Graded tensile-strained bulk InGaAs/InP superluminescent diode with very wide emission spectrum

Shurong Wang (王书荣)[1,2], Hongliang Zhu (朱洪亮)[1], Zhihong Liu (刘志宏)[1], Ruiying Zhang (张瑞英)[1], Ying Ding (丁 颖)[1], Lingjuan Zhao (赵玲娟)[1], Fan Zhou (周 帆)[1], Jing Bian (边 静)[1], Lufeng Wang (王鲁峰)[1], and Wei Wang (王 圩)[1]

[1] *Center of Optoelectronics Research & Development, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083*

[2] *Institute of Solar Energy, Yunnan Normal University, Kunming 650092*

Received January 12, 2004

A kind of novel broad-band superluminescent diodes (SLDs) using graded tensile-strained bulk InGaAs is developed. The graded tensile-strained bulk InGaAs is obtained by changing only group-III trimethylgallium source flow during low-pressure metal organic vapor-phase epitaxy. At the injection current of 200 mA, the fabricated SLDs with such structure demonstrate full-width at half-maximum spectral width of 106 nm and the output light power of 13.6 mW, respectively.

OCIS codes: 230.0230, 230.3670, 230.0250.

Superluminescent diodes (SLDs) are optimum light sources for applications in areas such as fiber optical gyroscopes and sensors, wavelength division multiplex passive optical networks (WDM-PON), multichannel optical amplifiers, mode-locked semiconductor lasers, and wide-range tunable external-cavity semiconductor lasers. Among these applications, it is very desirable for SLDs to have large spectral width and high optical power. Up to now, several methods have been used to obtain high output optical power, including tapered active region[1], integration of a SLD with a semiconductor amplifier[2,3], and quantum dot active structure[4]. Meanwhile, there are also many efforts to increase spectral width. Two effective ways of them are to deploy a single quantum-well (SQW) active layer with simultaneous transitions of $n = 1$ and $n = 2$ states[5] and to employ asymmetric multiple quantum-well (AMQW) structures with different transition energies[6-8]. All these structures have reached a wider emission spectrum, but at the expense of larger injection current and rigorous designs.

In this letter, we demonstrate the successful fabrication of novel broad spectral width SLDs based on symmetric graded tensile-strained bulk InGaAs. The symmetrical graded tensile-strained bulk InGaAs is obtained by changing only the group-III trimethyl-gallium (TMGa) source flow during low-pressure metal organic vapor-phase epitaxy (LP-MOVPE). At the injection current of 200 mA, the full-width at half-maximum (FWHM) spectral bandwidth and the output light power of the graded tensile-strained bulk InGaAs SLD are 106 nm and 13.6 mW, respectively. More important, the emission spectrum is very flat and has no dip.

For a ternary system bulk InGaAs, when it was grown on InP substrate, the different compositions can create the different strain values so as to produce the different energy gaps. As the result, the gain spectrum of the SLD could be broadened. Furthermore, using a ternary system InGaAs makes it easy to introduce the strain effect. This is because much different strain can be introduced into bulk InGaAs simultaneously by changing only the group-III TMGa or trimethyl-indium (TMIn) source flow during LP-MOVPE.

To achieve the broad-band characteristics, the transition energy difference of 30 MeV between the maximum tensile region and the minimal tensile region is designed. The SLD structure reported here is realized by LP-MOVPE and its layer structure is shown in Fig. 1. The grown structure consists of a 200-nm-thick undoped symmetric graded tensile-strained bulk InGaAs active layer sandwiched between 120-nm-thick lattice matched InGaAsP ($\lambda_g = 1.2$ μm) material layers. In the growth experiment, we quasi-linearly varied only the TMGa source flow content from 11.2 which corresponds to about -0.26% tensile strain of the InGaAs layer to 9.1 corresponding to lattice match to InP substrate. Then, let the TMGa flow return from 9.1 to 11.2 again, keeping the TMIn and the AsH_3 source flow constant. It is worth noting that the growth time is also an important parameter to be controlled for achieving wide and flat emission spectra. This is due to different strain corresponding to different growth rate. The larger the strain, the longer the needed growth time. The In and Ga compositions of the grown bulk InGaAs are determined by high resolution X-ray diffraction (XRD) using a double-crystal diffractometer.

