Nonlinear Distributed Feedback Waveguide for Polarization Independent All-Optical Switching

***S.-H. Jeong[1] T. Mizumoto[1] K. Nakatsuhara[2] M. Takenaka[3] Y. Nakano[3]**

[1]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology
2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, JAPAN
Phone & Fax: +81-3-5734-2578
[2]Department of Electrical and Electronic Engineering, Kanagawa Institute of Technology
1030, Shimoogino, Atsugi-shi, Kanagawa, 243-0292, JAPAN
[3]Department of Electronic Engineering, University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, JAPAN

1. Introduction

All-optical switch, which does not use any electronic device and, hence, can avoid an electronic bottleneck, will be an indispensable component for the implementation of ultrafast signal processing [1]. The combination of optical Kerr effect and distributed feedback (DFB) mechanism in nonlinear media enables us to realize all-optical bistable, thresholding and Boolean logic functions.

We have demonstrated all-optical bistable [2], thresholding [3], and AND-logic operation [4] in a strip-loaded DFB waveguide containing optical Kerr media. However, the state of polarisation of input light has to be adjusted precisely in all of these demonstrations, since those devices intrinsically have strong structural birefringence. From the viewpoint of practical application, polarization independent optical switching is strongly preferred.

Recent investigations of polarization independence are mainly based on the scheme of compensating [5,6] or eliminating [7,8] the structural birefringence of waveguide. The deep-ridge waveguide structure is a most promising candidate from the viewpoint of compactness, simple fabrication process and integration with other photonic devices. In this paper, the deep-ridge DFB waveguide is fabricated considering theoretical results [9]. It will be shown that the structural birefringence is nearly eliminated by adjusting the waveguide width. In addition, from the viewpoint of reduction of switching power and device size as well as polarization independence, raised-strip DFB waveguide is investigated.

2. Theoretical Consideration

Figure 1 shows a schematic drawing of the deep-ridge DFB waveguide. When signal light is solely incident on the input port of the device, it experiences Bragg reflection. However, when the pump light is accompanied with signal light, the signal light passes through the device because of a refractive index change caused by an optical Kerr effect. In this way, the signal light is switched by the pump light.

In a deep-ridge waveguide, structural birefringence can be eliminated by adjusting the waveguide width (***W***) precisely [8]. Moreover, the variation of birefringence is strongly influenced by the waveguide parameters such as composition of core (N_{co}) / cladding (N_{cl}) and thickness of upper cladding (T_{uc}) / core (T_{co}).

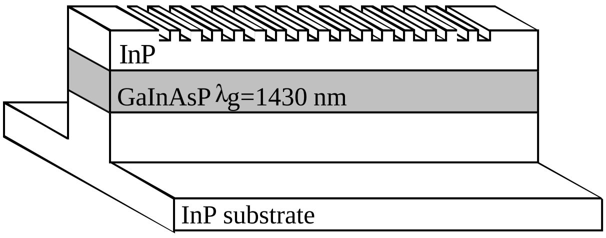

Fig. 1. Schematic drawing of nonlinear DFB waveguide with deep-ridge structure

We have investigated these influences caused by aforementioned parameters using semi-vector finite element approach. In the calculation model, T_{uc}, T_{co}, and T_{lc} is 500nm, respectively. The wavelength of optical source (λ_{op}) is 1.55µm.

