ACTIVELY CONTROLLED SAW MULTISTRIP COUPLER

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Abstract

An actively controlled SAW multistrip coupler has been fabricated which employs an SAW magic tee and a new acoustoelectric phase shifter. This device can be used as a continuously variable power divider or as a switch.

A new actively controlled SAW multistrip coupler was constructed which can be used to continuously vary the power transfer from one acoustic track to another, or to switch an acoustic signal from one track to another. It is novel in the sense that it is electronically activated and provides active control over the propagation route of a surface wave.

This device employs a new electronically controlled SAW phase shifter which uses the acoustoelectric interaction between a piezoelectric surface wave and non-drifting charge carriers in an adjacent semiconductor. This interaction perturbs the amplitude as well as the phase velocity of the surface wave.[1] The amount of attenuation and the change in phase velocity depend on the conductivity of the semiconductor. In the limiting cases of very high and very low conductivity, the attenuation of the SAW is small. However, the phase velocity of the SAW will be slower in the case of very high conductivity since the high density of carriers will effectively short out the evanescent electric fields of the surface wave. Thus, the phase velocity of the surface wave decreases as the conductivity of the semiconductor increases.

The acoustoelectric interaction between the evanescent electric fields of a SAW on a piezoelectric substrate and the charge carriers in an adjacent semiconductor has been utilized to construct several types of devices, the best known being air-gap SAW amplifiers and air-gap SAW convolvers. In both of these devices, the amplitude of the SAW is the primary concern. The velocity perturbation due to the acoustoelectric interaction is usually assumed to be either very small, undesirable or not important. It is this perturbation in the velocity of the SAW which is utilized to devise an electronically controlled SAW phase shifter.

An SAW phase shifter was constructed using an n-type, silicon wafer which was air gap coupled to a yz $LiNbO_3$ delay line (See Fig. 1). The air gap is maintained with sputtered SiO_2 rails. To provide a means of controlling the carrier concentration with which the surface wave evanescent electric field interacts, a voltage is applied between a contact on top of the silicon wafer and the ground plane beneath the $LiNbO_3$. The transverse electric field is used to produce an accumulation, depletion, or inversion layer at the surface of the silicon. The resulting change in the surface conductivity affects the acoustoelectric interaction and produces a change in the attenuation and the velocity of the surface wave. For certain values of surface conductivity the transverse field produces a change in phase velocity, and therefore a phase shift, without substantial change in amplitude.

The phase shift induced by the application of a transverse voltage (V_T) is illustrated in Fig. 1 (bottom). A negative voltage produces an accumulation layer on the face of the silicon which is adjacent to the $LiNbO_3$. The increase in surface conductivity decreases the velocity of the surface wave causing a lagging phase shift of greater than 90° with negligible perturbation in the amplitude.

This acoustoelectric phase shifter provides a means of directly shifting the phase of a SAW propagating on a piezoelectric substrate without reconversion of the SAW to an electromagnetic signal. Such a device is useful in applications where coherent interactions of SAW's is required, e.g., SAW oscillators, mixers and other phase sensitive devices. The transverse field structure is a capacitive structure. It does not dissipate large amounts of power and can easily be operated in a continuous mode. Photo-generation of carriers can be employed in addition to or in place of the transverse field control of the surface conductivity.

Problems which have been encountered in designing and constructing this phase shifter include: (a) mass loading; (b) acoustoelectric attenuation; and (c) surface states. Mass loading problems are common to all air-gap SAW structures. However, several air-gap structures have been introduced which have satisfactorily solved this problem.[2,3] The acoustoelectric attenuation is a well known function of the surface conductivity and the height of the air-gap. It is possible to design the phase shifter to give acceptable attenuation characteristics. Silicon is well known for its high density of surface states. Surface states trap mobile charge carriers and shield the external dc field, thus increasing the voltage required to achieve the desired surface conductivity. Optimization of the phase shifter performance requires the consideration of these problems.

