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SOME STUDIES ON SAW PROPERTIES OF THIN SiO_x FILMS ON YZ-$LiNbO_3$*

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Experimental investigations of propagation velocity and acoustic losses of surface acoustic waves in YZ-$LiNbO_3$ coated with a thin SiO film are reported. These films are prepared by thermal vacuum evaporation from a SiO powder, for evaporation baffelled tantalum crucibles are used. Measurements were performed by optical probe techniques, which are described in detail. The phase velocity dispersion was found to be about 34×10^{-3} for $0\leq hk\leq0.6$. Acoustic transmission losses as small as 1.2 dB/cm were observed.

ИССЛЕДОВАНИЕ СВОЙСТВ ТОНКИХ ПЛЕНОК SiO_x НА YZ-$LiNbO_3$ С ПОМОЩЬЮ АКУСТИЧЕСКИХ ПОВЕРХНОСТНЫХ ВОЛН

Приведены результаты экспериментальных исследований распространения скорости и акустических потерь акустических поверхностных волн в YZ-$LiNbO_3$, покрытом тонкой пленкой SiO. Эти пленки получены из порошкового SiO методом термического напыления в вакууме с использованием экранированных танталовых тигелей. Измерения выполнены с помощью метода оптического зонда, который в работе подробно описан. Определена дисперсия фазовой скорости, численное значение которой равно примерно $34\cdot10^{-3}$ для $0\leq hk\leq0{,}6$. Наблюдались также потери звукопроницаемости величиной до 1,2 дб/см.

I. INTRODUCTION

Thin dielectric film overlays have several applications in surface acoustic wave (SAW) devices. For example, deposited films can be used to protect micro-electrodes. Furthermore, they are capable of generating or compensating dispersive SAW propagation characteristics. Also other properties of the SAW structure may be affected by thin films (e.g. the temperature coefficient of delay and the electromechanical coupling coefficient).

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The theory of wave propagation in layered structures is of a complex nature. A general numerical treatment is given by Farnell and Adler [3]. We have studied the special case of SiO/YZ-LiNbO$_3$. Results will be given elsewhere. For the present, an experimental determination of the propagation parameters is desirable. Experimental data, concerning SiO$_x$ films on YZ-LiNbO$_3$ will be presented in the present paper. The phase velocity shift and acoustic transmission losses due to the films were measured by optical methods. These methods are described.

II. PREPARATION

Interdigital transducers were prepared by standard photolithographic techniques on Y-cut Z-propagating LiNbO$_3$ substrates. The transducers consisted of 11 fingers and a 20 μm periodicity corresponding to a 40 μm wave length (samples "a"), or 7 fingers and a 24 μm periodicity corresponding to a 48 μm wave length (samples "b"). For deposition the samples were arranged in a vacuum coating plant. Commercial grated silicon monoxide (SiO) powder was used as evaporant. The evaporation crucible was made from tantalum, and resistance heating was applied. At a crucible temperature of about 1350 °C the deposition rate was determined to be 12 μm/*h*. The evaporation was started at pressures ranging from $6.7 \ldots 10.7 \times 10^{-4}$ Pa ($5 \ldots 8 \times 10^{-6}$ torr). The pressure decreased to about $1.3 \ldots 2.7 \times 10^{-4}$ Pa ($1 \ldots 2 \times 10^{-6}$ torr) caused by the gettering action of the SiO. In this process some SiO powder was oxidized to SiO$_2$. In one deposition cycle we have obtained a maximum layer thickness $h \approx 3$ μm. The colour of the films depends on the thickness, changing with increasing thickness from amber-coloured to dark-brown. These amorphous films show a high bond strength on LiNbO$_3$. The preparation conditions and the colour of the films allow us to conclude that they consist for the most part of SiO [4].

