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Characterization of Narrow Mesa Width Waveguide for All Optical Switching Device Based on Intersubband Transition in II-VI Based Quantum Wells

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1. Introduction

Short-wavelength intersubband traditions (ISBT) in semiconductors quantum wells (QWs) with ultra fast carrier relaxation (~1ps) has attracted much attention, especially by aiming at potential applications for all-optical signal processing for high-bit-rate (above 160 Gbit/s) optical fiber communication system at λ~1.55 mm. Recently, sub-ps all-optical modulation at optical communication wavelength have been demonstrated in ISBT-waveguide devices based on some material systems, such as InGaAs/AlAsSb [1], GaN/AlGaN [2], (CdS/ZnSe)/BeTe [3]. And the operating energy to achieve 10 dB extinction ratio (ER) in these devices are 32 pJ, 100 pJ, 4 pJ respectively. However these figures are not sufficiently low for practical applications. Because the devices are operated by high-bit-rate above 100 Gbit/s with high operation energy (several tens pJ), the mean-operation-energy become several tens Watts which can not expect proper movement. To reduce the operation energy is most important problem for ISBT optical switches where 10dB-ER at 1pJ-input-energy is required as a mile stone to practical application.

One of the most important factors for reducing the operation energy is efficient absorption saturation by the strong confinement light in a narrow space of a waveguide. Therefore we had fabricated the high mesa waveguide structure with a separate confinement heterostructure (SCH) core which enhances light confinement in the active layer[4]. In this leaf presents, we report on the fabrication of the narrow mesa width waveguides and the absorption saturation characteristics of the ISBT optical switch waveguides. To increase the light intensity in the waveguide for more efficient absorption saturation, the mesa width is reduced to the submicron range.

2. Fabrication of Waveguide Device

The schematic of cross-section of the waveguide structure is shown in Fig 1. A epi-wafer of SCH structure which consist of a 3-μm-thick $Zn_{0.67}Mg_{0.21}Be_{0.12}Se$ bottom cladding layer (CL, n=2.35) , a 0.28-μm-thick $Zn_{0.97}Be_{0.03}Se$ bottom optical confinement layer (OCL, n=2.45), 0.24-μm-thick (CdS/ZnSe)/BeTe MQW (n=2.54) active layer, a 0.28-μm-thick $Zn_{0.97}Be_{0.03}Se$ upper OCL and a 1-μm-thick $Zn_{0.67}Mg_{0.21}Be_{0.12}Se$ upper CL, were grown sequentially on (001) GaAs homo-epitaxy substrate by dual chamber molecular beam epitaxy system. A active layer has 40 period of QWs which is designed such that 15-ML(mono layer)-thick BeTe barriers with ZnSe/CdS/ZnSe (1/~2/1 ML) well layers exhibit an ISB absorption spectrum at a wavelength of around 1.55 μm; n-type doping is achieved by $ZnCl_2$ in the CdS/ZnSe well. As the index contrast of this SCH structure, this system can set to 0.2 or more between active and cladding layer. In addition, we employed high-mesa type waveguide which is more effective for an optical confinement than the ridge structure due to that lateral directions are cladding by air. Consequently, this waveguide can strong light confinement into active layer. For the fabrication process, we employed electron beam lithography to fabricate various mesa width (~0.8 μm) of waveguide patterns and reactive ion etching in an inductive-coupled-plasma using Ar and BCl_3 gases. After fabricated the high-mesa structure, the sample wafer was cleaved to waveguide bars. And, both waveguide facets were coated by single SiO_2 layers that were used as antireflectors. For enhanced optical coupling between a lensed dispersion-shifted polarization-maintaining fiber (DS-PMF) and a waveguide with narrow mesa width, a tapered structure with a mesa width of 3 μm is added at the input and output regions.

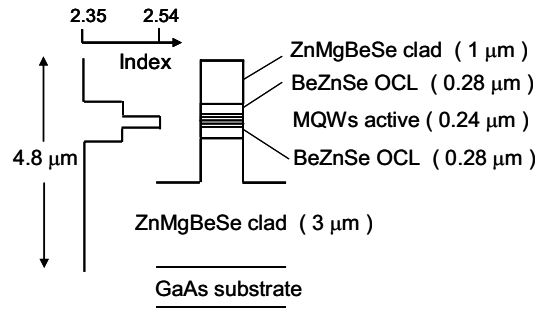

Fig. 1 Schematics of cross-sectional

3. Optical characteristics of waveguide

Fig. 2 shows SEM image of high-mesa waveguide. After fabricated the waveguide, we measured the insertion losses and absorption saturation energy. As a light source, an optical parametric oscillator (OPO) pumped by Ti:Sapphire mode-locked laser with repetition rate of 76 MHz wa used.

