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USE OF ATTENUATION AND PHASE DELAY CHARACTERISTICS OF SAW TO MEASURE AIR-GAP HEIGHT

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ABSTRACT

The attenuation and phase delay characteristics of a SAW which has been perturbed by a metallic plane above the surface of a piezoelectric delay line have been theoretically computed and experimentally measured. These measurements provide a diagnostic tool for determining the height of an air gap and for determining the minimum achievable air gap for a particular supporting structure.

Acoustoelectric interactions play an important role in SAW signal processing. Air-gap structures in which the evanescent electric field of a SAW on a piezoelectric substrate interact with charge carriers in an adjacent semiconductor have been used to construct convolvers [1], correlators [2], and optical imagers [3]. In analyzing and evaluating the performance of these devices it is valuable to have a measure of the air-gap height. It is also valuable to know the minimum achievable air gap below which mass loading occurs. Using experimentally measured phase delay characteristics of the surface wave and the theoretical predictions for the perturbation of the surface wave by a metal film, the height of the metal film above the surface of the piezoelectric substrate can be determined.

A metal film interacting with the evanescent electric fields of the SAW on a piezoelectric substrate perturbs the propagation constant, β, of the SAW. In the limiting case of infinite conductivity, there is no attenuation due to the metal film, only a decrease in the phase velocity, v_p. The fractional decrease in phase velocity due to a metallic film at a distance h above the surface of the piezoelectric is given by the following expression derived from results by Otto [4].

$$\frac{\Delta v_p}{v_p} = (\varepsilon_g/(\varepsilon_p+\varepsilon_g))(1+N)\ \exp(-2|\beta|h)\left.\frac{\Delta v_p}{v_p}\right|_{h=0} \qquad (1)$$

where

$$N = (\varepsilon_p+\varepsilon_g \tanh|\beta|h)/(\varepsilon_g+\varepsilon_p)\ \tanh|\beta|h)$$

ε_g = dielectric constant of gap

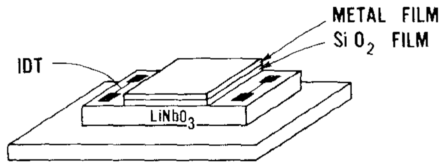
ε_p = dielectric constant of piezoelectric

$\left.\frac{\Delta v_p}{v_p}\right|_{h=0}$ = fractional change of phase velocity due to a metal film at h=0.

Since the perturbation of the phase velocity depends on the height of the gap relative to an acoustic wavelength, this structure is dispersive, i.e., the phase velocity is a function of frequency. The fractional change in group velocity is a measure of the amount of dispersion. The group velocity, v_g, can be computed using (2) once v_p versus frequency has been determined from (1)

$$v_g = v_p(f_1)\left(1 - \frac{v_p(f_2) - v_p(f_1)}{v_p(f_1)}\ \frac{f_1}{f_2 - f_1}\right)^{-1} \qquad (2)$$

Theoretical plots of the fractional decrease in group velocity versus gap height are plotted in Figs. 1 and 2 for a yz-$LiNbO_3$ delay line centered at 230 MHz.



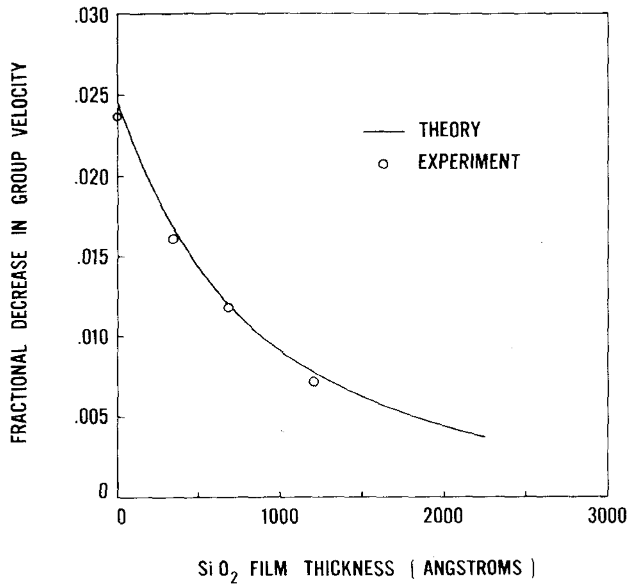


Figure 1 - Effect of SiO_2 film thickness on the fractional decrease in group velocity of a SAW produced by a metal film spaced above the surface of a yz-$LiNbO_3$ delay line by an SiO_2 film.

In Fig. 1 the gap is assumed to have a dielectric constant of 12.86 ε_o corresponding to an SiO_2 film. In Fig. 2 the gap is assumed to have a dielectric constant of ε_o corresponding to an air gap. Also plotted in Fig. 2 is the phase lag per unit length produced by lowering a metal film to a height above the surface which equals the SiO_2 rail thickness; this quantity was calculated using the fractional change in the phase velocity of (1). The attenuation due to the metal film is theoretically zero if no mass loading is assumed.

