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Surface-Wave Convolver Using Nonlinear Electron Interactions in Coupled Semiconductor-Piezoelectric Systems

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Convolution of surface acoustic waves in piezoelectric insulators and piezoelectric semiconductors has recently been demonstrated.[1)-4)] In the latter case, nonlinear acoustoelectric interactions in piezoelectric semiconductors have been used.[4)] In the case of surface acoustic waves, a piezoelectric semiconductor is not always for the acoustoelectric interaction. Generation of convolution signal in separated medium combinations, similar to that in a piezoelectric semiconductor, has been demonstrated.[5)6)] In this abstract, theoretical analysis of and experimental results of convolution in coupled piezoelectric-semiconductor systems are described.

Consider the parallel-plane geometry of Fig. 1. When an acoustic surface wave propagates on a piezoelectric insulator, it produces both a travelling space charge ρ and a travelling electric field E at the semiconductor surface through piezoelectric coupling of the insulator. In the presence of two oppositely directed acoustic waves, we obtain one component of the current density, given in following form:

$$\vec{j}=\mu(\rho_1\vec{E}_2+\rho_2\vec{E}_1) \qquad (1)$$

where, μ is the mobility of the semiconductor, and suffix 1 and 2 represent the quantities, associated with the wave-1 of, and those, with the wave-2 of Fig. 1, respectively. In usual conditions, the x component of the current density at the semiconductor surface is much larger than the z component of it and is given as follows:

$$j_x=-(A_1A_2)\mu\varepsilon_s\cdot\beta_D(\omega_c^2/\omega_1\omega_2)\times\exp(2\beta_D x)\exp\{i(\omega_3 t-k_3 z)\} \qquad (2)$$

where, A, k, ω, ω_c, and β_D are the amplitude of electric field at the semiconductor surface, the wave number, the frequency, the relaxation frequency of the semiconductor, and the inverse of Debye length of it, respectively. Also, ω_3 and k_3 are given as follows:

$$\omega_3=\omega_1+\omega_2$$
$$k_3=k_1-k_2\ .$$

If ω_1 is nearly equal to ω_2, k_3 is nearly equal to zero, and then the open circuit convolution voltage, appear-

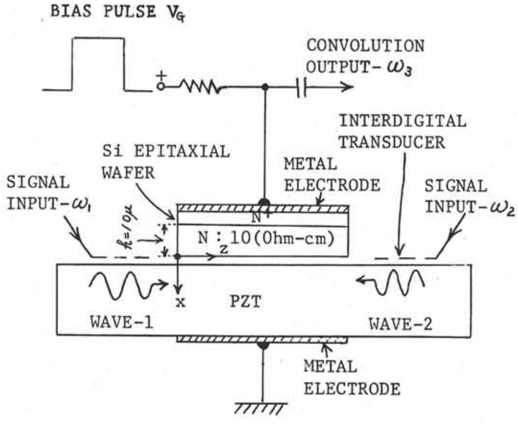

Fig. 1 Experimental arrangement.

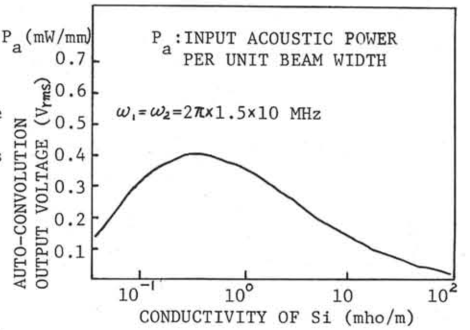

Fig. 2 Calucalated auto-convolution output vs. conductivity of Si.

ring between the top electrode of the semiconductor and the ground electrode of Fig. 1, is given as follows:

$$V_{out}=(1/\sigma\ell)\int_0^{\ell}\left\{\int_0^{-d} j_x dx\right\} dz=(\mu\,\mathcal{E}_s/2\sigma\ell)(\omega_c/\omega_1)^2 \times\int_0^{\ell} A_1(vt-z)A_2(vt+z)dz \propto \int A_1(\tau)A_2(2t-\tau)d\tau \qquad (3)$$

where, ℓ and v are the semiconductor length and surface wave velocity. One numerical example of output in PZT-Si is shown in Fig.2.

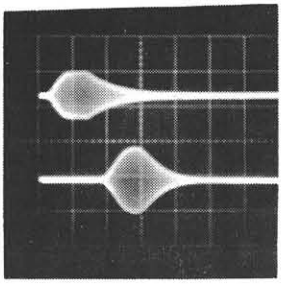

Fig.3 Auto-convolution (lower trace of two identical signals (upper trace). Time scale 2 μsec/div..

In our experiments, a PZT ceramic slice with the thickness of 1 mm and a Si epitaxial wafer (N on N^+) were used as piezoelectric insulator and semiconductor, respectively. (Fig. 1) Two shear surface waves are excited by 4-finger-pair interdigital transducers. A strong acoustoelectric interaction was easily obtained from soaking high permittivity liquid i.e. water in the gap between PZT and Si. Auto-convolution output for two identical 14.5 MHz input of 15 mW was observed, as shown in Fig. 3. The output, as shown in Fig. 4, was controlled by the application of DC-pulse between Si and ground electrode. The magnitude of the maximum nonlinear coupling constant M, defined by Lim et al.,[3] of our devices is 1.9×10^{-3} Vm/W. These large M value may originate from the strong nonlinear interaction between the high energy-density waves, localized near the Si surface, and from our sample configuration where the x component of the current induces convolution signal in contrast to the case of reference (4) and (6). It is noted that the characteristics of our convolver were remarcably controlled by the application of low voltage. Futhermore, if both the characteristic loss of PZT (5 dB/cm) and the additional loss of water (6 dB) are eliminated by using a low loss material and by realizing a very small air gap, such as $LiNbO_3$-Si surface wave amplifier, so as to be able to obtain the strong coupling without water, the larger output will be expected. Also, the control of convolution characteristics by illuminating semiconductor surface will be expected. These experiments, using $LiNbO_3$ and Si, are in progress.

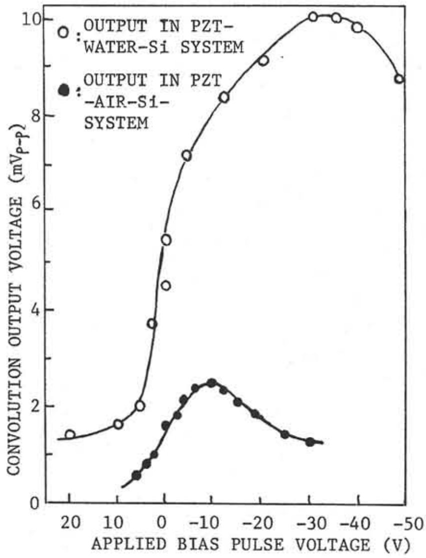

Fig. 4 Experimental values of auto-convolution voltage as function of bias pulse voltage.

References

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