

Design of Evanescent Semiconductor Waveguide Optical Isolators

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Abstract- We have designed evanescent waveguide semiconductor optical isolators to realize 8.7dB/mm-isolation and lower forward transparent current. They are composed of an upper InGaAsP waveguide layer with Fe layer at their sidewall upon the active layer.

I. INTRODUCTION

Integrable semiconductor optical isolators can realize previously impractical photonic integrated circuits where the direction of optical signals is clearly defined. Recently semiconductor waveguide optical isolators based on nonreciprocal loss have been reported [1] and monolithic integrations with distributed feedback lasers have been demonstrated [2]. Furthermore, by introducing nonreciprocal propagation to semiconductor optoelectronic devices, magnetically programmable semiconductor bistable lasers are theoretically proposed [3]. This is a novel application of semiconductor optical isolators toward all-optical signal processing.

In semiconductor waveguide optical isolators, optical isolation of 14.7dB/mm was demonstrated at the wavelength $\lambda = 1550\text{nm}$ for transverse electric (TE) mode light [1]. Semiconductor optical amplifier (SOA) waveguides with transversely magnetized ferromagnetic metal thin films provide nonreciprocal loss (= optical isolation) owing to transverse magneto-optic Kerr effect. Since almost all the edge-emitting semiconductor lasers operate in TE mode, TE mode semiconductor optical isolators are important for monolithic integration with semiconductor lasers. TE mode semiconductor optical isolators have been reported in SOA waveguides where the InGaAsP multiple quantum well (MQW) active layers are deeply etched and a ferromagnetic metal (Fe) thin film are deposited on one of the SOA sidewalls as shown in Fig. 1(a). This is because the magnetic field vector H of the propagating TE mode light must be parallel to the magnetization direction of the ferromagnetic metals to obtain nonreciprocal loss. However, deeply etched MQW active layer brings degraded SOA performance (smaller gain, larger SOA current, and shorter device lifetime) due to the non-radiative surface recombination at the etched sidewall of the MQW active layer. Semiconductor optical isolators of ref.[1] have larger than 10dB insertion loss even with SOA current. One of the reasons for the insertion loss is that MQW active layer is deeply etched and partly damaged by reactive ion etching and there is non-radiative surface recombination which leads to lower SOA gain and higher insertion loss. This is one of the

most important problems of TE mode semiconductor optical isolators to limit the optical isolator performance.

In this paper, we propose and discuss optical isolator performances of evanescent semiconductor optical isolators to avoid the above problems of the conventional TE mode semiconductor optical isolators. In evanescent semiconductor optical isolators, introduction of an InGaAsP upper guiding layer with an Fe layer at its sidewall upon the MQW active layer brings TE mode optical isolation without etching the MQW active layer. A new semiconductor optical isolator structure proposed in this paper enables TE mode optical isolation without etching the MQW active layer and can contribute to lower forward transparent current having comparable optical isolation with that of conventional ones.

II. OPERATION PRINCIPLE AND DEVICE STRUCTURE

A. Device structure

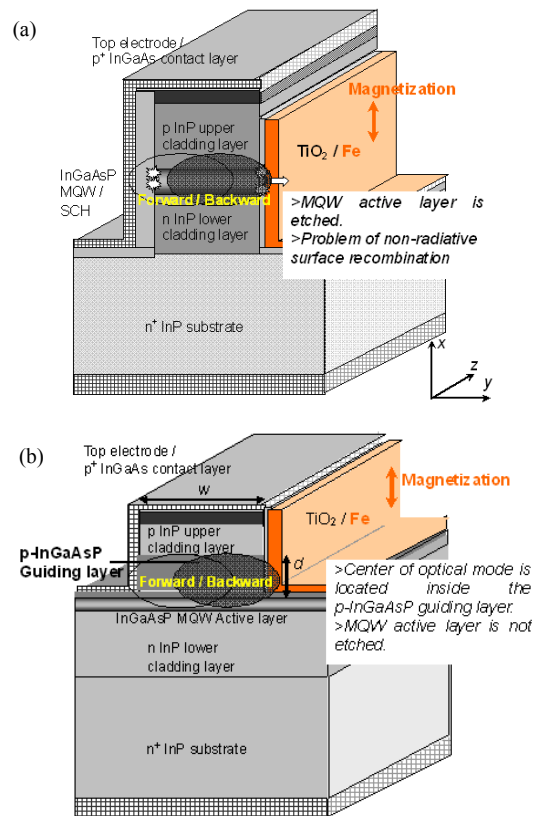


Fig. 1 Schematic images of (a) a conventional TE mode semiconductor optical isolator and (b) an evanescent semiconductor optical isolator proposed in this paper.

Fig. 1 shows schematic device structures of (a) a conventional semiconductor optical isolator and (b) an evanescent semiconductor optical isolator proposed in this paper. In semiconductor optical isolators of Fig. 1(b), a p -InGaAsP upper guiding layer is added upon the InGaAsP MQW active layer. Here the photoluminescence wavelengths of the p -InGaAsP guiding layer and InGaAsP MQW active layer are 1250nm and 1550nm. A ferromagnetic metal Fe thin film is deposited at one of the sidewalls of the p -InGaAsP guiding layer and magnetized along in x direction. A 30nm-thick TiO₂ buffer layer was inserted between the p -InGaAsP guiding layer and Fe layer to adjust the propagation loss by the Fe layer. Here, the operation wavelength λ is set at 1550nm. Refractive indices of p -InGaAsP guiding layer and InGaAsP MQW layer are set at 3.37 and 3.53. InGaAsP MQW active layer is composed of eight 10nm-thick compressively strained quantum wells and nine 10nm-thick barriers. Refractive indices of the TiO₂ and Fe layer are set at 2.1 and $3.18 + 5.27i$ [1]. p -InGaAsP guiding layer thickness d and waveguide width w are important parameters to determine the optical confinement factor in the Fe layer (Γ_{Fe}) and the optical isolation.

