Influence of transverse carrier drift on acoustoelectronic interaction in a layered piezodielectric-semiconductor structure

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The possibility of amplifying ultrasonic surface waves (USW) by transverse electric current in piezosemiconductors was indicated theoretically in[1,2]. In this paper we report observations of a strong influence of the transverse carrier drift on the effectiveness of the acoustoelectronic interaction in a layered piezodielectric-semiconductor structure ($LiNbO_3$-Si), and present some results of the experimental and theoretical investigation of this phenomenon, and offer a physical interpretation.

The schematic diagram of the experimental setup, in which the influence of the transverse carrier drift on the electronic absorption of the USW was investigated, is shown in Fig. 1. Short pulses of Rayleigh USW (frequency 95 MHz) of 0.1 μsec duration were excited and received by interdigital electromechanical converters with a sound conductor of *yz*-$LiNbO_3$. Its working surface was in contact with an *n*-Si plate of conductivity $5\times10^{-3}\Omega^{-1}cm^{-1}$ and dimension $0.4\times0.3\times0.003$ cm. To produce a transverse electron drift, a metallized dielectric plate was clamped to the upper surface of the silicon sample, and a metallic electrode was deposited on the lower surface of the sound conductor (see Fig. 1). A sinusoidal voltage of frequency 200 kHz was applied between this metallic electrode and the metallized dielectric plate. The transverse drift current flowed in this case through the capacitance made up of the lower electrode with the Si crystal, the thickness of the Si plate, and the capacitor made up of the Si crystal and the upper electrode grounded through the resistor *R*. At the chosen ratio of the length of the Si sample in the USW propagation direction and the frequency of the drift voltage, the change in the transverse current during the time of passage of the USW pulse under the Si crystal did not exceed 10%. The transverse drift field in the Si sample was taken to be the ratio of the drift-current density to the sample conductivity.

Figure 2 shows the experimental and theoretical dependences of the electron absorption of the USW on the transverse drift field. It is seen that the electron drift towards the boundary between the silicon plate and the sound conductor increases the electron absorption of the USW, and when the electrons drift in the opposite direction, the USW absorption decreases.

The theoretical calculation was performed by the method of[3] with allowance for the carrier drift in a direction perpendicular to the USW propagation plane. The formula for the electron absorption of the USW for this case is too cumbersome to present here, and we show only the curve calculated from this formula (Fig. 2). As seen from Fig. 2, the developed theory accounts satisfactorily for the observed experimental value.

Physically, the change of the electron absorption of Rayleigh USW under the influence of transverse carrier drift can be explained in the following manner. The Rayleigh USW propagating in the piezoelectric is accompanied not only by a longitudinal but also by a transverse alternating electric field. The joint action of these fields causes the maxima of the electron density to be shifted somewhat into the interior away from the surface of the semiconductor.[1] The transverse electron drift directed towards the boundary between the semiconductor and the piezodielectric "presses" the bunches towards the semiconductor surface in the region of the stronger electric fields, and by the same token increases the electron absorption of the USW. When the electrons drift in the opposite direction, the bunches move away from the interaction surface and a decrease in the electron absorption takes place.

It should be noted that the field effect[4] can also exert an influence on the value of the electron absorption of USW in a layered structure. Our experiments have

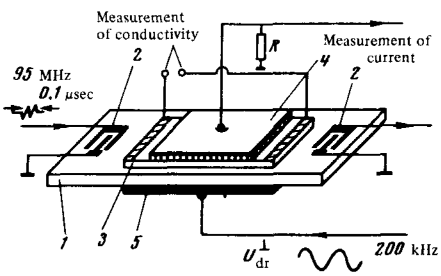

FIG. 1. Schematic diagram of experimental setup: 1-sound conductor of *yz*-$LiNbO_3$, 2-interdigital electromechanical converter, 3-silicon plate with Au + Sb contacts for conductivity measurements, 4-dielectric plate, 5-glass plate, 6-tin-oxide film, 7-lens, 8-illuminator.

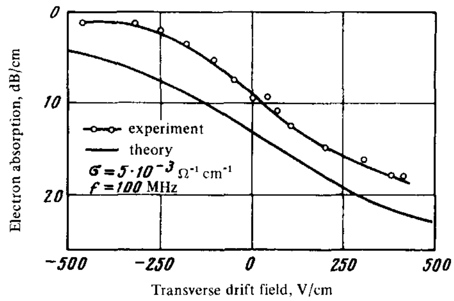

FIG. 2. Dependence of the electron absorption on the transverse drift field.

shown, however, that in our case neither the stationary nor the nonstationary field effect influences the electron absorption significantly.

We note in conclusion that the electron amplification of USW by a longitudinal electric current should increase strongly in the layered piezodielectric-semiconductor structure when a transverse drift is produced in the proper direction. This follows from the physical considerations advanced above and is confirmed by a theoretical calculation. Thus, for an $LiNbO_3$-Si layered structure with conductivity $10^{-2}\Omega^{-1}cm^{-1}$ at a USW frequency 500 MHz, the maximum gain due to longitudinal electric current can increase by 30 dB/cm under the influence of transverse electron drift with a velocity three times exceeding the USW velocity. The theory predicts in this case a certain decrease in the longitudinal drift field at which the maximum gain takes place.

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