ACOUSTIC SURFACE WAVEGUIDES, WITH SIMILARITIES IN OPTICS

Arthur A. Oliner
Polytechnic Institute of New York
Brooklyn, New York 11201

Abstract

An overview is presented first of the various types of waveguides for acoustic surface waves which have been studied theoretically and experimentally. Many of these waveguides resemble certain waveguiding structures proposed for use in integrated and fiber optics. The similarities and differences between corresponding waveguiding structures in the two different fields are then discussed from the standpoints of their properties and their mechanisms of operation.

Introduction

Most waveguides employed for electromagnetic microwaves do not resemble the various types of waveguide which have been considered for acoustic surface waves. On the other hand, some important similarities (and interesting differences) exist between such acoustic waveguides and waveguiding structures proposed recently for integrated and fiber optics and for electromagnetic millimeter waves. In addition, the techniques of microwave networks can be, and have been,[1-5] used to analyze and describe the properties of these acoustic waveguides. In this paper, the types and properties of various acoustic surface waveguides are summarized, comparisons are made between some of these waveguides and the corresponding structures proposed for optical or millimeter wave applications, and microwave network approaches are used where appropriate in the description of the guiding properties and mechanisms of operation.

Although at present almost all surface acoustic wave devices utilize wide-beam surface waves, such wide-beam waves possess certain limitations: beam spreading, inefficient use of the substrate area, and awkwardness in bending their paths. The most important of these is beam spreading, which causes cross talk between neighboring beams. All of these problems are automatically overcome by the use of waveguides for such surface waves, where the term waveguide implies a geometrical structure which confines the lateral extent of the surface wave and binds the wave to itself.

Acoustic surface waveguides are currently being investigated primarily (but not only) for use in long delay lines for the storage of either digital or analog signals, principally in order to overcome the beam spreading problem. But these contemplated applications barely scratch the potential of these waveguides. The most intriguing potential application is that of a highly-compact sophisticated circuit technology, often referred to as "microsound" technology.[6-8] A glance backwards to the electromagnetic microwave field shows that sophisticated electromagnetic microwave circuitry did not appear until waveguides were well utilized. One is encouraged to speculate, therefore, that the full potential of acoustic waves will not be realized until acoustic waveguides are thoroughly exploited.

The two fields of acoustic surface waves and integrated optics possess many similarities because of three features: the wavelengths in each are tiny, the fabrication technology is similar for each, and surface waves are common to both. It is important to be aware of such similarities because such recognition permits the interchange of ideas and technology between the two fields and helps to speed up the development of both fields. A comparison in broad terms has been presented[9] previously, considering such aspects as materials, devices and applications; the present discussion is restricted only to some corresponding waveguiding structures in each field. In this discussion, it will be shown what the corresponding structures are, which were conceived independently of the other field, and which resulted from knowledge of its analogue structure.

Types of Acoustic Surface Waveguide

Waveguides for acoustic surface waves may be classified into four types:

1. Overlay waveguides, in which a strip of one material is placed on a substrate of another material,
2. Topographic waveguides, which consist of a local deformation of the substrate surface itself (that is, a change in the local topography of the surface),
3. Waveguides in which a local change has been produced in the properties of the substrate material, and
4. Circular fiber waveguides, which do not employ a planar substrate.

Typical waveguiding structures in each of the four categories listed above are shown in Fig. 1.

The properties of all of these structures, and the advantages and limitations of each one, have been treated in a recent publication.[10] The principal features of these guides will be summarized in the talk, but we may here point out, in view of the interest in such waveguides for long delay-line applications, that several of these waveguides exhibit flat dispersion behavior over some frequency range. The wedge waveguide (Fig. 1(e)) is dispersionless above a certain minimum frequency, and the symmetric (pseudo-Rayleigh) mode of the ridge waveguide (Fig. 1(d)) has very small dispersion over the entire frequency range. Furthermore, the shorting-strip guide of Fig. 1(b), the slot guide of Fig. 1(c), and the fiber structures of Figs. 1(g) and 1(h) can all be designed so as to possess reasonably flat group velocities over some frequency range. The virtues of the symmetric ridge guide mode mentioned above have not been sufficiently appreciated to date; it is as close as one might come to an acoustic coaxial line mode or strip line mode, in the sense that it is very tightly confined, it propagates down to zero frequency, and it is essentially dispersionless.

Comparisons with Optical Waveguides

The optical waveguides which are actually counterparts of some of the acoustic waveguides shown in Fig. 1 are most easily recognized as such if we first recall the following facts relating to wide surface waves. In acoustics, a surface wave (the Rayleigh wave) can be supported by the interface between the substrate surface and air (or vacuum). In optics, for normal dielectric materials, a surface wave cannot be supported on a bare half space; surface waves require a layer or thin film of "slow" material on top of the substrate.

The wide surface waves mentioned above are confined vertically but not horizontally; a waveguiding structure also confines this wave horizontally. In this talk, optical counterparts will be considered for the following waveguides shown in Fig. 1: (a), (c), (d) and (h). In each case, the mechanism of guiding and the properties of the guide will be described, even though such discussion cannot be included here due to the limitations on space.

The optical counterparts to the strip guide of Fig. 1(a) and the slot guide of Fig. 1(c) are shown in Figs. 2 and 3, respectively. Note that the thin film is required in each optical case. In that context, the early strip structures shown in Fig. 2(b) are not true counterparts despite their resemblance. The optical analogue to the slot guide, shown in Fig. 3(b), becomes possible because at optical frequencies a metal behaves as an overdense plasma, with a negative real dielectric constant. Both of these optical waveguides have been treated theoretically and measured.