B. Calculation of optical isolation

We have calculated the optical isolations and required net gain ($g - \alpha_0$) of the MQW active layer for transparent forward light of evanescent semiconductor optical isolators of Fig. 1(b), where g and α_0 are the material gain and internal loss of the MQW active layer. Optical isolations were calculated using the perturbation method which is described in ref.[1]. Fig. 2(a) shows a calculated intensity profile of

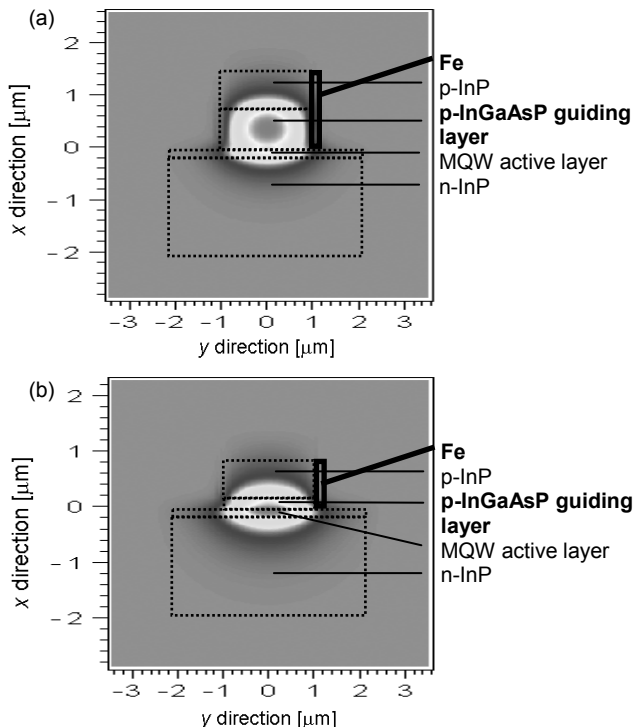


Fig. 2 Calculated profiles of TE mode light in the evanescent semiconductor optical isolators for (a) $d = 0.7\mu\text{m}$, $w = 2\mu\text{m}$ and (b) $d = 0.2\mu\text{m}$, $w = 2\mu\text{m}$ of Fig. 1(b).

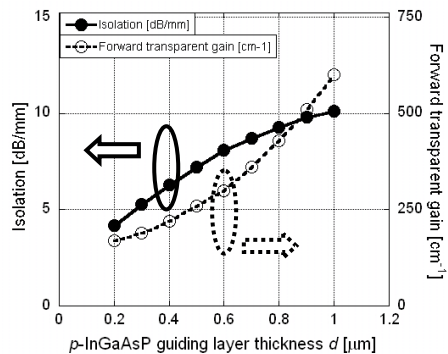


Fig. 3 Calculated optical isolation and forward transparent gain ($g - \alpha_0$) of semiconductor evanescent optical isolators for p -InGaAsP guiding layer thickness $d = 0.2 - 1.0\mu\text{m}$ at constant waveguide width $w = 2\mu\text{m}$.

the TE mode light in the device of Fig. 1(b), when $d = 0.7\mu\text{m}$ and $w = 2\mu\text{m}$ by beam propagation method. The center of the optical mode profile is located inside the p -InGaAsP guiding layer and Γ_{Fe} is 0.21%. Optical isolation of 8.7dB/mm is estimated for these conditions, which is comparable with conventional semiconductor optical isolators [1]. Fig. 3 shows the calculated optical isolation and forward transparent gain for p -InGaAsP thickness $d = 0.2 - 1\mu\text{m}$ at constant waveguide width $w = 2\mu\text{m}$. When p -InGaAsP guiding layer is thin ($d = 0.2\mu\text{m}$), the center of optical mode profile is located inside the MQW active layer as shown in Fig. 2(b), which results in smaller optical isolation. With increasing p -InGaAsP layer thickness, the center of optical mode profile is pulled inside the p -InGaAsP guiding layer, and optical isolation and required forward transparent gain become larger. However, when the p -InGaAsP guiding layer is thicker than $1\mu\text{m}$, a first order higher mode is allowed along x direction. This is the upper limit of the p -InGaAsP guiding layer thickness. Optimum p -InGaAsP layer thickness d is between 0.6-0.9 μm . From these designs, it is clear that TE mode optical isolation can be obtained without etching the MQW active layer. This is a solution of the reliability problem and insertion loss in conventional TE mode semiconductor optical isolators.

III. SUMMARY

We have newly designed and discussed the device structures of evanescent semiconductor optical isolators and their optical isolator performances. Optical isolation of 8.7dB/mm was estimated without etching the MQW active layer, and the obtained optical isolation is comparable with that of conventional semiconductor optical isolators.

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