The exact location of the cutoff frequencies of these H modes will, of course, depend on H and W, and on the sign, magnitude, and frequency dependence of X_1 and X_4. For the case of a symmetric square waveguide ($H = W$, $X_4 = X_1$), it can be shown that the cutoff frequency of the lowest H mode is *always* below that of the E_{11} mode. At cutoff, $\Gamma = 0$ and $k = k_c = (K_x^2 + K_y^2)^{1/2}$. If $X_4 = X_1$ is positive (inductive reactance) the lowest H mode (for which $K_y = K_x$) is associated with $H_z = H_0 \sin(K_x x) \sin(K_y y) \exp(-\Gamma z)$ and has a normalized cutoff frequency

$$k_c W = 2\sqrt{2} \cot^{-1} (\sqrt{2} X_1/Z_0).$$

The first solution of this equation is always less than $\sqrt{2}\pi$, the value of the normalized cutoff frequency of the E_{11} mode. If $X_4 = X_1$ is negative (capacitive reactance) the lowest H mode ($K_y = K_x$) is associated with $H_z = H_0 \cos(K_x x) \cos(K_y y) \exp(-\Gamma z)$ and has a normalized cutoff frequency

$$k_c W = 2\sqrt{2} \tan^{-1} (-\sqrt{2} X_1/Z_0).$$

Again, the first solution of this equation (recall that $-X_1$ is positive), is always less than $\sqrt{2}\pi$, the value for the E_{11} mode. Thus, based on this model, an H mode will always be the dominant mode of the waveguide, and the E_{11} mode can never be the dominant mode.

In their paper,[1] the authors state that in an experimental study of a square waveguide with longitudinally corrugated walls, they found no evidence of any H modes over a two-to-one frequency range which included the cutoff frequency of the E_{11} mode. They concluded that the E_{11} mode was the dominant mode of the waveguide. The fact that these experimental results conflict with the results of a correct analysis of the wall impedance model suggests that a critical reexamination of the whole problem should be undertaken to resolve this conflict. In view of this conflict, acceptance of the authors' contention that a longitudinally corrugated waveguide always has a dominant E mode appears inadvisable until an independent confirmation of their experimental results is available.

Comments on "Rectangular Waveguides with Impedance Walls"

M. S. NARASIMHAN AND V. VENKATESWARA RAO

In the above paper,[1] some comments seem to be necessary on the impedance compatibility relation

$$Z_1 Z_3 - Z_2 Z_3 + Z_2 Z_4 = 0 \qquad (1)$$

where Z_1, Z_2, Z_3, and Z_4 have been defined.[1] This relation was derived for obtaining a separable modal solution of fields. Though (1) appears to be mathematically correct, controversies arise when it is used for square or rectangular waveguides with all the four walls corrugated transversely to the direction of propagation. Bryant [1] in his analysis used a square corrugated waveguide excited in the TE to x mode of operation and observed that the H-plane walls, though corrugated, will act as a conducting surface and will not affect the propagation of TE to x modes. Dybdal *et al.* have pointed out that for this particular geometry (1) is not satisfied and in order to satisfy (1) the H-plane walls should be conducting. We would like to point out that it is well known that a separable modal solution of fields in a waveguide with impedance walls may be expressed in terms of

$$\left\{\begin{matrix}\text{TE}\\ \text{TM}\end{matrix}\right\} \text{ to } x \qquad \text{or} \left\{\begin{matrix}\text{TE}\\ \text{TM}\end{matrix}\right\} \text{ to } y \text{ modes [3].}$$

