Superheterodyne amplification of surface ultrasonic waves in a monolithic layered piezoelectric-semiconductor structure

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We present some results of an experimental study of the nonlinear interaction between ultrasonic surface waves of two different frequencies in a monolithic layered structure made up of lithium niobate and CdSe films under supersonic electron drift. It is observed that the electron amplification coefficient of a 28-MHz elastic surface wave increases in the presence of an intense 95-MHz wave at a definite conductivity of the CdSe film. Generation of elastic surface waves at the sum and difference frequencies (123 and 56 MHz, respectively) is observed in this case.

The increase of the electronic amplification of a volume ultrasonic wave (USW) of frequency f_1 in the presence of an intense USW having a frequency f_2 and a larger growth increment was first observed experimentally[1] in the piezosemiconducting crystal CdS. This phenomenon was explained in theoretical papers[2,3] where it was shown that the increase of the electronic amplification of the USW of frequency f_1 is due to generation of USW at the combination frequencies f_1+f_2 and f_2-f_1, with the "transfer" of a large electronic gain of the combination-frequency USW to the USW of frequency f_1. This phenomenon was called "distributed superheterodyne amplification of sound."[2,3]

We report in this paper, for the first time to our knowledge, observation of superheterodyne amplification of ultrasonic *surface* waves. This phenomenon was investigated by us in a monolithic structure with alternating $LiNbO_3$ and CdSe film layers. A thin CdSe film was deposited directly on the YZ-$LiNbO_3$ sound channel described in[4]. The electron drift mobility from a sample investigated by us was 250 cm^2/V-sec. This layered structure was chosen because of the high photosensitivity of the CdSe films, which enables us to carry out the investigations in a sufficiently wide range of conductivities.

The experimental setup is shown in Fig. 1. It consists of two YZ-$LiNbO_3$ reference sound channels (input and output). On each sound channels there are two pairs of electromechanical ridge-type converters with resonant frequencies $f_1=28$ MHz and $f_2=95$ MHz. The converters located on the opposite edges of the input and output sound channels are used for the generation and reception of the ultrasonic surface waves, respectively. The investigated layer structure is placed on the inner edges of the reference channels ducts and is pressed against converters located on these edges (see Fig. 1). The ultrasonic surface wave excited in the input sound channels goes over partially into the investigated structure through the system of metallic electrodes of the corresponding converter[5] (see Fig. 1). The ultrasonic surface wave goes from the layered structure to the output sound channel in a similar manner. The losses introduced by such a "bridge" (without allowance for the electronic absorption of the ultrasonic surface wave in the CdSe) were 30 and 36 dB at $f_1=28$ MHz and $f_2=95$ MHz, respectively. The converters with the resonant frequency f_2 made it possible to excite and receive ultrasonic surface waves also at the frequencies $f_1+f_2=123$ MHz and $f_2-f_1=67$ MHz, the losses introduced by the

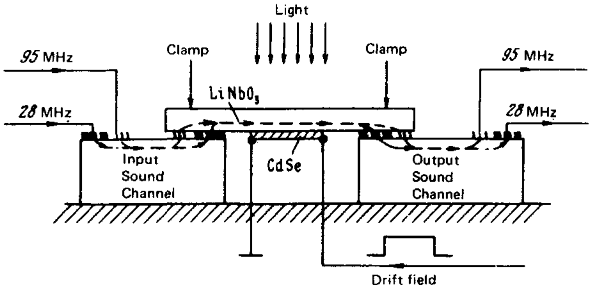

FIG. 1. Experimental setup. The active length of the CdSe film is 4 mm.

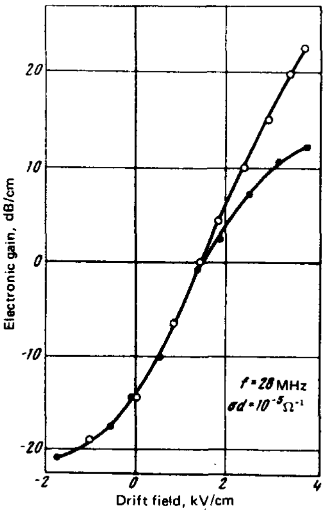

FIG. 2. Electronic gain at the ultrasonic surface wave frequency 28 MHz vs the drift field: ●) no pump, ○) intensity of 95-MHz ultrasonic surface wave (W_{95}) equal to 2 mW/cm, $\sigma d = 10^{-5}\ \Omega^{-1}$.