An actively controlled multistrip coupler was constructed by employing a SAW magic tee[4,5] and the acoustoelectric phase shifter in one track of the magic tee (see Fig. 2). The magic tee is fabricated on yz $LiNbO_3$. It consists of two input and two output interdigital transducers (IDT's) and a multistrip coupler. The IDT's have 4-1/2 finger pairs with a 108λ aperture. The center-to-center finger spacing is $d = 7.6$ microns, producing a center frequency of 230 MHz. The multistrip coupler is a half-transfer coupler consisting of 63 metal fingers which span the two adjacent tracks. The center-to-center finger spacing is $d = 5.6$ microns, giving the coupler a stopband frequency of 310 MHz. Each metal finger of the coupler is displaced $\lambda/4 = 3.8$ microns in the region where it crosses from one acoustic track to another.

In Fig. 2, let the input IDT's be labeled 1 and 2, where IDT 1 is the one whose track passes underneath the silicon. Let the output IDT which is in line with IDT 1 be labeled IDT 3, and the one which is in line with IDT 2 be labeled IDT 4. The operation of this structure as a variable power divider and as a switch for SAW's is described below.

With an input at IDT 1 only, the transverse dc voltage (V_T), over the range from -400 volts to +900 volts, produces a relatively small change in the amplitudes of the outputs at IDT 3 and IDT 4 (see Fig. 3). For voltages more negative than -400 volts, the acoustoelectric attenuation begins to decrease at a rapid rate. The large values of V_T are due to the thicknesses of the $LiNbO_3$ substrate and the silicon wafer, which can be reduced in an optimum design, thus reducing the required voltages.

With an input at IDT 2 only, the application of a transverse voltage has no effect on the amplitude of the signals received at IDT 3 and IDT 4 (see Fig. 3). This is expected, since the surface wave launched by IDT 2 does not pass underneath the silicon. The input at IDT 2 was adjusted in amplitude to give signals at IDT 3 and IDT 4 which approximately equal those resulting from an input at IDT 1 only with $V_T = 0$.

With inputs applied to IDT 1 and IDT 2 simultaneously, the amplitudes of the signals received at IDT 3 and IDT 4 were plotted as a function of V_T (see Fig. 3). While the transverse field only slightly changes the amplitude of the surface wave passing underneath the silicon as V_T is varied from -400 volts to +600 volts, it changes the phase of that surface wave by at least 180°. By controlling V_T, the relative phases of the two acoustic signals incident on the multistrip coupler can be controlled. The half-transfer multistrip coupler with $\lambda/4$ offset provides one-half the difference of the incident signals at IDT 4. By controlling the phase of the incident signal from IDT 1 with V_T, the amount of power divided between IDT 3 and IDT 4 can be controlled. Thus this actively controlled multistrip coupler can be used as a continuously variable power divider.

Figure 4 illustrates the operation of this actively controlled multistrip coupler as a switch. For V_T= -340 volts, all the power is delivered to IDT 4, and for V_T = +500 volts, all the power is delivered to IDT 3. V_T = 0 produces equal power at IDT 3 and IDT 4. The crosstalk between the two outputs of this switch is at least -20 dB.

Operation of this structure as an amplitude modulator is easily achieved by amplitude modulating the transverse voltage. The bandwidth of such a modulator depends on: (a) bandwidth of the transducers; (b) bandwidth of the multistrip coupler; and, (c) switching speed of the acoustoelectric phase shifter. The switching speed of the acoustoelectric phase shifter is limited by: (a) transit time of the SAW through the acoustoelectric phase shifter; (b) RC circuit time constant; and, (c) time constants associated with the surface states of the semiconductor.

In conclusion, an electronically controlled phase shifter has been constructed which uses the $\Delta v/v$ effect which occurs in an acoustoelectric interaction of a piezoelectric surface wave and an adjacent semiconductor. This phase shifter is combined with a multistrip coupler magic tee to implement a variable power divider. This power divider can be utilized as an electronically controlled SAW switch when V_T is switched between two specific values.

References

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SAW PHASE SHIFTER USING TRANSVERSE E-FIELD

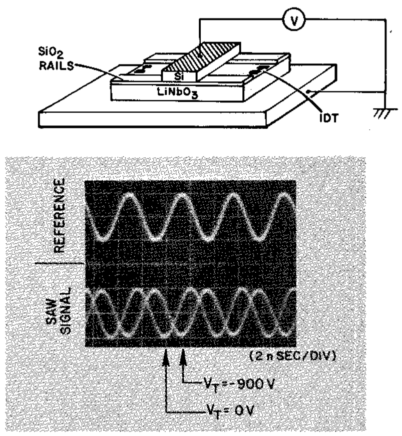

Figure 1 - (top) Acoustoelectric phase shifter using Si air-gap-coupled to $LiNbO_3$. (Bottom) Phase shift produced by application of a transverse voltage V_T.

