically lossless) reciprocal conversion of shear surface and body acoustic waves is possible under resonant conditions in the periodic structure on a crystal surface.

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