After growth of graded tensile strained bulk InGaAs active layer, we did high resolution XRD experiment. The measured (004) XRD rocking curve of grade tensile-strained InGaAs is shown in Fig. 2. There are many peak values on the right side of the (004) rocking curve

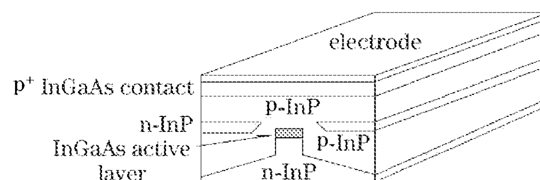

Fig. 1. Structure of the graded tensile-strained InGaAs SLD.

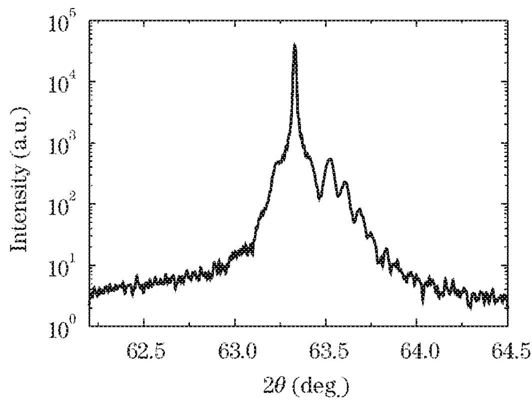

Fig. 2. Measured (004) rocking curve of the graded tensile-strained InGaAs structure.

compared with conventional tensile-strained bulk InGaAs, which indicates much different tensile strain was introduced into the grown InGaAs structure. The different tensile values are 0.13% ($2\theta = 63.52°$), 0.19% ($2\theta = 63.61°$), and 0.25% ($2\theta = 63.69°$), respectively. According to the experimental result, we can conclude that grade tensile-strained bulk InGaAs layer was fabricated. Meanwhile, from Fig. 2 we can see that the grown symmetric graded tensile-strained InGaAs bulk can also have a good device quality.

In order to partly eliminate the Fabry-Perot resonance and to reduce lateral current leakage, we fabricated the tilted-stripe and buried SLDs with typical processing techniques. The 2.5-μm-wide mesa stripes which are tilted at 7° from the normal to the cleaved facet were formed by combination of dry etching and wet chemical etching, and then buried by p- and n-type InP layers. Lastly, 2-μm-thick p-InP cladding layer and 0.2-μm-thick p^+-InGaAs contact layer were grown. Then, Ti/Pt/Au was evaporated for the metal contact to the p^+-InGaAs layer. The substrate was thinned to a thickness of about 100 μm and AuGe/Ni/Au was deposited for the n-type contact. After this, the SLD wafer was cleaved apart to be a lot of bars. The cavity length of the bar is about 800 μm and both facets were coated with a single layer of antireflective coating (ARC) to suppress the residual reflection from the end facets further.

We measured the characteristics of the fabricated SLDs. Figure 3 shows the measured output light power versus current (P-I) characteristics of the graded tensile-strained bulk InGaAs SLD under room temperature continuous wave (CW) operation. An output power of 13.6 mW is obtained at 200-mA injection current under CW operation. This output power is great enough for many applications, but less than that of high-power SLDs with tapered active region[1]. This may be due to a narrower active stripe. So, optimization of p-electrode is necessary to realize higher power and broader spectrum SLDs with graded tensile-strained bulk InGaAs. Namely, we will fabricate high power SLDs with tapered active region. This work is currently going.

The measured emission spectrum of the fabricated SLD at injection current of 200 mA under room temperature CW operation is demonstrated in Fig. 4. Very little spectral modulation is observed due to very small residual facet reflectivity, which also indicates that lasing is

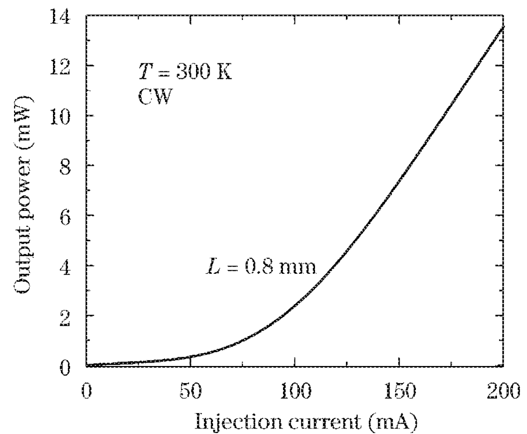

Fig. 3. *P-I* characteristics of graded tensile-strained InGaAs SLD.