ACTIVELY CONTROLLED MULTISTRIP COUPLER

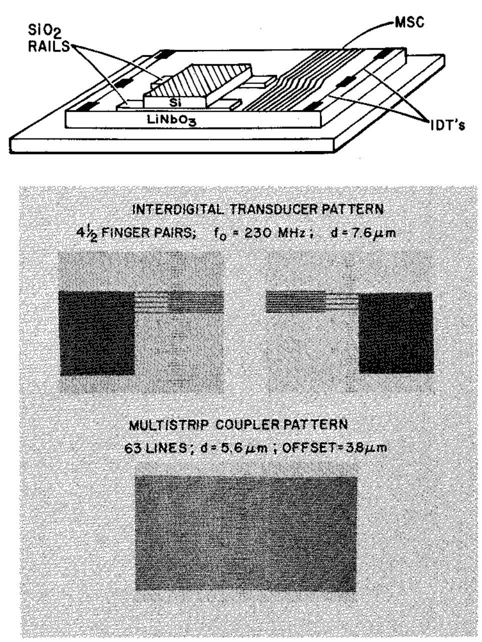

Figure 2 - (Top) Construction of actively controlled multistrip coupler. (Middle) Interdigital transducer pattern with 4-1/2 finger pairs. (Bottom) Multistrip coupler pattern with 63 lines and a $\lambda/4$ offset at midpoint of each line.

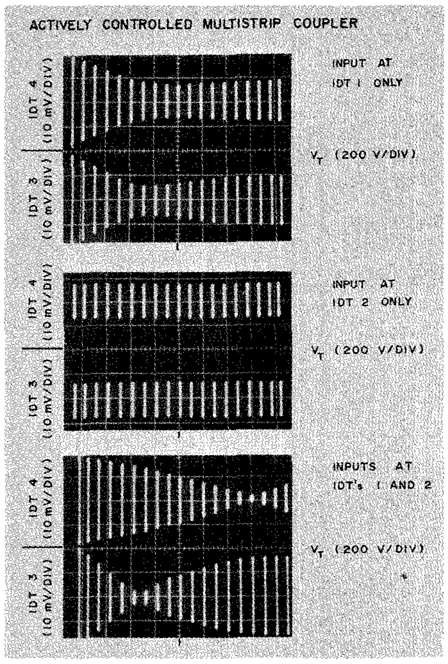

Figure 3 - Effects of transverse voltage, V_T, on the output signals at IDT 3 and IDT 4 for three different cw input conditions. (Top) Input at IDT 1 only. (Middle) Input at IDT 2 only. (Bottom) Inputs at IDT's 1 and 2.

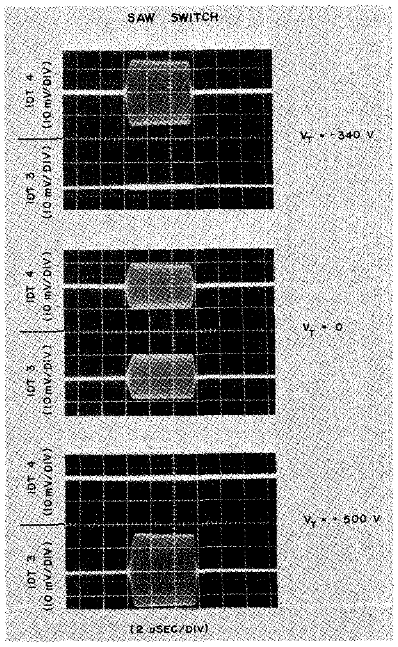

Figure 4 - SAW switch operation with pulsed inputs at IDT's 1 and 2. (Top) Output at IDT 4 only. (Middle) Equal outputs at IDT's 3 and 4. (Bottom) Outputs at IDT 3 only.