III. METHODS AND MEASUREMENTS

Before depositing the films we have measured the SAW velocity in all the substrates by a delay time measuring method [5] with high precision (about one part in 10^{+4}). On the layered structures we have determined the change of the phase velocity by the following optical probe techniques:

(1) The diffraction of a laser beam by surface acoustic waves [6] is shown schematically in Fig. 1. Due to the surface corrugations a moving phase grating is created which diffracts light primarily into ±1 orders. The diffraction angles $\Theta_\pm$ are given by the grating equation

$$\sin \Theta_\pm = \sin \Theta_0 \pm \lambda / \Lambda . \tag{1}$$

Θ_0 is the angle of incidence, λ is the laser wave length, and Λ is the surface acoustic wave length.

We assume that $\lambda \ll \Lambda$ and $\Theta_0 \ll 1\cdot$. These conditions can be fulfilled in most practical cases. With the help of the equation

$$v = f\Lambda , \tag{2}$$

where v is the phase velocity, and f is the frequency, we obtain

$$\vartheta = \Theta_+ - \Theta_- = 2 \frac{f}{v} \lambda . \tag{3}$$

By differentiation we find

$$\frac{v - v_0}{v_0} = \frac{\Delta v}{v_0} = - \frac{\Delta \vartheta}{\vartheta} = - \frac{\Delta y}{y} . \tag{4}$$

y is the distance between the diffracted beams measured at a point separated by 1 from the sample. Δy is the variation of y obtained by changing the optical probe from an uncoated region on the surface to a coated region. This can be done by moving the sample.

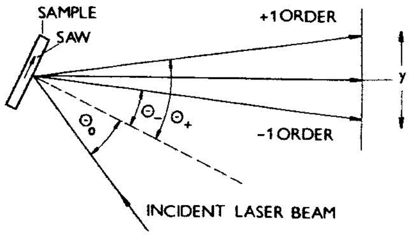

Fig. 1. Schematic representation of SAW velocity measurement by laser beam diffraction

(2) Now we assume that the power density in the SAW is sufficient to produce observable nonlinearity effects. In this case a second harmonic wave (frequency $2f$) will be generated. This wave can be investigated idependently of the fundamental wave by optical probing. Especially the energy of the SAW can be measured at every point on the surface of the sample, as the reflected intensity of the first-order diffracted beam detected with a photomultiplier tube is proportional to the energy of the SAW.

The coupled amplitude equations provide a description of the generation process. The amplitude of the second-harmonic wave neglecting the third- and higher order harmonics is written as [7]

$$A^{(2)}(z) = A_0^{(1)2} \Gamma_{211} \frac{\exp\left[\left(-2\alpha^{(1)} + i\Delta k_{211}\right)z\right] - \exp\left(-\alpha^{(2)} z\right)}{\alpha^{(2)} - 2\alpha^{(1)} + i\Delta k_{211}} , \tag{5}$$

where $A^{(2)}(z)$ is the amplitude of the second harmonic wave at point z, $A_0^{(1)}$ is the amplitude of the fundamental wave at point $z = 0$, Γ_{211} is a nonlinear coupling coefficient, $\Delta k_{211} = |k_2 - 2k_1|$ is the mismatch between momenta k_2 and k_1 of the waves, $\alpha^{(1)}$, $\alpha^{(2)}$ are the amplitude absorption coefficients of the fundamental and harmonic waves, respectively. Neglecting the losses ($\alpha^{(1)}, \alpha^{(2)} \ll 1$ dB/cm) we obtain from eq. (5)

$$A^{(2)}(z) = A_0^{(1)2} \Gamma_{211} F(z), \tag{6}$$

where

$$F(z) = \frac{\exp(i\Delta k_{211} z) - 1}{i\Delta k_{211}}. \tag{7}$$

Keeping in mind that the first-order diffracted intensity is proportional to the square of the amplitude we find

$$I_1^{(2)}(z) \sim F(z)^2 \sim [1 - \cos(\Delta k_{211} z)]. \tag{8}$$

By scanning the sample along the path of the SAW (that means the z-direction) and measuring the oscillation periodicity we can determine the momentum mismatch Δk_{211}. From this we find

$$v_2 - v_1 = \Delta v = v_1 \frac{\Delta k_{211}}{2k_1}, \tag{9}$$

where v_1 and v_2 are the phase velocities of the fundamental and the harmonic waves, respectively.