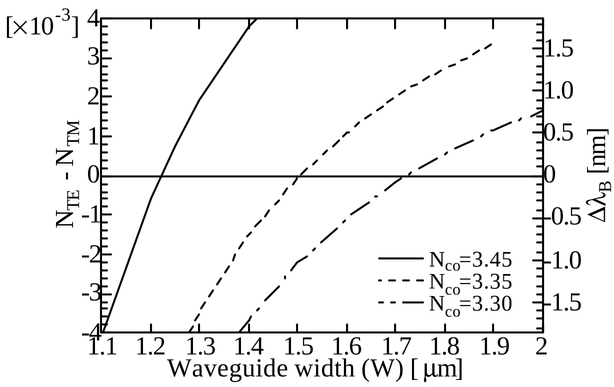

Fig. 2. Calculated birefringence with respect to composition of core

Figure 2 shows calculated birefringence (N_{TE}-N_{TM}) for λ_{op}=1.55µm and Bragg wavelength difference between the first order of TE and TM modes ($\Delta\lambda_B$). As the refractive index difference between core (N_{co}) and cladding (N_{cl}=3.17) increases, structural birefringence changes steeply against waveguide width variation, which means narrow fabrication tolerance. Therefore, smaller refractive index difference between core and cladding is advantageous for realizing a polarization independent waveguide. However, as N_{co} approaches to N_{cl}, that is, as the bandgap wavelength of core (λ_g) is far from the wavelength of light (λ_{op}=1.55µm), the magnitude of nonlinearity (optical Kerr effect) decreases dramatically, which means larger optical switching power is required to compensate weak nonlinearity.

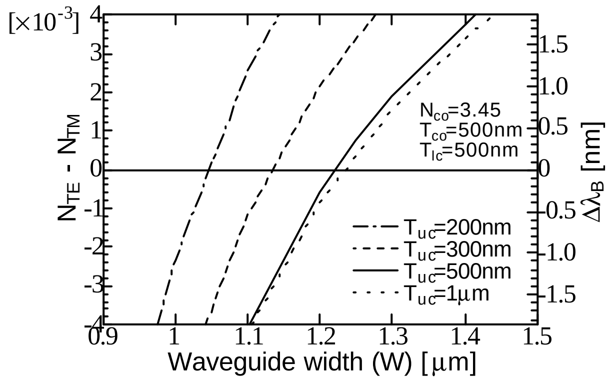

Fig. 3. Calculated birefringence with respect to the thickness of upper cladding layer

Fig. 3 shows the calculated birefringence as a function of the waveguide width with the thickness of upper cladding as a parameter. As shown in Fig. 3, thick upper cladding layer is desirable for polarization independence from the viewpoint of fabrication tolerance and efficient non-birefringent waveguide width. Meanwhile, large grating coupling coefficient (κ_g) must be needed for reducing switching power and device size. However, as T_{uc} increases, κ_g abruptly decreases. Care must be taken to the tradeoff between fabrication tolerance and available κ_g.

3. Experiment

The deep-ridge DFB waveguide was fabrication with a GaInAsP/InP wafer as shown in Fig. 1. T_{uc} and T_{co} is 300nm and 450nm, respectively. λ_g is 1430nm. The deep-ridge was formed by reactive ion etching with $CH_4/H_2/O_2$-mixture. Corrugated grating with 235nm-periodicity was loaded on the waveguide stripe. Grating length was 1.5mm. For the measurement of transmittance, an amplified spontaneous emission of EDFA was used as an optical source. TE-mode and TM-mode light was launched into the input port of the device through a polarization maintaining fiber, respectively. The transmission spectra from the output port were measured using spectrum analyzer.