At first, we discuss the effect narrow mesa on insertion losses and absorption saturation of waveguide. Fig.3 (a) shows the measurement of transverse electric (TE) and transverse magnetic (TM) polarization insertion losses, and 10-dB absorption saturation energy as a function of

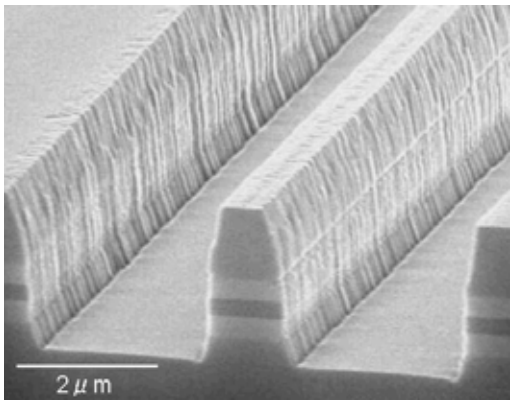

Fig. 2 SEM image of high-mesa waveguide.

waveguide mesa width. The ISBT can be induced only by light with its electric field component along the growth direction i.e, TM polarization. Therefore the TM losses are larger than TE losses by ISB absorption. When the mesa width was narrower than 1.5 μm, the TE polarization insertion losses increased suddenly. On the other side, the TM polarization insertion losses did not increase as shown in fig. 1(a). It seems that this polarization dependence is caused by two reasons. The one is propagation loss which is scattered the light by roughness of waveguide sidewall. The electric field of TE polarization light is perpendicular to growth direction. When the mesa width is very narrow with strong light confinement, the both side of sidewall roughness scatter the TE polarization light directly. Therefore TE polarization loss change was larger than TM polarization light losses. The other is cut off of waveguide. Fig 3(b) shows the effective indices of the waveguide structure as shown in Fig. 1 calculated by varying mesa width. In this calculation, we estimated the cut-off mesa width of waveguide. The TM polarization cut-off width is about 0.15 μm narrower than TE polarization. Therefore, even if TE polarization losses changed suddenly, TM polarization losses did not change.

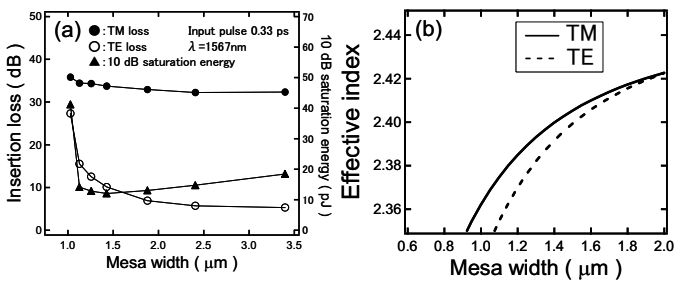

Fig. 3 (a) TE and TM polarization Insertion losses and 10-dB absorption saturation energy, (b) Effective indices of waveguide structure shown in Fig. 1 calculated by varying mesa width.

For the absorption saturation, the 10-dB saturation energy decreased with mesa width decreasing by 40% as shown in Fig. 3(a) . It indicates that ISB absorption saturation occurred more effectively in the waveguide with narrow mesa due to strong confinement light into core part. Furthermore, the mesa width became narrow, the energy suddenly increased. It seems that this increase mainly caused by cut-off. Because if it has connection with propagation loss, TM losses should increase with mesa width became narrow. In fig 3(a), we did not observe the large change of TM losses dependence which looks like TE polarization losses. Therefore this suddenly increase of energy is caused by cut-off.

4. Improvement of operation energy

Next, we discuss the improvement of optical confinement. Fig. 4 (a) shows the calculation of absorption saturation varying with mesa width and layers index. And Fig.4 (b) shows 10-dB saturation power which estimated from calculation of Fin.4(a). For the 10-dB saturation power, when it compares ■ with ● index profile in fig 4 (b), the high index contrast profile of power (■) is low by 20 % at 3.0 μm mesa width. In addition, the cut-off mesa width became narrow by 0.4 μm. These improvements are caused by strong optical confinement with high index contrast. Thereby we can confirm that the waveguide structure with high index contrast between active and clad layer is effective for improvement of operating energy.

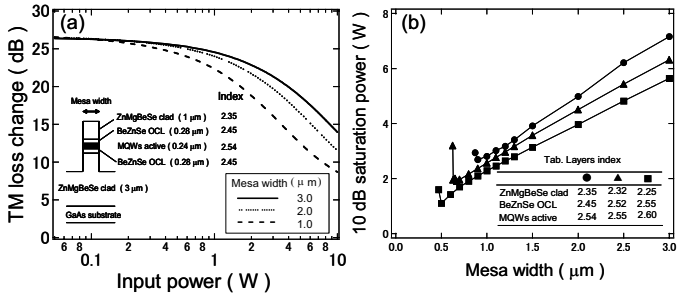

Fig. 4 (a) Calculation of absorption saturation, (b) Calculation of 10-dB saturation power varying with layers index and mesa width.

5.Conclusions

We fabricated the ISBT optical switch waveguide with narrow mesa width (~0.8 μm). The reduction of operation energy is limited by waveguide cut-off. For the improvement, we confirmed that the high index contrast waveguide structure is effective for improvement of operating energy. These results indicate that optical modulation up to 1 Tbit/s is possible in present II-VI-based ISBT waveguide.

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