The optical analogue of the acoustic waveguide in Fig. 1(h) is the well-known single-mode step-index optical fiber. In fact, the acoustic structure was proposed (also analyzed and measured) as an acoustic counterpart of that optical fiber. The topographic waveguide of Fig. 1(d), on the other hand, has no optical counterpart; if optical energy is fed into the ridge, the wave will become a leaky wave. In optics, topographic structures cannot guide purely-bound modes.

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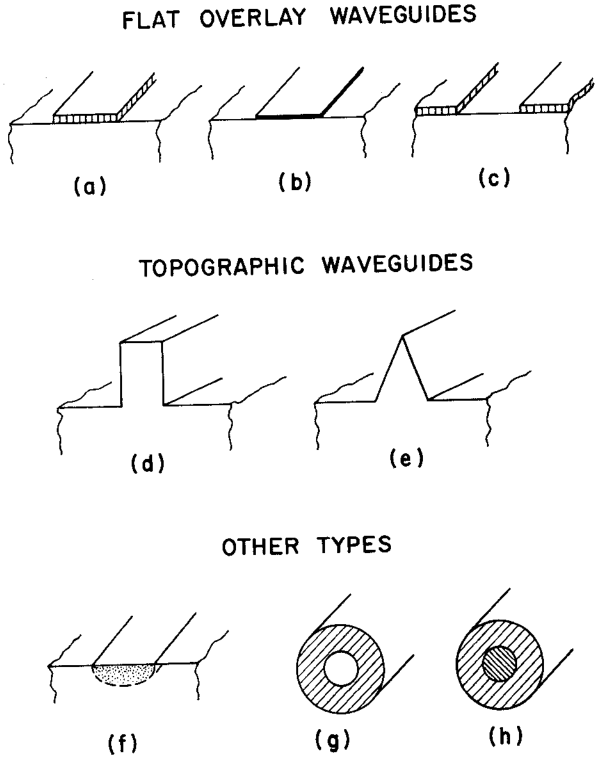

Fig. 1. Various types of waveguide for acoustic surface waves. Flat overlay waveguides: (a) strip, (b) shorting-strip or $\Delta v/v$ (metal strip on a piezoelectric substrate), (c) slot. Topographic waveguides: (d) rectangular ridge, (e) wedge. Other types: (f) in-diffused or ion-implanted, (g) capillary fiber, (h) cladded-core fiber.

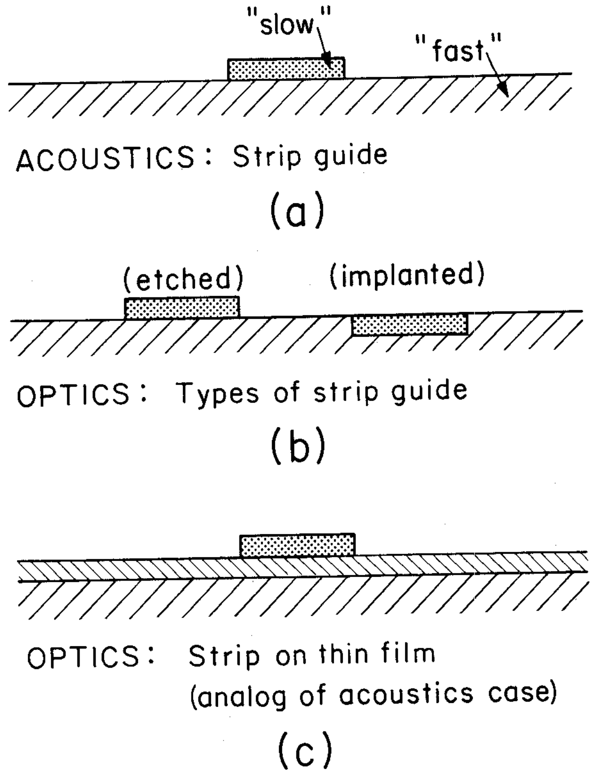

Fig. 2. Examples of strip waveguides in both acoustics and optics. Note that optical waveguide (c) is the analogue of acoustic waveguide (a).

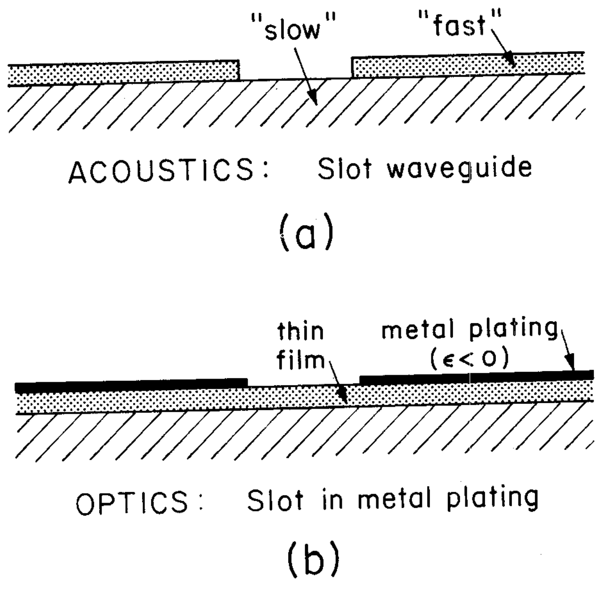

Fig. 3. The acoustic slot waveguide and its optical analogue employing metal platings.