



Research Center for Advanced Science & Technology
THE UNIVERSITY OF TOKYO

4-6-1 Komaba, Meguro-ku, Tokyo, 153-8904, JAPAN
<http://www.ee.t.u-tokyo.ac.jp/~nakano/lab/welcome.html>

Yoshiaki NAKANO
Professor
Phone: +81-3-5452-5150

Facsimile: +81-3-5452-5151
+81-3-5452-5156
Internet: nakano@rcast.u-tokyo.ac.jp

Letter of Significance

14.7dB/mm TE Mode Nonreciprocal Propagation in an InGaAsP/InP Active Waveguide Optical Isolator

Hiromasa Shimizu and Yoshiaki Nakano

Research Center for Advanced Science and Technology, the University of Tokyo

Integration of optical isolators with semiconductor laser diodes is considered to be difficult, because the materials are not compatible; optical isolators are composed of garnet Faraday rotators and linear polarizers, which are difficult to integrate on semiconductor substrates. However, optical isolators are indispensable for stable operation of telecommunication laser diodes, and thus realization of monolithically integratable waveguide optical isolators has been desired for a long time.

Here in this paper, we reported the fabrication of TE mode InGaAsP/InP active waveguide optical isolators and demonstrated 14.7dB/mm isolation and 7.1dB/mm insertion loss over a wavelength range of 1530-1560nm, the best data amongst papers ever reported. Our waveguide optical isolators have a very simple device structure, an InGaAsP/InP semiconductor optical amplifier waveguide with an Fe thin film on one of the sidewalls of the high mesa waveguide. Our active waveguide optical isolator can be directly integrated with single mode edge-emitting semiconductor laser diodes, achieving a great breakthrough in the field of photonic integrated circuits. Also, the realization of semiconductor- waveguide-type nonreciprocal devices allows us previously impractical cascading of various semiconductor optoelectronic devices in more powerful highly functional photonic integrated circuits.

Therefore, this paper has great significance for presentation at the 2005 Optical Fiber Communication Conference & Exposition and the National Fiber Optic Engineers Conference.

14.7dB/mm TE Mode Nonreciprocal Propagation in an InGaAsP/InP Active Waveguide Optical Isolator

Hiromasa Shimizu^{1,2} and Yoshiaki Nakano^{1,2}

¹Research Center for Advanced Science and Technology, The University of Tokyo

4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan, Tel: +81-3-5452-5155, Fax: +81-3-5452-5156

² Japan Science and Technology, SORST

Abstract: We have fabricated TE mode InGaAsP/InP active waveguide optical isolators demonstrating 14.7dB/mm TE mode isolation ratio with reduced insertion loss at the wavelength of 1550nm for monolithically integratable optical isolators.

© 2005 Optical Society of America

OCIS codes: (230.3810) Magneto-optical devices; (250.5980) Semiconductor optical amplifiers;

1 Introduction

Optical isolators are indispensable for stable operation of telecommunication semiconductor lasers. Commercially available optical isolators are composed of Faraday rotators and linear polarizers, and are not compatible with semiconductor lasers. Semiconductor-waveguide-type optical isolators, which can be integrated with edge-emitting semiconductor lasers and other III-V optoelectronic devices are awaited for reducing overall system sizes. Also, such nonreciprocal semiconductor-waveguide-type devices would enable flexible design and robust operation of photonic integrated circuits. We have thus proposed and designed a TE mode semiconductor-waveguide-type optical isolator based on the nonreciprocal loss shift to answer this demand. This device is composed of a semiconductor optical amplifier (SOA) waveguide and a ferromagnetic metal. The ferromagnetic metal provides the nonreciprocal loss and the SOA compensates the forward propagation loss from the ferromagnetic metal. Although TM mode waveguide optical isolators have been

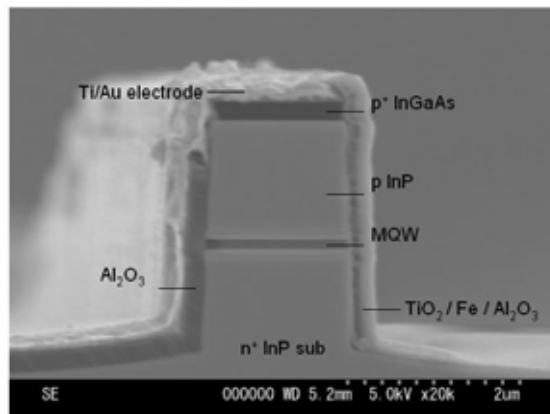


Fig.1 A cross-sectional scanning electron microscope image of the fabricated InGaAsP/InP active waveguide isolator having an Fe layer on one of the sidewalls.

proposed [1-3], for the TM case, only nonreciprocal amplified spontaneous emission has been recently reported [4]. Furthermore, TE mode waveguide optical isolators are desired for integration with edge-emitting semiconductor lasers, which generally operate in the TE mode. Recently we demonstrated 9.3dB/mm TE mode nonreciprocal propagation in an InGaAsP/InP active waveguide having an Fe layer on one of the sidewalls (see Fig. 1) at the wavelength of 1560nm [5]. Here, we report improved nonreciprocal loss shift of 14.7dB/mm with reduced insertion loss for monolithically integratable optical isolator applications.