"bridge" being 58 and 56 dB, respectively. The width of the sound beam at all frequencies was equal to the width of the CdSe film, namely 2 mm. Thus, the procedure employed by us enabled us to avoid the laborious processes of constructing converters on each investigated structure.

Figure 2 shows the experimentally obtained drift-field dependence of the electronic gain of the 28-MHz ultrasonic surface wave. We see that at the given $\partial d = 2.5\times10^{-6}$ cm^{-1} (d is the thickness of the CdSe film and ∂ is its conductivity) the gain increases in the presence of an intense 95 MHz ultrasonic surface wave frequency in a drift field exceeding the threshold value. Under these conditions, generation of comparatively intense ultrasonic surface waves was observed at the sum (123 MHz) and difference (67 MHz) frequencies, in qualitative agreement with the theory.[2,3] The generation of the sum and difference frequencies in the case of nonlinear acoustoelectric interaction of ultrasonic surface waves of high and low intensity in a passive lithium-niobate—silicon structure was observed in[6]. At low values of σd, a decrease was observed in the electronic gain of the 28-MHz ultrasonic surface waves under the influence of the intense 95-MHz ultrasonic surface wave.

Such a nonlinear effect of the suppression of a drift amplification of the weak acoustic signals by a strong acoustic pump of a different frequency was first considered theoretically in[7] for the case of volume waves. The experimental dependence of the increment of the electronic gain (the superheterodyne increment) of the 28-MHz ultrasonic surface wave on the parameter σd at a drift field in excess of the threshold value is shown in Fig. 3. As seen from the figure, the effect of suppression of the gain of the weak signal by the strong pump increases with decreasing conductivity of the signal, in qualitative agreement with the theory.[7] The same figure shows plots of the electronic gain of the 95-MHz ultrasonic surface wave (α_{95}) (at two different wave intensities) and of the high-power ultrasonic surface wave at the sum and difference frequencies against σd. At low intensity of the 95-MHz ultrasonic surface wave α_{95} is maximal at $\sigma d = 1.25\times10^{-6}$ cm^{-1}, which is in good agreement with the theory.[8] With increasing ultrasonic surface wave intensity the maximum of α_{95} decreases in magnitude and shifts towards higher value of σd. It is seen from Fig. 3 that the superheterodyne increment is positive in that region of σd where intensive generation of ultrasonic surface waves at the sum and difference frequencies is observed. At a 95-MHz intensity 2 mW/cm, all the plots shown in Fig. 3 reach a maximum at the same value of σd.

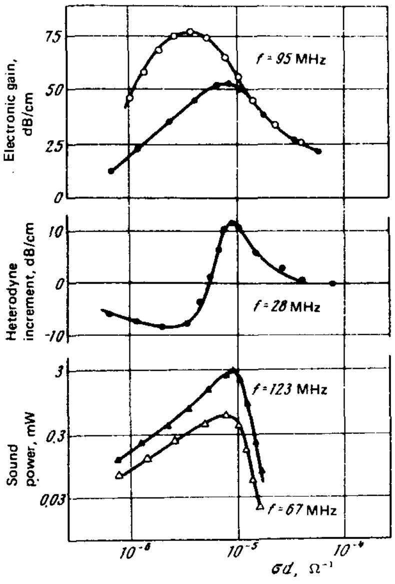

FIG. 3. Plots of: a) the electronic gain of the 95-MHz ultrasonic surface wave (○—$W_{95} = 1.5$ mW/cm, ●—$W_{95} = 2$ mW/cm); b) of the heterodyne increment at 28 MHz ($W_{95} = 2$ mW/cm); c) of the sound powers leaving the CdSe film at the sum and difference frequencies ($W_{95} = 2$ mW/cm, $W_{28} = 0.3$ mW/cm), all as functions of σd at $E_{dr} = 3.75$ kV/cm.

We note that the acoustic power of the generated ultrasonic surface waves at the sum and difference frequencies exceed the power of the 28-MHz acoustic input signal by 17 and 10 dB, respectively, i.e., a frequency conversion of the weak input ultrasonic surface wave signal takes place with the amplification.

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