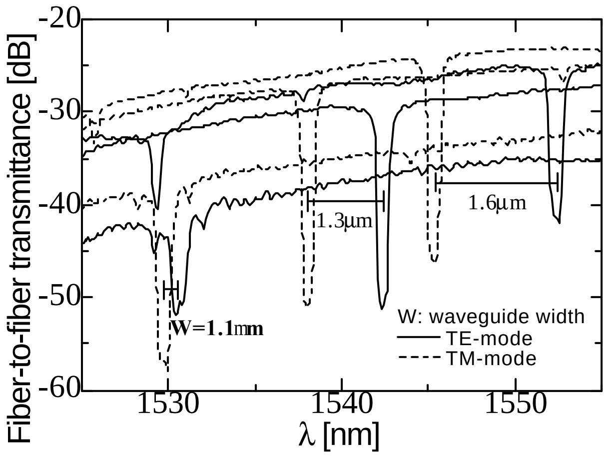

Fig. 4. Measured transmission spectra for TE and TM-modes

Figure 4 shows the measured transmission spectra for TE and TM-modes. κ_g was estimated to be 30cm^{-1} for both TE and TM modes. There was no polarisation dependence of κ_g between TE and TM modes. As the waveguide width (***W***) becomes narrower, $\Delta\lambda_B$ tends to be reduced, which means small structural birefringence. When ***W***=1.1μm, the structural birefringence was nearly eliminated ($\Delta\lambda_B$=0.8nm).

Rib DFB waveguides (rib height = 200nm) were fabricated using the same wafer as deep-ridge DFB waveguides in order to compare the birefringence change resulting from the difference in device structure. Figure 5 shows calculated and measured birefringence of the fabricated devices. As shown in Fig. 5, experimental results agree well with the theoretical ones.

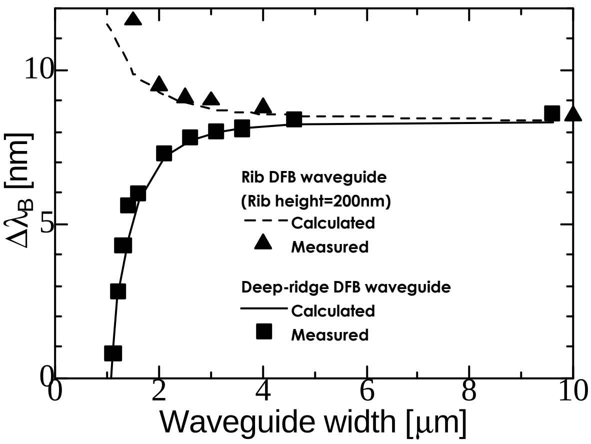

Fig. 5. Comparison of structural birefringence between rib DFB waveguide and deep-ridge DFB waveguide

In deep-ridge DFB waveguides, by narrowing ***W***, $\Delta\lambda_B$ was considerably reduced up to 0.8nm at ***W***=1.1μm. Contrary to this, it was unable to eliminate structural birefringence in rib DFB waveguides by controlling ***W***.

One of important issues for polarization independent all-optical switching in a nonlinear DFB waveguide is to obtain large κ_g, since large κ_g contributes reduction of device size and switching power resulting from the abrupt change of transmittance with shorter grating length. In a deep-ridge DFB waveguide, κ_g was 30cm^{-1}, which is relatively small. Now, we will be concerned with the question of how a raised-strip DFB waveguide is suitable for realizing large κ_g as well as polarization independence of the waveguide.

We calculated the structural birefringence for various thickness of upper cladding layer (T_{uc}) at λ_{op} =1.55μm, and found the waveguide parameters which give rise to polarization independence for the case of ***W***=1.1μm and λ_g=1430nm. The thinner the upper cladding layer, the thicker the core height becomes to cancel the structural birefringence, e.g. T_{co}=450nm for T_{uc}=300nm and T_{co}=650nm for T_{uc} =100nm. Figure 6 shows that calculated κ_g as a function of grating depth. κ_g increases as T_{uc} decreases. When T_{uc}=0, the highest grating coupling coefficient is obtained. We call the waveguide with T_{uc}=0 as a raised-strip waveguide.

