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Wide-Band Polarization-Independent Semiconductor Optical Amplifier Gate with Tensile-Strained Quasi-Bulk InGaAs*

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Abstract: A semiconductor optical amplifier gate based on tensile-strained quasi-bulk InGaAs is developed. At injection current of 80mA, a 3dB optical bandwidth of more than 85nm is achieved due to dominant band-filling effect. Moreover, the most important is that very low polarization dependence of gain (< 0.7dB), fiber-to-fiber lossless operation current (70~ 90mA) and a high extinction ratio (> 50dB) are simultaneously obtained over this wide 3dB optical bandwidth (1520~ 1609nm) which nearly covers the spectral region of the whole C band (1525~ 1565nm) and the whole L band (1570~ 1610nm). The gating time is also improved by decreasing carrier lifetime. The wide-band polarization-insensitive SOA-gate is promising for use in future dense wavelength division multiplexing (DWDM) communication systems.

Key words: semiconductor optical amplifier gate; wide bandwidth; polarization-insensitive; tensile-strained quasi-bulk InGaAs; fiber-to-fiber lossless operation current; extinction ratio

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1 Introduction

Photonic wavelength division multiplexing (WDM) switching systems in the future will require a number of optical gate elements for both routing and buffering operation[1]. The semiconductor optical amplifier (SOA) is one of the most promising candidates for such a gate element because it provides a switching time under 1ns, fiber-to-fiber lossless operation and a high extinction ratio over a wide wavelength range. It has been reported that a SOA gate with quasi-square unstrained bulk active layer provides a high extinction ratio, low polarization sensitivity and enables fiber-to-fiber lossless operation under very low current injection[2~4]. However, it is very difficult to fabricate such SOA with near square active region due to its submicrometer stripe width (< 0.5μm). As a result, it is also difficult to integrate such bulk SOA gate into passive waveguides having a typical stripe width of 1.5μm[5]. In addition. a SOA gate

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with a tensile-strained multiquantum well (MQW-SOA) as an active layer is also developed[6,7]. But in order to be a polarization-insensitive MQW-SOA gate, two material gains both for TE and TM modes should be equal. It requires introducing large tensile strain into MQW.

It is very desired for SOA gate to have a larger 3dB optical bandwidth. So far, to our knowledge, only a tensile-strained InGaAsP/InP multiquantum well optical amplifier has been developed which has 92nm optical bandwidth at an injection current of 50mA[8]. But SOA with that structure is polarization-sensitive. This paper develops a wide-band polarization-insensitive SOA gate with tensile-strained quasi-bulk InGaAs active layer for the first time. Our goal is to use very thin active layer so as to obtain large 3dB optical bandwidth due to dominant band filling effect and by introducing small tensile-strain into the active to achieve polarization-insensitive. The fabricated SOA gate with thin tensile-strained bulk layer has a more than 85nm optical bandwidth(1520~ 1609nm) which almost covers the spectral region of the whole C band (1525~ 1565nm) and the whole L band (1570 ~ 1610nm). Besides, over this wide optical bandwidth, SOA gate also has very low polarization-insensitive (< 0.7dB) and a large extinction ratio(> 50dB). The fiber-to-fiber lossless operation current is less than 90mA.

2 Device fabrication and characteristics

SOA gate with tensile-strained quasi-bulk active region was fabricated by three-step metal-organic vapor phase epitaxy (MOVPE) and conventional wet-etching technique. First, 0.6μm thick n-type InP buffer layer, 100nm-thick undoped lattice matched quaternary InGaAsP (λ_g = 1.2μm) lower optical confinement layer, 45~ 50nm-thick undoped tensile-strained-bulk ternary InGaAs active layer, 100nm-thick undoped lattice matched InGaAsP (λ_g = 1.2μm) upper optical confinement layer and 30nm-thick undoped InP layer were successively grown on a (100) n-InP substrate by MOVPE. The tensile strain value of the active layer was set to 0.27% by only variation of trimethylgallium (TM-Ga) source supply. The active waveguide mesa stripe was 2.5μm wide, formed by chemical etching using SiO_2 as mask. The waveguide was tilted 7° with respect to [110] crystalline direction to reduce facet reflectivity. The active waveguide mesa was then buried under p-InP and n-InP current blocking layers by MOVPE. After the removal of the active waveguide SiO_2 mask, a 3μm-thick p-InP cladding layer and a 0.3μm p^+-InGaAs contact layer were in turn grown by MOVPE. After the electrodes were fabricated, 800μm-long devices were cleaved and both facets of which were anti-reflection coated.

