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A Broadband Long-Wavelength Superluminescent Diode Based on Graded Composition Bulk InGaAs*

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Abstract: A novel unselective regrowth buried heterostructure long-wavelength superluminescent diode (SLD) with a graded composition bulk InGaAs active region is developed by metalorganic vapor phase epitaxy (MOVPE). At a 150mA injection current, the full width at half maximum of the emission spectrum of the SLD is about 72nm, ranging from 1602 to 1674nm. The emission spectrum is smooth and flat. The ripple of the spectrum is less than 0.3dB at any wavelength from 1550 to 1700nm. An output power of 4.3mW is obtained at a 200mA injection current under continuous-wave operation at room temperature. This device is suitable for the applications of light sources for gas detectors and L-band optical fiber communications.

Key words: broadband; superluminescent diodes; graded composition; buried hetero-structure
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1 Introduction

Superluminescent diodes (SLDs) are optimum light sources for many applications such as optical fiber gyroscopes, sensors, and optical fiber communications. It is very important for SLDs to have broad spectra, small fluctuation of emission spectra, and high output power in these applications[1~3].

To date, several methods have been used to increase spectral width, such as using the $n=1$ and $n=2$ simultaneous transitions in a quantum well[4] and employing non-uniform multiple quantum-wells[5]. However, it is difficult to obtain a smooth amplified spontaneous emission (ASE) spectrum using these methods.

In this paper, a novel broadband long-wavelength SLD with unselective regrowth buried heterostructure (BH) fabricated by metalorganic vapor phase epitaxy (MOVPE) is described. We adopt a graded composition bulk (GCB) InGaAs active layer[6~9] to get a wide bandwidth[10] in the long-wavelength region. Although graded composition has been applied for a long time to GaAs-based material, it has seldom been applied to InP-based material because the concomitant strain easily leads to relaxation and dislocation. The GCB InGaAs active layer presented here is different from previous devices in that it includes a tensile strain and a compressed strain[11].

We also study unselective regrowth BH tech-

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nology. Unselective regrowth BH is independent of the mesa shape and the dielectric mask, so it is easy to realize a confined structure.

Our experimental results show that the SLD chip has a 3dB bandwidth of 72nm at a long wave band. The ASE spectrum is smooth and flat. This kind of long-wavelength broadband SLD can be employed as a methane detector because methane's absorption lines represent the first overtones of the infrared active fundamentals and are located at about 1.65μm[12]. Furthermore, there are many potential applications for this kind of SLD including optical communications[13], remote sensing, molecular spectroscopy, and medical uses[14].

2 Device structure

The unselective regrowth BH SLD was fabricated in three steps of MOVPE growth. First, a 1.2μm thick n-doped InP buffer layer was grown on an n-InP substrate. The active region waveguide structure was grown on the buffer layer. The active region consists of an 85nm undoped GCB InGaAs active layer sandwiched between 90nm undoped and lattice-matched InGaAsP separate confinement heterostructure (SCH) layers with a band gap wavelength of about 1.2μm (1.2Q). The symmetric-graded composition of the bulk InGaAs active layer is obtained merely by changing the TMGa flux and keeping the TMIn and the AsH_3 constant during epitaxy growth. The TMGa flux changed from 10 to 6.9 and back to 10 continuously. A TMGa flux of 8.5 corresponds to the $In_{0.53}Ga_{0.47}As$ matching to the InP substrate for our MOVPE system, 10 corresponds to a tensile strain of -0.22%, and 6.9 corresponds to a compressed strain of 0.16%. The energy band diagram of the growth structure including the InP cladding layer developed in the third growth step is shown schematically in Fig. 1. From Fig. 1, we can see that the GCB InGaAs active layer includes a complex strain region, viz. a tensile strain region and a compressed strain region. The tensile strain region has a larger energy gap and the compressed strain region a smaller energy gap than that of the $In_{0.53}Ga_{0.47}As$ material. The photoluminescence (PL) spectrum of the active region is shown in Fig. 2. The peak wavelength is about 1636nm. The full width at half maximum (FWHM) is 161nm from 1545 to 1706nm. The reason for the wide spectrum and relatively long-wavelength is that different compositions correspond to different energy gaps for the GCB InGaAs active region even though the strain effect partly counteracts the gap shift resulting from the composition change. Even so, the GCB InGaAs active region with a complex strain structure yields a wider and smoother spectrum than an active region with a simple strain. Following the first structure epitaxy shown in Fig. 3(a), a 1.8μm-wide mesa stripe tilted by 10° was made by photoresist mask lithography and wet etching as shown in