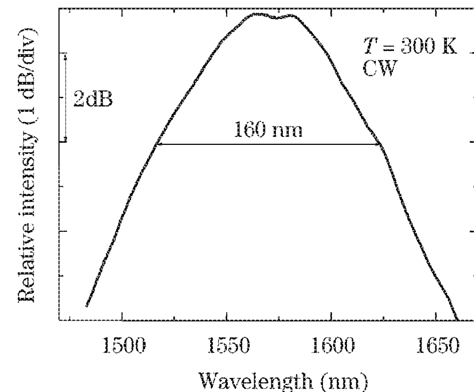

Fig. 4. Emission spectrum of graded tensile-strained InGaAs SLD at the injection current of 200 mA.

well suppressed by combination of tilted stripe and single layer ARC. A flat spectrum is attained and the FWHM of the spectrum is 106 nm at the injection current of 200 mA, covering the range of 1516−1622 nm, which is more than 2 times of that of the conventional SLD[9]. From the experimental results, we can conclude that the SLDs with graded tensile-strained bulk InGaAs can produce a wide and flat spectrum width. This is mainly due to different strain corresponding to different energy gaps. It is worth noting that the developed symmetrical graded tensile-strained bulk InGaAs structure is also very suitable to fabricating wide-band semiconductor optoelectronic devices such as semiconductor optical amplifiers and tunable semiconductor lasers.

In conclusion, a novel broad-band spectral width long wavelength SLD with symmetrical graded tensile-strained bulk InGaAs is developed. The graded tensile-strained bulk InGaAs is fabricated only by quasi-linearly variation of group-III TMGa source flow during the LP-MOVPE. The broad and flat emission spectrum is achieved by controlling the transition energy difference between the maximum and the minimal tensile regions. The measured FWHM spectral width of the fabricated SLD is 106 nm at an injection current of 200 mA, and the output light power is 13.6 mW. This structure is found to be quite effective for broadening the spectral width, although further study is required to realize higher power. More important, the wide and flat spectral width,

hence the short coherence length, improves the noise performance of devices such as fiber gyroscopes. The presented structure is also very suitable for other wide-band semiconductor optoelectronic devices application, such as semiconductor optical amplifiers and tunable semiconductor lasers.

The authors would like to thank Prof. Yutian Wang for XRD measurements. This work is financially supported by the National Natural Science Foundation of China (No. 90101023) and the National "973" Project of China (No. G20000683-1). S. Wang's e-mail address is shrw@red.semi.ac.cn.

References

1. T. Yamatoy, S. Mori, F. Koyama, and K. Iga, Jpn. J. Appl. Phys. **38,** 5121 (1999).
2. L. Goldberg and D. Mehuys, Electron. Lett. **30,** 1682 (1994).
3. G. T. Du, C. D. Xu, Y. Liu, Y. S. Zhao, and H. S. Wang, IEEE J. Quantum Electron. **39,** 149 (2003).
4. D. C. Heo, J. D. Song, W. J. Choi, J. I. Lee, J. C. Jung, and I. K. Han, Electron. Lett. **39,** 864 (2003).
5. A. T. Semenov, V. R. Shidlovski, and S. A. Safin, Electron. Lett. **29,** 854 (1993).
6. C. F. Lin and B. L. Lee, Appl. Phys. Lett. **71,** 1598 (1997).
7. B. R. Wu, C. F. Lin, L. W. Laih, and T. T. Shin, Electron. Lett. **36,** 2093 (2000).
8. C. F. Lin, B. L. Lee, and P. C. Lin, IEEE Photon. Technol. Lett. **8,** 1456 (1996).
9. Y. Noguchi, H. Yasaka, O. Mikami, and H. Nagai, J. Appl. Phys. **67,** 2665 (1990).