Figure 1 shows amplified spontaneous emission (ASE) of SOA measured at injection current of 80, 160, and 200mA. It is worth noting that the measured spontaneous emission spectra have 0.1nm bandwidth resolution. As a result, the gain ripple seems large. But in fact, it is still less than 0.3dB even at the driving current of 200mA. TM and TE modes are shown by solid and broken lines, respectively. At the driving current of 80mA, the SOA exhibits a 3dB optical bandwidth of 89nm (1520~ 1609nm) which nearly covers the whole C band (1525 ~ 1565nm) and L band (1570 ~ 1610nm). Obviously, the SOA has a wider bandwidth than conventional bulk SOA[9] does. Nearly 90nm optical bandwidth is achieved because the active region of SOA is so thin that the band filling effect is dominant. From Fig. 1, we can see that the peak in ASE spectrum of the TE mode is almost the same as that of the TM mode. Besides, the difference in ASE spectrum between TE and TM mode is less than 0.7dB over this wide 3dB optical bandwidth and this value is even becoming smaller with increasing operation current. Thus from the results shown in Fig. 1, the polarization insensitive can be attained over 3dB optical bandwidth and a large operation current range. This means that the

SOA-gate with tensile-strained quasi-bulk has a very wide range of current and wavelength characteristics of polarization insensitivity, which is very useful for dense wavelength division muitiplexing (DWDM) systems.

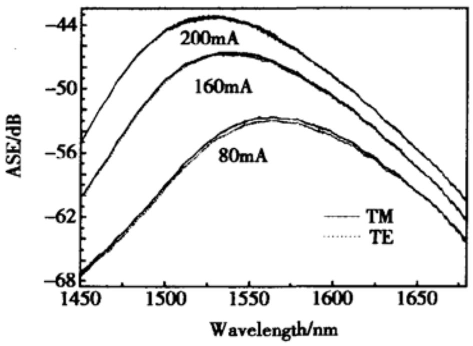

Fig. 1 Measured amplified spontaneous emission spectra with 0.1nm bandwidth resolution at respectively driving current of 80, 160, 200mA Solid line: TM mode, broken line: TE mode

Signal gain characteristics were measured with a tunable laser. A signal light was injected into the amplifier through a polarization controller and an optical fiber with a taped-end. Then, optical output was coupled into another optical fiber and detected by a power meter. Figure 2 shows the measured gain characteristics versus driving current for both TE and TM modes at 1.55μm for a - 13dBm input power. The TM mode gain is always slightly higher than the TE mode gain ranging injection current from 80mA to 180mA. When the driving current increases to 200mA, the TE mode gain becomes larger than TM mode gain. But the most important is that the difference between them is always kept at less than 0.7dB, which agrees with that of Fig. 1. At a driving current of 200mA the fiber-to-fiber gain of 8dB is obtained. The value is a little lower compared with conventional tensile strained bulk SOA which have a thicker active layer[10]. This is mainly because the active layer of our SOA is so thin that the optical confinement factor (Γ) gets small. But this can be compensated by employing a longer device. In addition, the coupling loss between the amplifier and the optical fiber is too large, which is estimated to be 9dB/facet. Therefore a higher fiber-to-fiber gain of SOA can be reached by increasing SOA length and improving coupling efficiency. From Fig. 2, one can also see that at 1550nm signal for a - 13dBm input power, the fiber-to-fiber lossless operation current is 80mA and the extinction ratio, defined as the difference in the optical power between 0dB fiber-to-fiber gain and the off level, is more than 55dB.

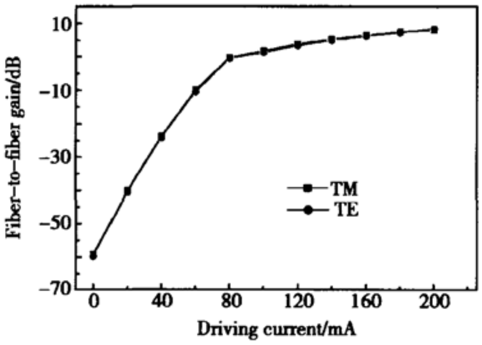

Fig. 2 Measured SOA gate gain characteristics versus driving current for both TE and TM modes at 1.55μm for a - 13dBm input power

Figure 3 shows the wavelength dependence of the fiber-to-fiber lossless operating current at an input of - 13dBm. The lossless current slightly increases with decreasing wavelength. But over the entire 3dB optical bandwidth of 1520~ 1600nm, the maximal lossless operation current is not more than 90mA. Obviously the lossless current is a little larger. This is because our SOA gate has a