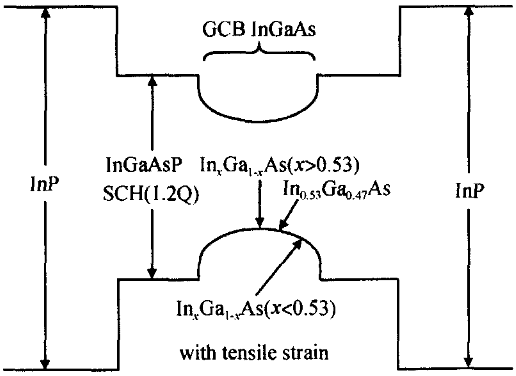

Fig. 1 Schematic energy band diagram of growth structure

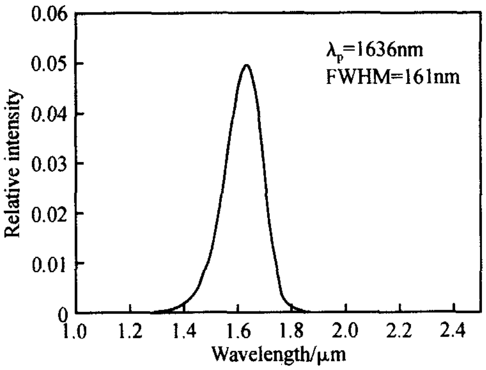

Fig. 2 PL spectrum of SLD's active region at room temperature

Figs. 3(b) and (c). Second, a pair of p/n current-blocking layers were formed on the whole area by unselective MOVPE regrowth as shown in Fig. 3 (d). Third, a current channel was made by wet etching in the current-blocking region above the active region stripe as in Fig. 3(e), and then a 2μm-thick p-doped InP cladding layer and a 0.2μm-thick p^+-doped InGaAs contact layer were grown by MOVPE. After the MOVPE growth, the wafer was thinned down to 100μm and was metallized and alloyed. Then, the wafer was cleaved into about 800μm-long bars, both facets of which were coated by antireflection coating (AR coating) to diminish emission spectrum modulation. Finally, the chips cut from the bars were mounted on a heat sink. Figure 3 (f) shows the whole schematic structure after the third epitaxy growth and electrode fabrication.

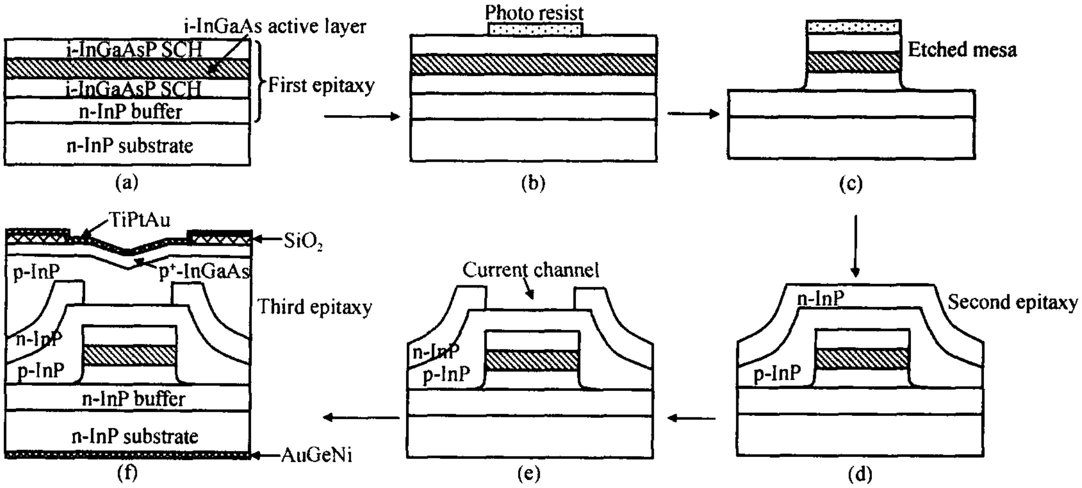

Fig. 3 Schematic diagram of the SLD fabrication process (a) First epitaxy growth; (b) Etched photoresist; (c) Wet-etched mesa by photoresist mask; (d) Second epitaxy growth to form p/n current-blocking layers; (e) Wet-etched current channel; (f) Whole structure after the third epitaxy growth and electrode fabrication

