11.4dB Isolation on an Amplifying AlGaInAs/InP Optical Waveguide Isolator

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Abstract: 11.4dB optical isolation combined with forward transparency is demonstrated on a TM-mode amplifying AlGaInAs/InP optical waveguide isolator operating at 1300nm. Basis for this isolator configuration is non-reciprocal absorption caused by the magneto-optic Kerr effect.

OCIS codes: (230.3240) Isolators; (230.3810) Magneto-optical devices; (250.5980) Semiconductor optical amplifiers

1. Introduction

An optical isolator avoids one of the main noise sources in an optical communication system by blocking optical feedback in the laser source. Current commercial isolators are bulk components requiring collimating lenses and expensive alignment techniques when applied in a laser diode package. Development of an integrated laser-isolator system is highly desirable as it would reduce cost and size and enhance mechanical and thermal stability. Traditional research focuses on applying ferrimagnetic garnets to induce non-reciprocity [1]. The interest in this class of materials comes from their unique combination of low optical loss at telecom wavelengths and a considerably strong magneto-optic (MO) effect, the source of the non-reciprocity. Stand-alone devices with good isolation performance have been reported. The integration with III-V host material however remains an issue. The best reported result demonstrated isolation not higher than 5dB in a device of several millimeters long [2].

A novel concept for a – TM-mode – monolithically integrated optical isolator was theoretically proposed in 1999 [3] and experimentally demonstrated in 2003 [4]. Recently, an equivalent concept for TE-polarization was proposed and demonstrated [5]. Even though a large non-reciprocal effect has been shown, the corresponding internal losses are very high. In this paper we report on the development of a TM-mode component with demonstration of 11.4dB optical isolation combined with transparency in the forward propagation direction.

2. Principle of operation

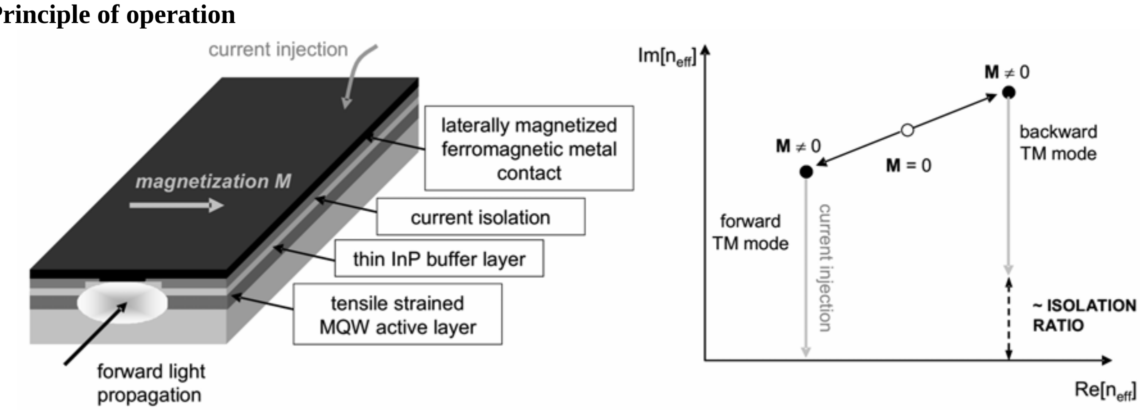

Fig. 1. Schematic lay-out and operation principle of the TM-mode optical waveguide isolator.

The optical waveguide isolator basically is a semiconductor optical amplifier (SOA) with a ferromagnetic metal contact very close to the active region. Lateral magnetization – perpendicular to the light propagation direction and parallel to the metal-semiconductor interface – of the metal film induces a non-reciprocal shift of the complex effective index of TM-polarized guided modes, caused by the MO Kerr effect. In other words, the modal absorption is dependent on the light propagation direction. The loss in the forward propagation direction can be compensated by electrical pumping of the device, with the ferromagnetic metal as the electrical contact. The result is an optical component which, being transparent in one direction while providing loss in the opposite, is isolating. Fig. 1 illustrates the device lay-out and the operation principle. The advantage of this approach over the garnet-based components is obvious. As the isolator basically has the same structure as the laser source it is to be integrated with, monolithic integration is possible. In addition, the ferromagnetic film can easily be sputter-deposited and the fabrication of the entire component can be done with standard InP-SOA processing.