Hence the impedances which can influence the propagation of these modes will be limited to three only. This can be explained physically also by observing that given the polarization for a desired mode of operation (viz., TE to x or TE to y) only one pair of walls will act as an anisotropic surface and the other (with corrugations parallel to the E field) will act only as a conducting surface [4]. This observation has been made by Dybdal *et al.* also.[1] Further considering the modal solution corresponding to the TE to x mode within the corrugated guide of this type one observes that $E_x = 0$ everywhere, $E_y = 0$, and $E_z = 0$ on the H walls [2]. Hence $Z_1 = Z_3 = Z_4 = 0$ and $Z_2 \neq 0$, which satisfy (1). Recently it has been confirmed experimentally [4] that a waveguide with all the four walls corrugated transversely gives satisfactory results when it is excited in TE to x or TE to y mode. This has also been verified by us by constructing a square corrugated guide. Similarly, when the corrugated guide is excited in the TE to y mode $Z_1 = Z_2 = Z_4 = 0$ and $Z_3 \neq 0$. Again (1) is satisfied. For this mode of operation the E-plane corrugated surface behaves like a conducting surface and the H-plane walls are anisotropic. From the previous discussions it is obvious that the corrugated surface can behave as an anisotropic as well as an isotropic surface, depending upon the choice of the mode of excitation used. From these observations the authors believe that the square corrugated guide may be used most efficiently as a wide-band dual polarized device by a judicious choice of the corrugation depth.

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Surface Acoustic Wave Properties of Tantalum Pentoxide Thin Films on *YX* Quartz

J. F. WELLER AND T. G. GIALLORENZI

***Abstract*—The properties of a Rayleigh surface wave propagating in tantalum oxide thin films on *YX* quartz are presented. Dispersion and acoustic wave loss measurements are made using the optical probe technique.**

The propagation characteristics of surface acoustic waves (SAW) in layered structures differ in several ways from those on a free surface. Rayleigh waves on a free surface are normally dispersionless and have low losses for frequencies less than 300 MHz ($\leq$1 dB/cm in *YX* quartz). The introduction of a thin film causes velocity dispersion [1] as well as an increase in the losses of the SAW. The film can either mass load the surface which slows the SAW or effectively strengthen the elastic properties of the surface which increases the velocity. In the latter case the wave velocity increases to the point where the wave becomes leaky, i.e., when it has a phase velocity equal to that of the lowest transverse bulk wave; eventually at large film thicknesses, mass loading will again predominate and the wave slows down. Finally, the film introduces more loss due to increased scattering caused by grain boundaries and other surface imperfections [2] and by step discontinuities as recently discussed by Munasinghe and Farnell [3].

The introduction of velocity dispersion resulting from a thin film overlay leads to several applications for SAW devices. Mass loading can be used to produce acoustical waveguiding and provides a means for steering, focusing, or defocusing the SAW [2]. In a few cases where the thin film causes an increase in the phase velocity,

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The authors are with the Optical Sciences Division, Naval Research Laboratory, Washington, D.C. 20375.

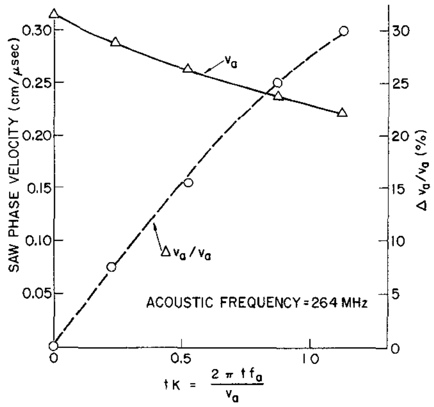

Fig. 1. Dispersive properties for SAW in Ta_2O_5 films on YX quartz.

enhanced coupling of the interdigital transducer (IDT) is accomplished by overcoating the IDT's with the film [4]. The dispersive property can also be used in an acoustooptical deflector for better resolution, and improved efficiency could result by adjusting the film thickness [5]. Moreover, optically guided waves [6] interact with SAW's to make deflectors, switches, and mode converters.

In some cases, the dispersion introduced by the thin film overlay can be calculated if the elastic properties of the film as well as the substrate are known [1]. If the elastic properties of the film material are not known, the SAW dispersive properties of the thin film can be measured experimentally. This letter reports the properties of a Rayleigh surface wave propagating in a tantalum pentoxide (Ta_2O_5) film on YX quartz; the Ta_2O_5 film is of interest because it is a low loss optical waveguide material [7] in the visible and near IR. Moreover, it has been shown recently that in Ta_2O_5 films on YX quartz, efficient deflection of optically guided waves can be obtained [8].

