PREFACE

The invention of laser has given birth to many new diversified fields in Physics like nonlinear optics, fibre optics, integrated optics etc. The basic concept of integrated optics lies in the fact that light waves can be guided and confined in dielectric transparent layers (of a few microns thickness and few square centimeters area) which are sandwitched between substrates and superstrates of appropriate materials. Integrated optics involves the intrinsically two-dimensional integrated optical circuits (IOC's) fabricated on an optical quality substrate which supports optical waveguides and a variety of passive and active components. The IOC's are advantageous over the IC's due to their capabilities of logic and signal processing, high switching speeds and compatibility with fibre optic links, efficient interaction of guided light with SAW devices due to the confinement of energy to the surface layer, miniature size and low cost.

The optical waveguides are the key elements of an IOC. These can be either planar, striped, tapered or of other shapes. The wave guiding region consists of either homogeneous (with constant refractive index) or inhomogeneous (with graded refractive index) materials. The propagation of light waves through such guiding layers involves many linear and nonlinear optical phenomena. A considerable interest has been developed in the recent past to investigate the propagation characteristics of surface waves and nonlinear guided waves through multilayer wave-guiding structures. In the present work, a few theoretical problems related to these topics have been attempted. The author has first examined the propagation characteristics of TE and TM modes in planar optical waveguides with nearly parabolic index materials for the guiding layer. In order to get familiarised with the method of analysing surface waves, the author has next revisited Tomlinson's analysis of surface wave at a nonlinear interface*. Finally he has examined the field variation of nonlinearly propagating TE waves in high- and low-index guiding media. The work incorporated in this Dissertation has been presented in four chapters.

In Chapter 1 the concept of integrated optics is introduced at the outset. This is followed by a brief account of electromagnetic mode theory which is the basis of analysing various problems related to the propagation of electromagnetic waves through planar optical waveguides. Maxwell's wave equation and its solutions in different media are given. Next the propagation of plane waves is explained by considering both s- and p-type of polarisations (i.e. TE and TM modes) in bounded media. The mode analysis of an asymmetric dielectric waveguide is then discussed at length for both the TE and TM guided modes. Finally the expressions for the minimum film thickness required to cut-off TE and TM modes have been obtained.

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* Tomlinson W.J., Optics Letters (USA), 5, 323, (1980).

The propagation characteristics of multilayer slab waveguides forms the topic of study of Chapter 2. In the beginning we have taken a brief survey of the structural details, theoretical investigations and practical applications of three- , four- and five-layered symmetric and asymmetric slab waveguides reported in the literature so far. This is followed by the electromagnetic mode treatment of planar waveguides having parabolic index media with reference to both TE and TM solutions. At the end, the importance of group delay and radiation confinement factor has been explained.

In Chapter 3 the author has reported his investigations of planar optical waveguides with nearly parabolic index media. In the beginning, the expression for the parabolic refractive index profile with a flat continuation has been established. This is used in the scalar wave equation first to calculate the field distributions of TE_N modes in terms of Hermite polynomials. The necessary eigenvalue equation is obtained. For this purpose `effective' beam-waist and normalised propagation constant ($\bar{b}$) have been defined. The expressions for logitudinal propagation constant and group delay are also deduced. This procedure is repeated in the case of TM_N modes also. In both cases the field distributions, $\bar{b}$ - v curves, group delay and radiation confinement factors have been numerically estimated. The calculated results are presented in a number of figures and tables. The following interesting observations have been noted from the above study :

1) For TE_o / TM_o mode the field variation is represented by a Gaussian curve independent of the relative distortion present in the refractive index profile. With the increase in distortion, the peak value of the field pattern increases to higher field side and at the same time the extent of the pattern gets reduced towards the waveguide axis. This favours for more confinement of the mode power near the waveguide axis.

2) For higher order TE/TM modes the field patterns exhibit oscillatory character irrespective of the distortion level in the index profile.