3. Design and fabrication

The gain material needed to compensate the loss induced by the MO metal film is a novel AlGaInAs-based multi-quantum well (MQW) active layer structure. Built-in tensile strain realizes TM-selective material gain while suppressing TE-gain. At 1300nm wavelength, AlGaInAs/InP material has shown considerably better gain performance than the more conventional InGaAsP/InP [6], which was used in [4]. The optimized active core is built up of 10nm tensile strained (-1.16%) wells (9QWs), 20nm strain compensating compressively strained (+0.64%) barriers and optimized separate confinement heterostructure (SCH) layers [6].

In the isolator configuration under study the ferromagnetic metal film fulfills two functions: it is the source of the MO non-reciprocal effect and it provides the electrical contact for the underlying SOA. The optical (complex refractive index) and MO (Voigt parameter) constants of $Co_{50}Fe_{50}$ have been experimentally extracted at the operation wavelength of 1300nm [7]. It was found that this equiatomic compound combines a lower optical absorption with a higher MO strength compared to the $Co_{90}Fe_{10}$ alloy that was used in [4]. A hybrid p^{++}-doped InGaAsP/InGaAs contact structure has been developed that realizes an ohmic electrical contact and has minimal optical absorption at 1300nm.

Opposite to previous work where the isolation ratio (in dB/cm) was maximized, the current procedure for the design of the geometric device parameters – the thicknesses of InP cladding and SCH layers – targets optimization of the practical device specifications. The corresponding figure of merit to be minimized is the total bias current required for transparency in the forward propagation direction corresponding to a certain value of the total optical isolation. The 1D simulations have been done with an optical mode solver [8] extended with a perturbation-based algorithm for MO waveguide calculation [9]. A steepest-descent algorithm was implemented to obtain the best values for the three geometric parameters. Fig. 2 shows a simulation example. The forward transparency current (left) and the cavity length (right) corresponding to 10dB isolation are calculated for a range of InP cladding and upper SCH layer thickness values. In this picture the lower SCH layer thickness is kept constant at 0nm. The transparency clearly goes through a minimum. Theoretically, a 10dB optical isolator with a bias current for forward transparency equal to 62mA and a cavity length of 2mm can be realized.

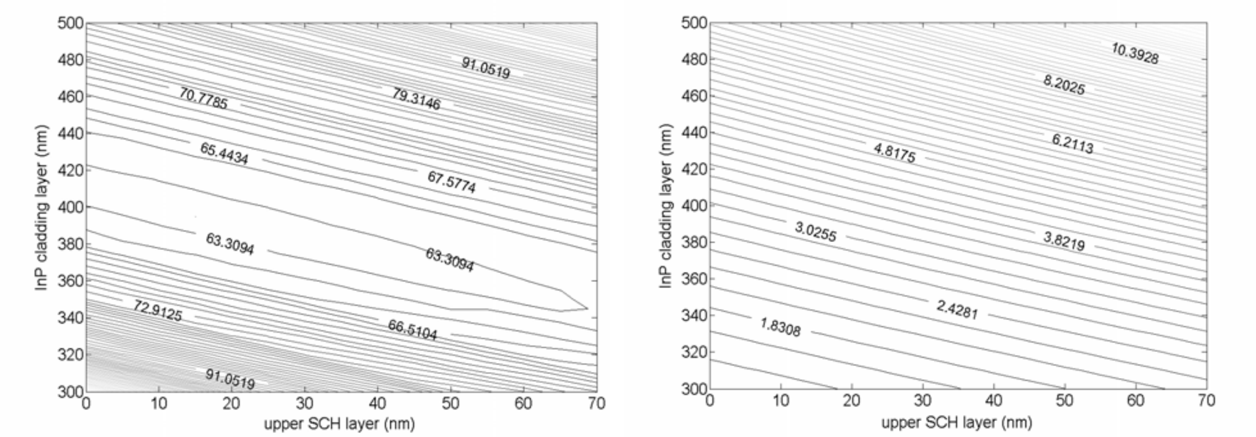

Fig. 2. Simulation example: transparency current (in mA) (left) and cavity length (in mm) (right) for variation of InP cladding and upper SCH layer thickness. The lower SCH layer thickness is kept constant at 0nm.

