Kodaikanal Obs.Bull.(1991) 11, 99-104

Rib Waveguide polarizer in GaAs/AlGaAs

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Abstract

Metal clad wave guides have an extremely large differential attenuation of TE and TM states of polarization and can be used to design efficient integrated polarizers. Described here is a AlGaAs rib wave guide polarizer in which extinction ratio in excess of 20dB has been measured. The effective index method is used to design single mode rib wave guides, and losses due to gold coatings are estimated by a first order perturbation calculation. The imaginary metal index is treated as correction to the real metal index.

Key words: Rib wave guide, polarizer, integrated optics

Introduction

The optical characteristics of planar metal clad waveguides have been investigated by various authors (Yamamoto, Kamiya & Yanai 1975; Polsky & Mitchel 1974; Shou, Xianshe 1988; Thyagarajan et al.1985; Markatos, Zervas & Giles 1988; Johnstone et al. 1989; Feth & Chang 1986), particularly with reference to applications to polarization and mode filtering in integrated optics devices. Numerical investigation of the propagation characteristics of a metal clad waveguide indicate that TE waves are attenuated less than TM waves at optical wave lengths. This large TM-to-TE loss ratio may be used as an effective polarizer in integrated optics circuits (Johnstone et al.1989; Feth & Chang 1986). In this paper we describe a Rib wave guide polarizer on a AlGaAs/GaAs/Gold/air configuration. Rib wave guide structures provide powerful technique for lateral confinement and for interconnection (Shelton, Reinhart & Logan 1979) in monolithic integrated optics.

The Effective Index (EI) Method (Adams 1984) is used to design single mode Rib wave guides and losses due to gold coating have been estimated by a first order perturbation calculation. The perturbation results are in good agreement with the results obtained by exact calculation of the complex Eigen value equation of the structure (Sharma et al. 1991) Hence the EI method, and first order perturbation analysis are of the great practical value in the design of metal clad or absorbing wave guide devices. We have also analysed effect on TE/TM losses by other metals (Au,Al) as knowledge of the attenuation is important in selecting the correct metal cladding and size of the device.

Theory

(i) Effective Index:

In the EI method as applied to the Rib wave guides, effective refractive indices NI and NII are first calculated for two slab regions (I & II) of the Rib wave guide geometry Fig.1 in isolation for TE and TM polarizations. For calculating NI of the middle section only the real part of the metal refractive index $(n_m^2 - i\delta_m)$ is considered. The two effective indices NI and NII are then used to define a third (symmetric) slab wave guide of width 2a in perpendicular direction. The effective index N_e of this slab is taken as the model index of the whole structure.

(ii) Attenuation:

The attenuation can be calculated using the imaginary part of the metal index as a perturbation in two steps: first the metal index is considered as a perturbation on the first slab to calculate the imaginary part of NI, next the imaginary part of the NI is considered as perturbation of slab three (NII/NI/NII) to calculate the final correction of N_e^2.

The perturbation correction to effective index N_e^2 in a slab waveguide due to imaginary part $\delta(x)$ of the indices is given by

$$\Delta N_e^2 = (N_e.w.\epsilon_0 \int_{-\infty}^{\infty} \delta(x) \mid E^2 \mid dx)/TotalPower \tag{1}$$

where $\mid E^2 \mid$ is the normalised modal electric field for slab one, and w is the angular frequency.

$\delta(x) = \delta_m$ in the metal only and zero elsewhere, and for slab three it is non-zero only in the middle section.

Further, one has to be careful when applyhing perturbation theory to TM modes where E has both E_z and E_x components. The final effective index is obtained in the form of