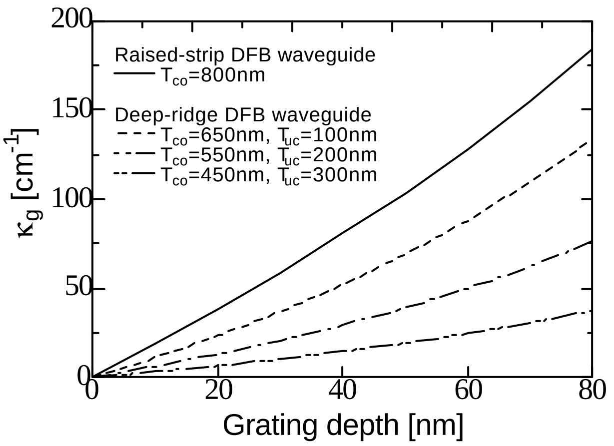

Fig. 6. Calculated k_g as a function of grating depth

The raised-strip DFB waveguide was fabricated using a GaInAsP/InP wafer with an 800nm-thick GaInAsP (λ_g=1430nm) core. Grating length and ***W*** was 500μm and 3μm, respectively. We measured the transmission spectra of the fabricated device for TE-mode through an aforementioned process.

From the experimental results, κ_g for raised-strip DFB waveguide was estimated to be 120cm^{-1}, which was much larger than the case of deep-ridge DFB waveguide. Consequently, it is helpful to reduce the device size and the switching power.

Acknowledgement: The study was supported by "Research for the Future" Program No. JSPS-97P00103, from the Japan Society for the Promotion of Science.

Reference

[1] LiKamWa. P, Robson P. N., David J. P. R., Hill G., Mistry P., Pate M. A., Robert J. S. : *'All-optical switching effects in a passive GaAs/GaAlAs multiple-quantum-well waveguide resonator'*, Electron. Lett., 1986, **22**, (21), pp. 1129-1130

[2] Nakatushara K., Mizumoto T., Munakata R., Kigure Y., and Naito Y. : *'All-optical set-reset operation in a distributed feedback GaInAsP waveguide'*, IEEE, Photon. Technol. Lett., 1998, **10**, (1), pp. 78 -80

[3] Nakatushara K., Mizumoto T., Takahashi E., Hossain S., Saka Y., Ma B.J., and Nakano Y. : *'All-optical switching in a distributed-feedback GaInAsP waveguide'*, Appl. Opt., 1999, **38**, (18), pp. 3911-3916

[4] Nakatushara K., Jeong S. H., Tsukishima Y., Mizumoto T., Ma B. J., and Nakano Y. : *'All-optical threshold device and its application to AND gate'*, Proc. Int. Conf. on Mocrooptics, July 1999, Makuhari, Japan, pp. 316-319

[5] Inoue Y., Takahashi. H., Ando S., Sawada T., Himeno A., and Kawashi M. : *'Elimination of polarisation sensitivity in silica-based wavelength division multiplexer using a polyimide half waveplate'*, IEEE, J. Lightwave Technol., 1997, **15**, (10), pp. 1947-1957

[6] Vreebrug C.G.M., Herben C.G.P., Leijtens X.J.M., Smit M.K., Groen F.H., van der Tol J.J.G.M., and Demeester P. : *'A low-loss 16-channel polarization dispersion-compensated PHASAR demultiplexer'*, IEEE, Photon. Technol. Lett., 1998, **10**, (3), pp. 382-384

[7] Soole J.B.D., Amersfoort M.R., LeBlanc H.P., Andreadakis N.C., Rajhel A., Caneau C., Koza M.A., Bhat R., Youtsey C., and Adesida I. : *'Polarisation independent InP arrayed waveguide filter using square cross-section waveguides'*, Electron. Lett., 1996, **32**, (4), pp. 323-324

[8] Kohtoku M., Sanjoh H., Oku S., Kadota Y., and Yoshikuni Y. : *'Polarization independent semiconductor arrayed grating using a deep-ridge waveguide structure'*, IEICE, Trans. Electron., 1998, **E81-C, (8)**, pp. 1195-1204

[9] Jeong S. -H., Mizumoto T., Nakatsuhara K., Ma B. -J., and Nakano Y. : *'Highmesa distributed feedback waveguide for polarization insensitive all-optical switching'*, Proc. Conf. OECC, July, 2000, Makuhari, Japan, pp. 158-159