2 Device structure and analysis

For practical integrated optical isolator applications, the insertion loss should be lower and the nonreciprocal loss shift (isolation ratio) larger. To meet these requirements, SOA waveguides with thicker multiple quantum well (MQW) active layers are effective, because thicker MQW active layers in the SOA structure enhance not only the optical confinement factor in the Fe layer on the waveguide sidewall but also the isolation ratio. The isolation ratio was calculated with the effective index method and perturbation theory [5]. By introducing the 15MQW active layer, the isolation ratio and the required MQW gain were estimated to be 22.5dB/mm and 270cm^{-1} , respectively. The required MQW gain was decreased by 40%, compared with that of the 7MQW SOA, which is advantageous for practical applications. Also, the maximum MQW gain increases with an increasing number of QWs, which also contributes to the improvement of the insertion loss of the active waveguide optical isolators.

3 Experiments

We fabricated waveguide optical isolators based on the above simulations. Fourteen-MQW SOA layer structures were grown by metal organic vapor phase epitaxy (MOVPE). The gain peak of the SOA was 1540nm. The highmesa waveguide was formed by Cl_2/Ar reactive ion etching (RIE). The 100nm-thick Fe thin films were deposited on one of the sidewalls of the waveguide by angled electron-beam evaporation, as shown in Fig. 1. The Fe thin films were separated from the waveguide layer by 20nm-thick TiO_2 thin films. The vertically magnetized single-sidewall Fe thin film provides a TE mode-selective nonreciprocal loss shift through the transverse magneto-optical Kerr effect.

The cleaved waveguide facets were uncoated, and the width and the length were $1.5\mu\text{m}$ and 0.7mm , respectively. We measured the nonreciprocal loss shift using two circulators and two optical switches to change the propagation direction under a fixed magnetic field of 1kG applied by a permanent magnet. The device was kept at 10°C .

Fig. 2 shows the nonreciprocal loss shift (isolation ratio) for the 1550nm TE mode. The bias current was 100mA and the incident light intensity was 2.5dBm. In the TE mode, $10.3\text{dB} / 0.7\text{mm} = 14.7\text{dB} / \text{mm}$ nonreciprocal loss shift was observed. The insertion loss was $10\text{dB} / 0.7\text{mm} = 14\text{dB}/\text{mm}$. These values are great improvements upon the first reported prototype device [5]. The corresponding transmitted intensity difference was less than 1dB for the TM mode. Because this device operates in the TE mode, this polarization dependence is clear evidence of the nonreciprocal loss shift, which is promising for TE mode waveguide optical isolator applications.

Fig. 3 shows the wavelength dependence (1530-1560nm) of the isolation ratio and the insertion loss of the forward propagating light. The bias current was 150mA. The isolation ratio and insertion loss were increased at longer wavelengths. Although the isolation ratio of 1530nm was the smallest (9.9dB/mm) within the

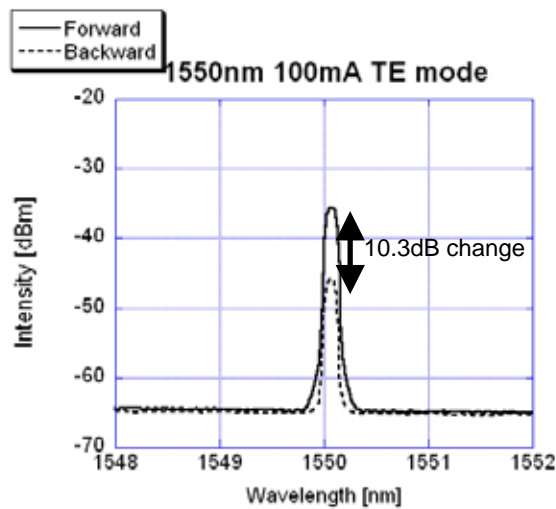


Fig. 2. TE mode nonreciprocal loss shift of the fabricated device at the wavelength of 1550nm.

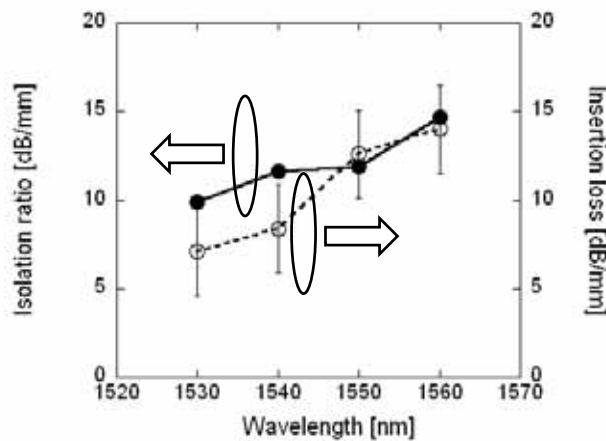


Fig. 3. Wavelength dependence of the isolation ratio and the insertion loss of the forward propagating light from 1530 to 1560nm. The bias current was 150mA.

wavelength range, the insertion loss was also the smallest (7.1dB/mm), providing favorable conditions for practical applications.

4 Summary

We have fabricated TE mode InGaAsP/InP active waveguide optical isolators and reported the improved nonreciprocal loss shift (14.7dB/mm) with a reduced insertion loss at 1560nm. At 1530nm, the insertion loss was small (7.1dB/mm). By further improvement to the insertion loss, it is possible to realize practical waveguide optical isolators and integration with distributed feedback laser diodes.

References

- 1 M. Takenaka et al., Proc. 11th International Conference on Indium Phosphide and related materials., 289 (1999).
- 2 W. Zaets et al., IEEE., Photon. Tech. Lett. **11**, 1012 (1999).
- 3 H. Shimizu et al., Appl. Phys. Lett. **81**, 5248 (2002).
- 4 M. Vanwollegem et al., Appl. Phys. Lett., **85**, 3980 (2004).
- 5 H. Shimizu et al., Jpn. J. Appl. Phys. **43**, L1561 (2004).