3) From the $\bar{b}$ - v curves it is noted that the cut-off frequency of a given TE/TM mode shifts towards zero value with the increase in relative distortion of the profile. Also the asymptotic part of $\bar{b}$ - v curve shifts towards $\bar{b} = 1$ level. Further for a given distortion the cut-off frequency increases with increase in mode order.

4) For zero relative distortion, the values of group delay per unit length for both TE and TM modes are found to be the same irrespective of their mode order. This suggests TE/TM mode degeneracy. For either mode, the increase in distortion level causes the group delay values to change only in the decimal part, the order of magnitude remaining the same. Comparatively speaking this change for TE mode is more significant than that for a TM mode.

5) For N = 0 and 1 TE/TM modes, the radiation

confinement factors rapidly increase for lower v-values and reach a saturation level athigher v-values. This behaviour is seen to be more significant for lower relative distortions. With the increase in relative distortion, the initial parts of Γ - v curves come more and more closer for either mode.

In the final Chapter 4, the author has attempted a few problems related to surface waves and nonlinear guided waves in homogeneous and inhomogeneous media. In order to understand the method of analysing the surface wave at a nonlinear interface, Tomlinson's analysis has been revisited in detail at the outset of this chapter. The expressions for various field parameters (in terms of a single field parameter D) both in linear and nonlinear media have been derived again. In obtaining the expression for total critical power of the surface wave, a small correction has been noticed in Tomlinson's expression in which the critical power in the linear medium is erroneously reported to be double its actual value. After correcting this contribution from the linear medium, the expression for total critical power is rewritten. The expression for critical power of self-trapped wave is also deduced. For a comparative study a relation between the peak-field amplitudes for the two types of waves has been obtained. The validity of all the expressions derived in this work has been tested by numerical estimates of various quantities. The calculated results are reported both in figures and tabular form.

Next we have investigated the nonlinear propagation of TE wave in a planar optical waveguide having a high-index guiding layer. First the expression for effective refractive index profile is established. This is used in the scalar wave equation and the resulting nonlinear equation is solved for the electric field by adopting Dufing's method. The field variation with the propagation distance is examined by numerical calculations.

Finally a nonlinear propagation of TE waves in a low-index guiding layer has been considered. Holland's nonlinear scalar wave equation* has been solved again by Dufing's method and the variation of electric field is examined numerically.

From our study presented in this last chapter, we list the following few findings :

1) When compared with the critical power of the self-trapped wave, the corrected total power in the surface wave is found to be larger only for lower values of the single field parameter D in the range 10^{-3} to 1 and not for all D values as reported by Tomlinson. In fact for $D \geq 10$ the two powers under consideration are found to be practically the same. Similarly the peak-field amplitude (and hence the total stored energy) of the surface wave has a smaller value than that of self-trapped wave only for D>1.

2) $D = 0$ represents the threshold for the existance of surface wave which travels with an amplitude constant in the

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* Holland W.R., Opt. Soc. Am. B, 3(11), 1529, (1986).

linear medium but monotonically decreasing in the nonlinear medium. With the increase in D value the wave becomes more and more intense at the peak which shifts into the nonlinear medium, upto a maximum distance for D = 2.277.

3) At D = 0 the critical power in the surface wave has infinite value which decreases upto a minimum value at D = 1 and afterwords increases again.

4) In the study of nonlinear propagation of TE wave in a high-index guiding medium, the electric field profile is found to be sharply confined across the guiding layer. This implies that the wave tends to self-focus due to the intensity effect. While considering the propagation through a low-index medium the nature of field profile is seen to be similar to that of intensity plots reported by Holland. With increase in mode index the energy of the guided wave is found to be more and more tightly confined across the guiding layer.

In order to evaluate all the numerical results and graphs with accuracy and speed a software Lotus-1-2-3 package has been utilised with Zenith PC/AT which is available in the Department of Physics, Shivaji University, Kolhapur.