IV. RESULTS AND DISCUSSION

In Fig. 2 the experimental values of the phase velocity are plotted against hk (h thickness, $k = 2\pi/\Lambda$). The change of the phase velocity is proportional to hk in the investigated interval $hk \leq 0.6$. The dependence can be approximated by $\Delta v/v_0 = Bhk$, where the slope is $B \approx 0.034$.

We have not found any published work dealing with the layered system SiO/YZ-LiNbO$_3$ so far. Nevertheless, the following approximation given by Farnell [8] for the general case of a thin isotropic film should be applicable:

$$\frac{\Delta v}{v_0} = \frac{\omega}{4}\frac{hk}{w_1}\varrho_L(Av_{tL}^2 - u^2 v^2), \tag{10}$$

$$A = 4(1 - v_{tL}^2/V_{lL}^2)u_1^2, \quad u^2 = u_1^2 + u_3^2. \tag{11}$$

In accordance with our experimental conditions we have assumed $u_2 = 0$, u_1, u_3 are the longitudinal and the normal components of the particle displacement, respectively. $\omega = 2\pi f$, W_1 is the total power per unit width of the acoustic beam carried parallel to the surface by the surface wave, $\omega u_1^2/W_1$ is a material constant of the substrate, v_{tL}, v_{lL} are the velocities for shear and longitudinal bulk waves in the layer material, respectively, ϱ_L is the mass density of the layer material.

For most layers $A \approx u^2$ (8). Therefore we have $\Delta v \sim hk$, and the sign of the velocity change is usually determined by the relative magnitudes of v_0 and v_{tL}. A qualitative agreement of our measurements with the simple theory can be seen.

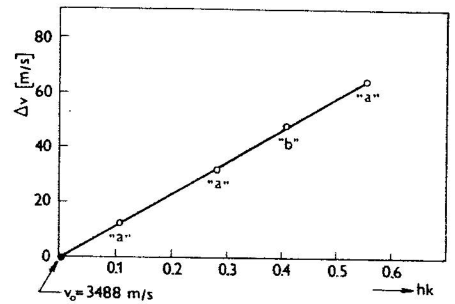

Fig. 2. Measured velocity shift as a function of hk

A qualitative comparison is impossible at present because v_{tL} and v_{lL} for silicon monoxide are unknown.

Our result may be compared with theoretical investigations of the system SiO$_2$/YZ-LiNbO$_3$, given by Solie [2]. From Fig. 13 of [2] a value of B is derived, which is about one half of the B-value for SiO layers found by us. Obviously, the application of SiO layers to LiNbO$_3$ produces a larger velocity dispersion.

We also have measured the acoustic transmission losses for a SiO film 3.1 μm thick at the SAW frequency 77.44 MHz. By optical probing of the SAW before entering into the film and after transmission the loss was determined to be $\alpha^{(1)} \leq 2$ dB/cm. The result of measurements in the layered region by the same method is $\alpha^{(1)} \approx 1.2$ dB/cm. We think that the difference is due to the edges of the film causing some energy to be reflected or converted into bulk waves. Almost similar results in relation to SiO$_2$/LiNbO$_3$ structures are given in (9).

V. CONCLUSION

We investigated the change in the phase velocity for SAW's on layered structures of SiO/YZ-LiNbO$_3$. The SiO films were deposited by vacuum evaporation. The velocity dispersion was determined to be $B \approx 0.034$. This is approx. twice as large as for SiO$_2$ layers and can be of interest to SAW devices. The films show small losses. Special optical methods were used for the investigations.

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