$$N_e^2 = N_e^2 + i(\Delta N_e^2) \tag{2}$$

and attenuation coefficient α is given by

$$\alpha = ((\Delta N_e)^2 k_0)/2.N_e \tag{3}$$

and the single pass-loss through a polarizer of length l is given by

$$\Gamma = 8.6859.\alpha.l dB \tag{4}$$

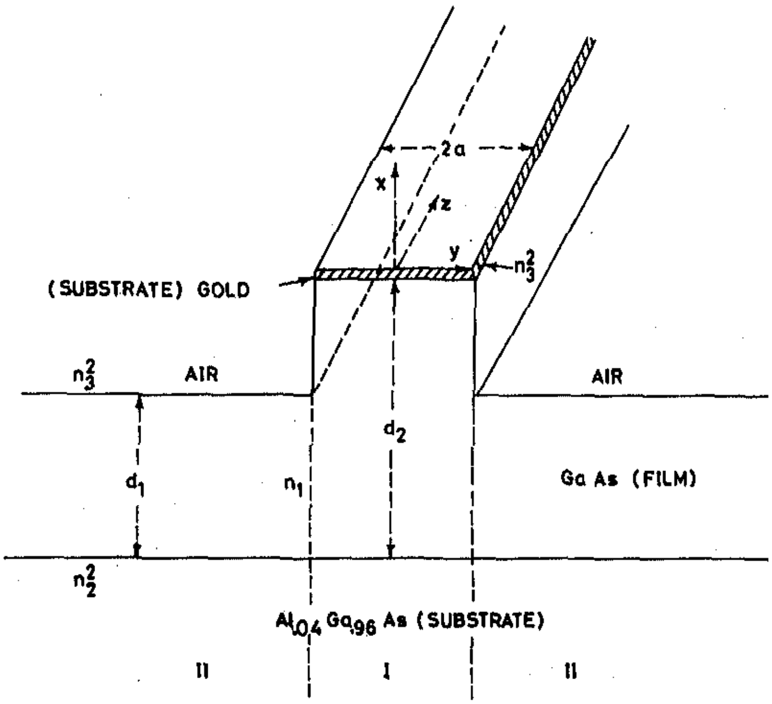

Figure 1. Rib waveguide geometry.

Fabrication and Measurement

The Rib waveguide was designed for single mode propagation. State-of-the-art of material growth and lithography impose certain limits on the waveguide size. (1) Using, MOCVD technique, Aluminium concentration less than 5% was not feasible and (2) the narrowest strip that could be readily drawn by photolithography was $2\mu m$. Having fixed the material composition the waveguide dimensions were calculated using EI method to give a single mode rib structure. The layered structure of GaAs was followed by a $4\mu m$ AlGaAs(5%Al) substrate, on that a 1.5 μm thick GaAs film was grown. The sample was cleaved off in 4 cm^2 test pieces, and gold was evaporated to 500 Å thickness. Finally to get the rib configuration of Fig. 1 this sample was wet etched to the desired height of the rib.

Fabry-Perot resonance technique (Walker, 1984) was used for determining the loss, both for TE and TM propagation. Light from a 1.15 μ m. He Ne laser was end-fire coupled to the cleaved facet of the waveguide with the help of microscope objectives. The changes in the power transmitted through the waveguide were recorded as the Fabry-Perot response of the cavity swept by gently heating the waveguide from above and was uniform over several cycles (Figs 2 and 3), which shows that the input coupling remained constant. Loss Γ was calculated as

$$\Gamma = -10log[1/R(\sqrt{k}-1)/(\sqrt{k}+1)]/L \qquad (5)$$

where, $K = P_{max}/P_{min}$ (Figs 2 and 3), R is the average facet reflection coefficient (assumed to be 30%) and L is the length of the rib sample. Following were the results obtained for gold clad-polarizer shown in Fig.1.