Figures 4 (a) and (b) show the scanning electron microscope (SEM) photographs of a cross-sectional view taken in the SLD fabrication process corresponding to Figs. 3 (e) and (f). In Fig. 4(a), we can see a 2μm-wide current channel above the active region located in the center of the figure with a fuscous color. The width of the current channel is almost equal to that of the active region.

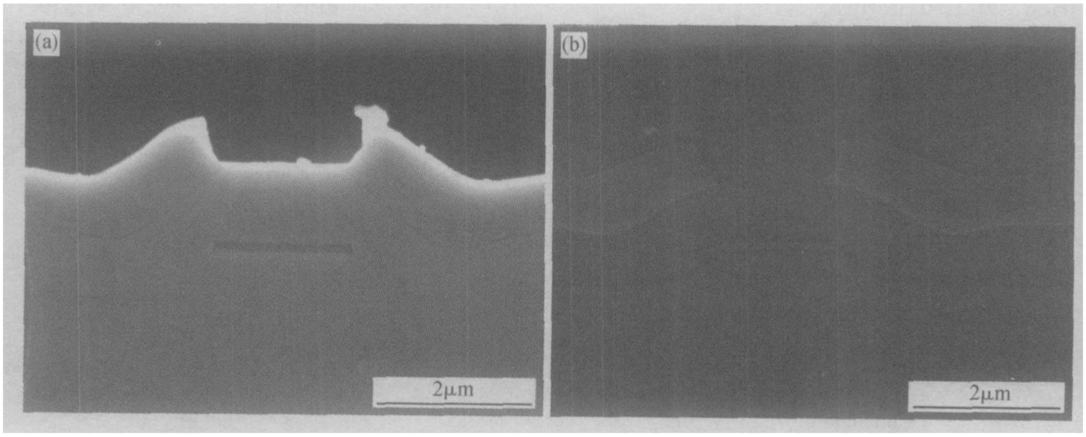

Fig. 4 SEM photograph of cross-sectional view taken in process (a) Correspond to Fig. 3 (e); (b) Correspond to Fig. 3 (f) which was the whole structure after the third epitaxy growth

Figure 5 shows a microscope photograph of the planform view of a 300μm chip surface. The inset is a local amplification. The stripe is tilted 10° from the normal to the cleaved facet to suppress resonance. This angle is larger than conventional tilt angle of 7° to much further decrease the ripple of emission spectra.

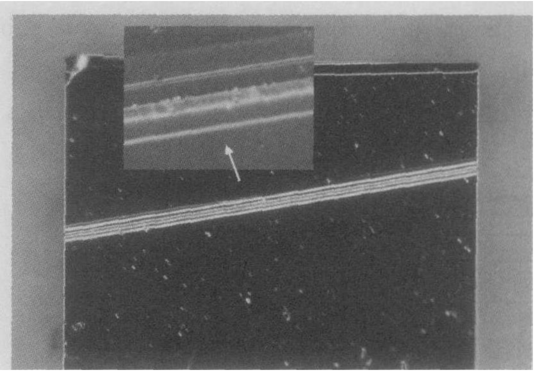

Fig. 5 Microscope photograph of planform view of the chip surface

3 Results and discussion

Before applying the AR coating, the lasing light power versus injection current of the chip with a cavity-length of 500μm was measured under continuous-wave (CW) operation at room temperature as shown in Fig. 6. It shows that the lasing threshold current is about 40mA. It also shows that the chip has a strong fluorescence before lasing due to a strong spontaneous emission. The lasing characteristic of the 10° tilted cavity indicates the high electro-optical performance of the unselective regrowth buried heterostructure.