The optimized active structure was grown with metal organic vapor phase epitaxy (MOVPE). It was topped with a 400nm thick p-doped InP layer and the p^{++}-doped contact structure. The sputter-deposited, 50nm thick $Co_{50}Fe_{50}$ film, capped with a Ti/Au protective bilayer, was patterned into 2μm wide stripes through standard lift-off. Ridge waveguides were defined with CH_4:H_2 reactive ion etching (RIE), using these metallic stripes as an etch mask. With this technique full covering of the ridge with metal was achieved.

4. Characterization

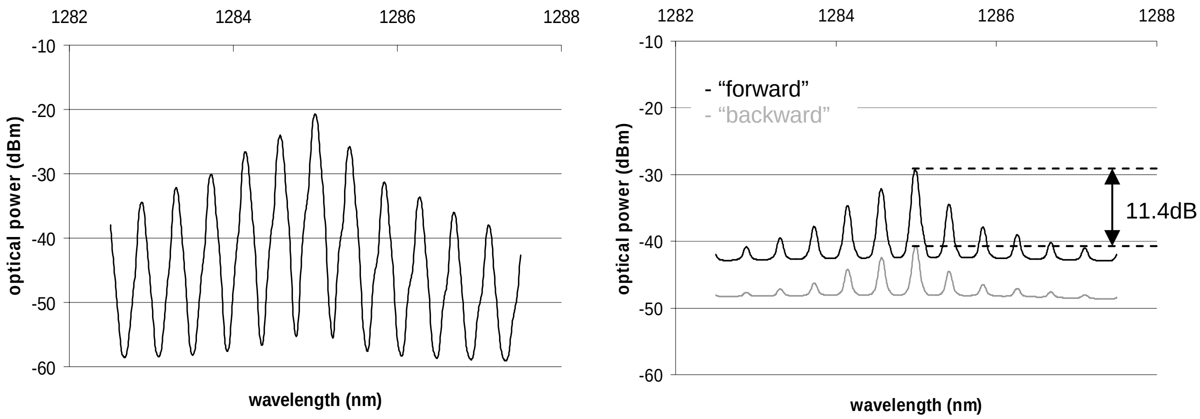

Fig. 3. (left) Spectrum of the FP laser used as the optical input source and (right) spectrum of the output signal for saturation magnetization in both lateral directions, showing 11.4dB isolation; measured with 150mA bias current.

Extraction of the isolator performance can be done through the evaluation of transmitted optical power at saturation magnetization in both lateral directions – switching the magnetization direction is equivalent to switching between forward and backward propagation. The applied input laser source is a Fabry-Pérot (FP) laser, of which the optical spectrum is given in Fig. 3 (left). The isolator devices are 2mm long and the facets are AR-coated. The bias current equals 150mA. The output signal is detected with a spectrum analyzer (resolution bandwidth 0.1nm). As presented in Fig. 3 (right) the difference in optical power between “forward” and “backward” direction equals 11.4dB and the insertion loss in the forward propagation direction is 8.6dB. The fiber-to-chip coupling losses were measured to be 4 to 5dB per facet, proving that the isolator device is transparent in the forward propagation direction.

5. Conclusion

11.4dB optical isolation has been demonstrated on a device that is transparent in the forward propagation direction for a bias current of 150mA. It is the result of an adapted design strategy combined with novel TM-gain material and a better choice of the MO metal. Refining the device fabrication will result in further reduction of the modal loss, or equivalent the transparency current. This will open up the possibility of realizing practical waveguide isolators and monolithic integration with distributed feedback lasers.

6. References

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