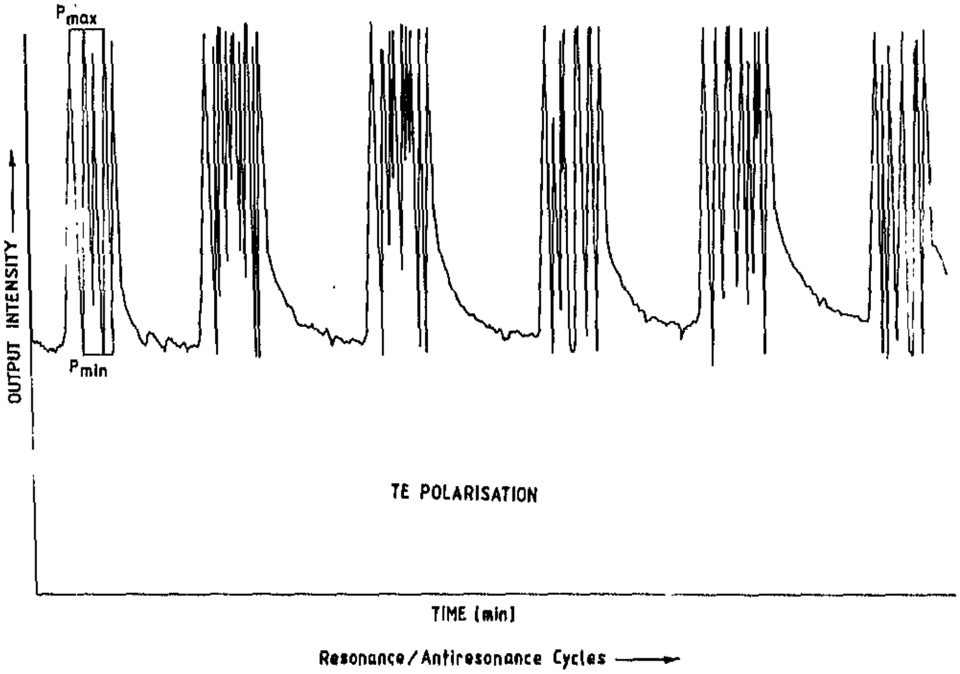

Figure 2. Resonance/Antiresonance Cycles -TE polarization.

Loss for TE polarization = 4.7 dB/cm

Loss for TM polarization = 24.74 dB/cm

and the extinction ratio 20 dB/cm

For comparison the losses were estimated by the EI and perturbation method for different metals and the results are tabulated below:

The larger values of loss observed experimentally are expected since the Rib waveguides fabricated by wet etching have an intrinsic loss due to scattering at the edges of the waveguides, in addition to losses due to metal cladding and non-uniform facets.

Metal	Refractive index n^2 of metal at 1.15 μm	Loss in dB/cm TE	TM
Gold	-55.088 -i (1.751)	1.6590	12.7583
Silver	-69.3266 -i (4.6293)	4.46988	32.798
Aluminium	-130.9591 -i (27.259)	8.0979	123.995

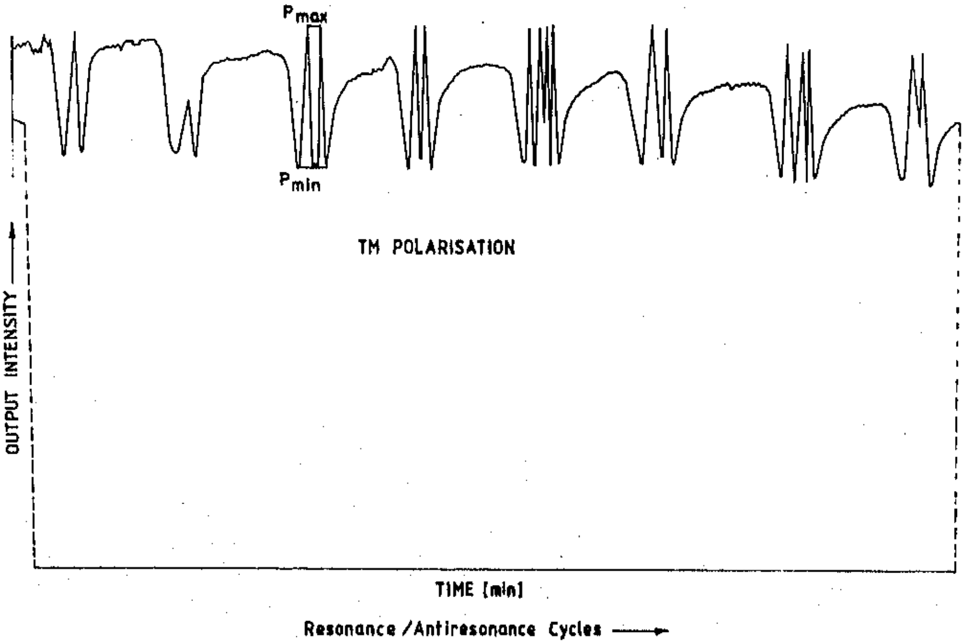

Figure 3. Resonance/Antiresonance Cycles -TM polarization.

Acknowledgement

The fabrication and measurement work was carried out at Department of Electrical and Electronics Engg. University of Sheffield, U.K., in Prof.P.N.Robson's Laboratory during the visit of one of the Authors (VLG) under the ALIS LINK Programme. Grateful thanks are due to Prof.P.N.Robson for his active support and encouragement. Thanks are also due to Mr.M.A.Pete and Dr.D.A.Roberts for their help in fabrication and loss measurements.

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