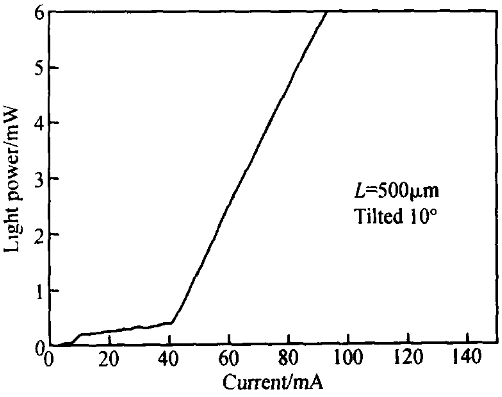

Fig. 6 Light-current characteristic of chip before AR coating

The ASE light power versus injection current for the SLD chip with an 800μm cavity-length after applying the AR coating is shown in Fig. 7. A single-side output power of 4.3mW is obtained with a 200mA injection current under CW operation at room temperature. The output power is relatively low, primarily due to the very narrow active region stripe. Furthermore, Auger recombination is larger to longer wavelength. A tapered, broad p-electrode and active region stripe of SLD are necessary to realize high power.

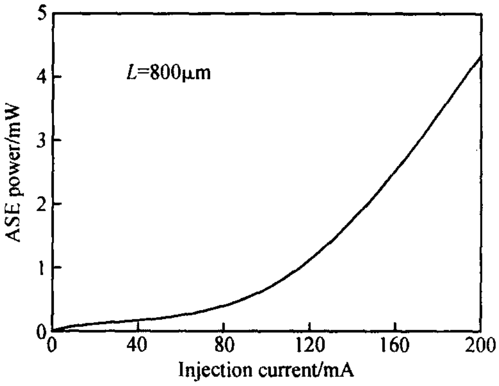

Fig. 7 ASE power versus current characteristic of SLD chip after AR coating

Figure 8 shows the ASE spectrum of the SLD chip at an injection current of 150mA under CW operation. The peak wavelength is about 1637nm, which is close to that of the PL spectrum. The 3dB emission spectrum bandwidth (FWHM) of the ASE spectrum is about 72nm, ranging from 1602 to 1674nm. The ripple is less than 0.3dB at any wave-

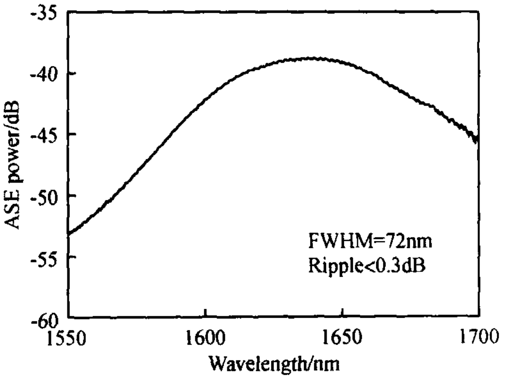

Fig. 8 ASE spectrum of SLD chip at 150mA under CW operation

length from 1550 to 1700nm. This very small spectral ripple indicates the very small residual facet reflectivity, which also indicates that lasing is well suppressed by the tilted stripe and AR coating. Figure 8 also shows that the ASE spectrum is very flat and smooth at a 3dB bandwidth indicating a uniform gain produced by the GCB InGaAs active layer.

4 Conclusion

In this paper, we show the fabrication process and the results of a novel unselective regrowth buried heterostructure long-wavelength SLD which was developed by a three step MOVPE growth process. A flat and wide emission spectrum and a small spectral ripple are achieved in the long-wavelength band by the combination of the graded composition active layer, tilted cavity, and AR coating. The FWHM of the SLD's ASE spectrum is 72nm, with a ripple of less than 0.3dB. An output power of 4.3mW is obtained at a 200mA injection current under CW operation at room temperature. This device is quite promising for many applications because of its wide emission spectrum and long-wavelength band, although further study is required to optimize its output power.

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基于渐变组分体材料InGaAs的宽带长波长超辐射二极管[*]

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摘要: 研制了一种新型的非选择性再生长掩埋异质结构长波长超辐射二极管(SLD). 该器件采用渐变组分体材料InGaAs作为有源区,由金属有机物化学气相外延制备. 150mA下,SLD发射谱宽的半高全宽为72nm,覆盖范围从1602到1674nm. 发射谱光滑、平坦,光谱波纹在1550到1700nm的范围内小于0.3dB. 室温连续工作,注入电流200mA下,器件获得了4.3mW的出光功率. 器件适用于气体探测器和L-band光纤通信的光源.

关键词: 宽带; 超辐射二极管; 渐变组分; 掩埋异质结构

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