The experimental apparatus as well as the film fabrication techniques are described elsewhere [9] but some essential details are presented here. A microwave generator, operating in a pulsed mode (10–50-Hz repetition rate and a 1.0-μs pulsewidth), and an external matching network provide the power to a set of interdigital transducers with 19 finger pairs. The IDT's have 3-μm finger widths and a 6-μm periodicity corresponding to a 12-μm wavelength. Input and output transducers are separated by approximately 17.0 mm and have apertures of 1.0 mm.

The YX-quartz substrates are 2.54 × 2.54 × 0.100 cm; only a 5.0–6.0-mm length between the transducers is used for depositing the films; the other areas are masked off by microscope slides which also cover the transducers and electrical leads. In order to insure high quality thin films on the substrates, the substrates are thorougly cleaned before deposition with several organic solvents and then sputter-etched for 15 min at 50 W. The films are then deposited by RF sputtering a Ta_2O_5 target in an argon–oxygen atmosphere. Film thicknesses are measured with a Sloan Dektak thickness sensor and by accurately measuring the coupling angles for optical waveguiding; this latter technique also gives values for the index of refraction. In these films, the refractive index is found to be 2.10 ± 0.01, which is lower than the 2.22 value reported [7] for films deposited by evaporating tantalum and then oxidizing it. The lower value for refractive index is due to the lack of total oxidation of the tantalum.

Dispersion and SAW losses are measured using the standard optical probe technique [10]. The optical probe measures the first-order diffraction intensities from the phase grating created by the SAW in propagating across the surface of the solid; these intensities can then be related to the surface corrugations and acoustical power. The diffraction angle ϕ is given by the grating equation

$$\sin\phi = \sin\phi_0 \pm m\lambda/\Lambda = \sin\phi_0 \pm m\lambda f_a/v_a \qquad (1)$$

where ϕ_0 is the incident angle, m is the order, λ is the optical wavelength, Λ is the acoustical wavelength, v_a is the acoustic phase velocity, and f_a is the acoustic frequency. According to (1), the diffraction angle is dependent on the phase velocity. This is very easy to observe experimentally when the thin film strip is deposited with an unlayered portion between the transmitter and the film edge. As the optical probe is translated from the unlayered portion through the film keeping the acoustic frequency constant, the diffraction angle changes if the wave velocity changes. The change in diffraction angle $\Delta\phi$ can then be simply related to the change in velocity by

$$\Delta v_a/v_a = \Delta\phi/\phi. \qquad (2)$$

In this manner the dispersive properties of a thin film on a SAW material can easily be determined. As usual, losses can be measured by translating the optical probe along the path of the SAW. For all these measurements, a 6.0-mW He–Ne laser provides the probe beam and the reflected first-order diffraction intensities are measured at a distance of 1.0 m from the sample.

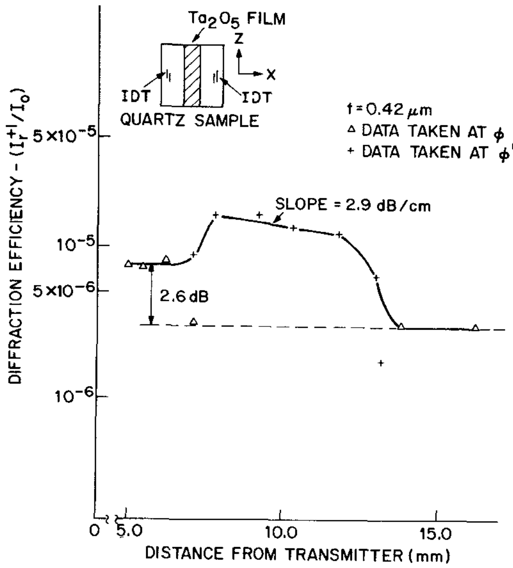

Fig. 2. SAW losses for a 0.42-μm Ta_2O_5 on YX quartz; insert illustrates film and IDT orientation.