Two experiments were performed in which the perturbation of the SAW by metal films at different hieghts above the surface of a yz-$LiNbO_3$ delay line was measured. In the first case, the metal films were separated from the $LiNbO_3$ by sputtered SiO_2 films ranging in thickness from 0 - 1200 Å. For each thickness two SAW delay lines centered at 230 MHz were fabricated with the same SiO_2 film thickness. On one of these delay lines a 1000 Å aluminum film was evaporated, covering a 1 cm path length. Figure 3 illustrates the experimental set-up used to measure the phase delay characteristics of these delay lines.

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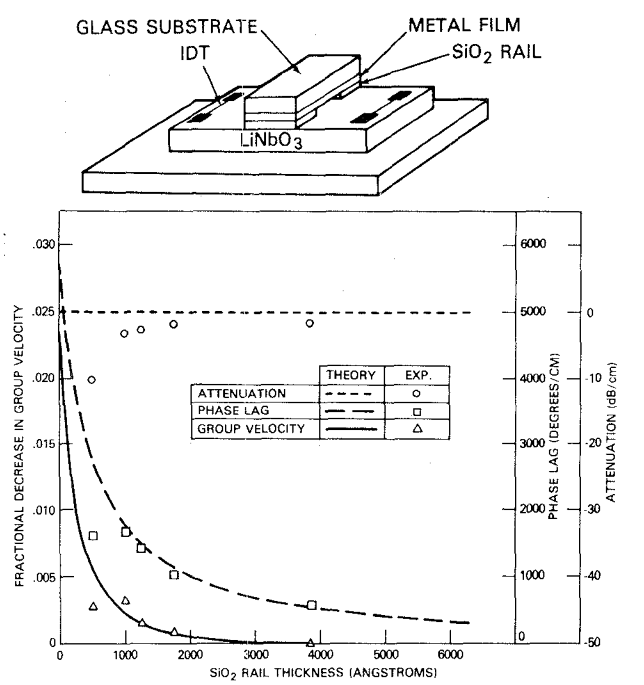

Figure 2 - Effect of SiO_2 rail thickness on the attenuation, phase lag, and fractional decrease in group velocity of a SAW produced by an air-gap-coupled metal film supported by SiO_2 rails.

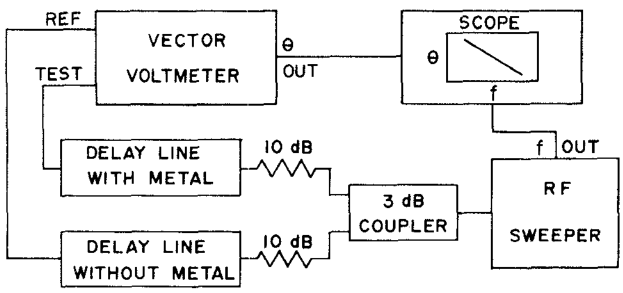

Figure 3 - Experimental set-up for measuring attenuation and phase delay characteristics.

Using the delay line without the metal film as a reference, the relative phase delay, θ, of the delay line with the metal film was measured as a function of frequency using the swept source and vector voltmeter. The fractional decrease in group velocity is related to the slope of the θ versus frequency curve by the following expression

$$\frac{\Delta v_g}{v_g} = \frac{v_g}{2\pi \ell} \frac{d\theta}{df} \tag{3}$$

where v_g is the group velocity of the reference line and ℓ is the path length covered by the metal film. For each SiO_2 film thickness the fractional decrease in group velocity was calculated from the experimentally measured θ versus f curve, and is plotted in Fig. 1. The experimental data points fall very close to the theoretical curve. Such good agreement suggests the possibility of utilizing experimentally measured fractional decrease in group velocity as a diagnostic tool to determine the height of a metallic plane above the surface of a piezoelectric.

In a second experiment, this technique was applied to the case of an air-gap-coupled metal film. An aluminum film was evaporated on a polished glass substrate. Subsequently, SiO_2 rails were sputtered on the metal film. Five such samples were fabricated having rail thicknesses ranging from 3840 Å down to 500 Å. As each sample was lowered onto a yz-$LiNbO_3$ delay line operating at 230 MHz, the attenuation and phase lag which occurred were measured. Once in position the phase lag, θ, versus frequency curve was taken from which the fractional decrease in group velocity was computed. The experimental values for these three quantities are plotted in Fig. 2 for each SiO_2 rail thickness.

The experimentally measured quantities and the theoretical curves of Fig. 2 are in good agreement for SiO_2 rail heights down to 1000 Å. Thus the height of the air gap can be determined using the phase delay characteristics of the surface wave. For the case of a 500 Å rail height, severe mass loading occurs producing attenuation of 10 dB/cm. In addition, the full phase lag and fractional decrease in group velocity which are expected theoretically cannot be achieved. Thus the practical limit on the minimum air gap for this particular configuration appears to be 1000 Å.

In summary, the attenuation and phase delay characteristics of a SAW which is perturbed by a metallic plane at a height h above the surface of a piezoelectric substrate have been computed for the two cases of a dielectric-filled gap and an air gap. Experimentally measured characteristics are in good agreement with theory. This suggests that a measurement of the attenuation and phase delay characteristics is a useful diagnostic tool in the evaluation of an air-gap structure. The phase delay characteristics provide a quantitative measure of the height of the air gap. Such measurements can lead to a determination of the minimum achievable air gap. In our particular air-gap structure which utilizes a rail support structure, it was readily apparent that the practical limit on the minimum air gap was 1000 Å.

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