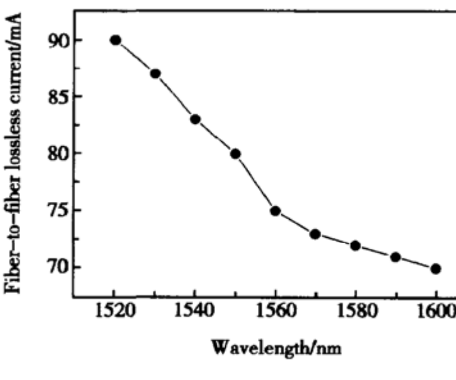

Fig. 3 Measured wavelength dependence of the fiber-to-fiber lossless operating current at an input of - 13dBm

wider mesa width (nearly 2.5μm wide). Later, we can decrease the lossless current by making active region narrower.

Figure 4 shows the wavelength dependence of the extinction ratio at an input of − 13dBm. The extinction ratio decreases with increasing wavelength. However, a high extinction ratio of more than 50dB still obtains over the entire 3dB optical bandwidth of 1520~ 1600nm which almost covers the whole C band (1525~ 1565nm) and the whole L band (1570~ 1610nm) simultaneously. This parameter is very crucial for SOA as an optical gate for future DWDM communication systems.

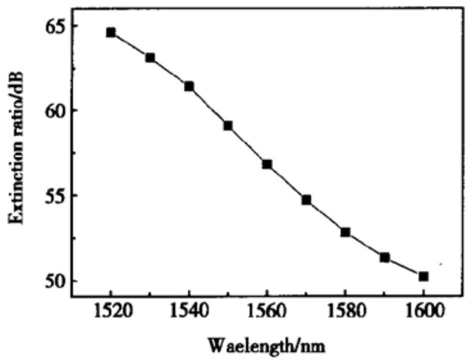

Fig. 4 Measured wavelength dependence of the extinction ratio at an input of − 13dBm

In fact, the extinction ratio of SOA can be improved in further by increasing cavity length. But too long cavity length will give rise to a narrower 3dB optical band width[11]. In other words, the SOA gate can get a wider 3dB optical bandwidth by using a shorter cavity. But in turn, this will decrease device gain and extinction ratio. So a trade off among them is needed. We conclude that when SOA is used as an amplifier, we can deploy longer cavity to attain higher gain. When SOA is used as a gate, we can deploy a moderate cavity length to keep a high extinction ratio and a wider 3dB optical bandwidth.

It should be noted that another advantage of our fabricated SOA with quasi-bulk InGaAs is the reduced carrier lifetime due to increased carrier density in the active layer at the same injection current compared with thicker active layer. This is useful for SOA as a gate because gating time can be improved.

3 Conclusions

We develop a SOA gate based on tensile strained quasi-bulk InGaAS active structure. A wider 3dB optical bandwidth is obtained mainly due to the dominant band-filling effect of such kind of structure. At the driving current of 80mA, more than 85nm of 3dB optical bandwidth is reached, which covers nearly the whole C band and the whole L band simultaneously. The most important is that the polarization sensitivity is less than 0.7dB over this wide 3dB optical bandwidth and does not change throughout the 80~ 200mA operation current. In the meantime, 70~ 90mA of fiber-to-fiber lossless operation current and more than 50dB extinction ratio are also attained over the wider 3dB optical bandwidth. In addition, the gating time is also improved due to decreased carrier lifetime. The disadvantage of our design is a slightly elevated lossless current. The performance of the SOA gate will be improved further by optimizing the device structure. In a word, the tensile-strained quasi-bulk InGaAs SOA gate is very promising for the network device application, especially for the future DWDM systems.

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宽带偏振不灵敏张应变 InGaAs 半导体放大器光开关*

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摘要: 研制了一种张应变准体 InGaAs 半导体放大器光开关. 该结构具有显著的带填充效应, 从而导致在 80mA 的注入电流下, 器件的 3dB 光带宽大于 85nm(1520~1609nm). 该带宽几乎同时全部覆盖了 C 带(1525~1565nm) 和 L 带(1570~1610nm). 最为重要的是, 在 3dB 光带范围内, 光开关的偏振灵敏度小于 0.7dB; 光纤到光纤无损工作电流在 70~90mA 之间; 消光比大于 50dB. 通过降低了载流子寿命, 开关速度有所提高. 在未来密集波分复用通信系统中, 这种宽带偏振不灵敏半导体放大器光开关很有实用前景.

关键词: 半导体放大器光开关; 宽带; 偏振不灵敏; 张应变准体 InGaAs; 光纤到光钎无损工作电流; 消光比
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