The measured phase velocity and velocity changes in several thicknesses of Ta_2O_5 films are shown in Fig. 1. These data are plotted as a function of the product of the thickness t, and acoustic wavevector K, using the measured value of v_a to calculate K. For the largest film thickness measured, $t = 2.1$ μm, the velocity change is approximately 30 percent, whereas only a 7.5-percent change is observed in the smallest thickness measured $t = 0.42$ μm. However, the films have substantial acoustic losses which are shown in Fig. 2.

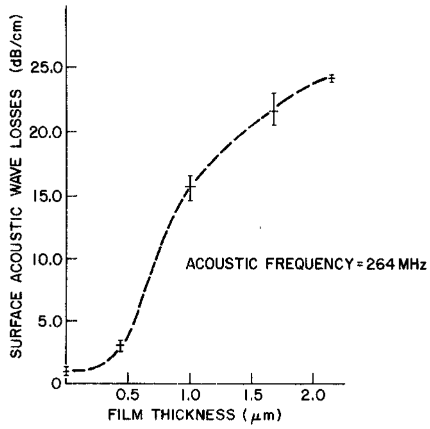

Fig. 3. SAW losses in Ta_2O_5 films on YX quartz.

Fig. 2 is the loss curve measured for a 0.42-μm film. Data taken in the unlayered portion are deflected at an angle ϕ, but in the film the deflection angle ϕ' is larger due to a slower velocity as indicated in Fig. 1. The data in Fig. 2 are presented on a semilog plot, and are linear in regions where the probe beam does not overlap in the two areas. Points falling off the curve indicate an overlap region where the probe beam hits both layered and unlayered regions and the beam is deflected into two separate angles. Each IDT is used to launch the SAW and the losses measured to be the same within the experimental accuracy. From Fig. 2, the loss for this particular film thickness is determined to be 2.9 dB/cm in the linear region; using this loss value and a 5.7-mm film width underestimates the total loss in this sample by approximately 1.0 dB. The additional loss could be due to edge imperfections or step discontinuities at the film edge; losses attributed to the edge are never found to be larger than 1.0 dB in these films. In most of the samples measured, the diffraction efficiency increases in the film as shown in Fig. 2; the maximum increase observed is 4.6 and is found in a sample with a 1.67-μm thickness. The increase is due to additional constructive reflections at the film–substrate interface, and a longer interaction length between the optical wave and the SAW. The diffraction efficiency also appears to decrease by a larger amount leaving the film than it increases entering the film. Again, this could be attributed to the step discontinuity but it is interesting to note that the effect is opposite to that observed in a film where the SAW speeds up in the film [9]. Losses for three other thicknesses were measured and the data are shown in Fig. 3 as a function of film thickness. Finally, acoustic wave loss values for polycrystalline Ta_2O_5 have not been measured, but the data presented here indicate that they are greater than 340 dB/cm/GHz² assuming that the quantity for the thickest film is approaching the bulk loss value.

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Comments on "Scattering by a Ferrimagnetic Circular Cylinder in a Rectangular Waveguide"

PRAKASH BHARTIA

In the above paper,[1] the authors have arrived at a general and rigorous solution for the scattering by a demagnetized ferrimagnetic cylinder in a rectangular waveguide. Corrections to the above paper have appeared separately [1], and a proof has been presented to show that the unitary condition on the S matrix is guaranteed for any size of truncation in the formulation of that paper. However, a number of errors still remain and for completeness, they are pointed out here. Thus (7)[1] should read

$$\frac{\partial E^i}{\partial r} + \frac{\partial E^s}{\partial r} = M\frac{\partial E'}{\partial r} - jK\frac{1}{r}\frac{\partial E'}{\partial \theta}, \qquad \text{at } r = R.$$

The second part of (30)[1] should read

$$vJ_p'(v)\sin\left(\frac{\pi x_0}{a} + p\alpha\right) + vJ_p'(v)\sum_{n=-\infty}^{\infty} A_n h_{np} + A_p v H_p^{(2)}(v) = B_p D_p J_p(u).$$

Finally, (33)[1] should read

$$A_p = G_p \sin\left(\frac{\pi x_0}{a} + p\alpha\right) + G_p \sum_{n=-N}^{N} A_n h_{np}.$$

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The author is with the Faculty of Engineering, University of Saskatchewan, Regina, Sask., Canada.
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