ABSTRACT

Key words : *Integrated optics, Lithium niobate, Ti:LiNbO$_3$, optical waveguide, directional coupler, Ti-concentration profile, refractive index profile, propagation constant, effective-index, matrix method, excitation efficiency, coupling length, curved waveguide, bending loss, transition loss, S-type bend, conformal mapping, EIMM, Ti:LiNbO$_3$ waveguide technology, propagation loss, coupling loss, mode-mismatch loss, Fresnel reflection loss, insertion loss, white light spectral analysis, near-field profile, three-waveguide coupler, power splitter, polarization-independent, excess loss.*

The present thesis deals with the studies of titanium indiffused lithium niobate (Ti:LiNbO$_3$) waveguides, directional couplers and three-waveguide polarization independent power splitter for integrated optic applications.

A review of LiNbO$_3$ integrated optics has been made as a back-up for the work undertaken in the thesis (Chapter-2). It outlines different fabrication methods of optical waveguides in LiNbO$_3$ substrate. Theoretical methods based on different concepts to analyse Ti:LiNbO$_3$ waveguides and directional couplers, are also briefly discussed and compared. The developments in optical integrated circuits (OICs) on LiNbO$_3$ have been scanned, and the important achievements highlighted.

A simple method has been developed to compute the Ti-concentration and the refractive index profiles of Ti:LiNbO$_3$ waveguides as a function of the fabrication parameters (Chapter-3). The Ti-concentration profile of a Ti:LiNbO$_3$ waveguide is obtained using closed-form expressions derived from an analytically simple, quasi-2D solution of the two-dimensional diffusion equation. The refractive index profiles are computed from the Ti-concentration data at desired wavelengths. The computed results are validated with the published experimental results. The work is also extended to Ti:LiNbO$_3$ coupled waveguides.

The critical coupling length (L_C) is the most important design parameter of an integrated-optic directional coupler, which is the basic building block of a variety of optical integrated circuits (OICs). The existing methods of estimating L_C of a Ti:LiNbO$_3$ directional *coupler are based on the beam propagation method (BPM) [10,12,14,15,17], which requires huge CPU time and memory. A considerably simpler and computationally faster analytical method involving only multiplication of 2x2 matrices with practically no iteration has been developed (Chapter-4). A staircase type step-index profile is generated from the one-dimensional effective index profile in the lateral direction by partitioning the latter into a large number of thin sections of different refractive indices. The overall transfer matrix of the step-index layered structure so obtained has been computed by the progressive multiplication of individual transfer matrices (2x2) relating the field components in adjacent layers. Hence the wave amplitude in any layer may be computed as a function of the input wave amplitude for different angles of incidence. This effective index based matrix method (EIMM) has been successfully employed to compute the propagation constants for symmetric and antisymmetric guided modes in the coupled region of the direction coupler and hence compute the critical coupling length. The values of* L_C *computed for a variety of devices agree closely with the published experimental results reported by several research groups. The computer program implementing the model runs reasonably fast in an ordinary PC and is versatile enough to handle waveguides with arbitrary dimensions, Ti-flim thickness, and diffusion parameters, for any wavelength of input light and for both transverse electric (TE) and transverse magnetic (TM) polarizations.*

EIMM in combination with a conformal mapping technique has been developed for the computation of the bending loss of $Ti{:}LiNbO_3$ *channel waveguide bends (Chapter-5). Conformal mapping technique [32] is used to transform the effective-index profile of the waveguide bend to that of an equivalent straight waveguide. EIMM is then applied on the discretised equivalent refractive index profile to compute the overall transfer matrix of the structure and hence the excitation efficiency of wave in the guiding layer. The excitation efficiency versus propagation constant plot shows resonance peak around the mode propagation constant. The full-width-half-maximum (FWHM) of this peak determines the radiation loss from the bend. The transition loss arising from the discontinuity of curvatures has also been considered. The model has been extended to study different S-curve configurations. The computed values of total bending loss have been validated with the published experimental results for TE and TM modes at 1.3* μm *wavelength. The model, in principle, is also applicable to any arbitrary waveguide provided that the refractive index profiles are known.*

A detailed experimental study has been carried out on the fabrication and characterization of Ti:LiNbO$_3$ waveguides and directional couplers at 1.3 μm transmitting wavelength (Chapter-6). The fabricated waveguides have low coupling and propagation losses. White light spectral analysis of Ti:LiNbO$_3$ waveguides is introduced as a technique to determine the wavelength ranges for single-mode, cutoff and multimode operations of the fabricated Ti:LiNbO$_3$ waveguides. Refractive index profiles of the single-mode waveguides extracted from the measured near-field intensity profiles match reasonably well with the simulated results.

Finally, a novel polarization-independent, power splitter is developed using a three-waveguide directional coupler designed by using the coupled mode theory [36] in conjunction with the effective-index-based matrix method (Chapter-7). Uniform power splitting between the output ports (imbalance ≤ 0.2 dB) and polarization insensitivity of the excess loss (within ± 0.03 dB over 90^o) are experimentally demonstrated.