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# Long-wavelength Strained MQW Lasers

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Improved performance of long-wavelength laser diodes (LDs) using strained multiple quantum well (MQW) active layers are reviewed. High-power output was experimentally demonstrated in the compressively strained InGaAsP MQW LD at 1.48 μm. For high speed characteristics with small chirp, advantage of InGaAsP/InGaAsP MQW structure was examined in 1.55 μm distributed feedback (DFB) LDs. Polarization insensitive optical amplification was achieved by use of a tensile- strained MQW structure.

## 1. Introduction

The material science and technology have been pushing laser diode (LD) performance. In particular, materials of active layers have been improved to achieve higher performance. In recent years, multiple quantum well (MQW) structures have been widely used as active layers in high performance lasers. The long-wavelength LDs are currently standing at a frontier of optoelectronics such as high speed and high capacity transmission systems. More improvements of performance of long-wavelength LDs are required for the future systems. The LD performance such as spectral stability, modulation speed, lasing threshold and so on are mainly limited by active layer materials, because the structure and fabrication technology are already mature for the conventional long-wavelength MQW LDs. Recently, strained MQW structures is attracting the attention as potential active layer materials. The strained MQW structures can provide attractive electronic properties due to both two dimensional quantum confinement and strain induced modification in the electronic structure. In this paper, we describe experimental demonstrations of improvements of performance in the long-wavelength LDs and optical amplifiers using the strained MQW structures.

## 2. Scheme of LD performance improvement using strained MQW structure

The improvement of LD performance using strained MQW structure as a active layer material is based on its electronic structure modified by the strain. The compressive strain introduced into the well layers by the lattice-mismatched well layers usually InGaAs or InGaAsP which modifies the electronic structure of the well materials. To maintain the particular wavelength, the well width is thinner than that of unstrained well because of its larger lattice constant
which corresponds to wider band gap. On the same time, band-offset of the conduction band become larger and splitting between heavy-hole (HH) and light-hole (LH) are increased by the compressive strain. The strain also reduces the hole masses. These modifications in the electronic structure can provide some changes of device parameters such as small valence band density of states (DOS), narrow gain spectral width, enhancement of TE mode, large differential gain, suppression of Auger transition, and reduction of leakage current. Then, some improvements can be expected as shown in Fig. 1. First proposal in the improvement of LD performance using the compressively strained MQW structure has been the reduction of lasing threshold.[1] Some improvements including narrow spectral linewidth, high speed modulation and so on have been also theoretically predicted and experimentally demonstrated. We have experimentally demonstrated the improvements of performances of LDs and semiconductor optical amplifiers (SOAs) using compressively and tensile strained MQW structures as described in the following sections.

3. High Power Laser

By use of compressively strained MQW structure, the internal loss due to nonradiative Auger recombination and intraband valence band absorption can be reduced. Then, output power characteristics will be improved. We tried to demonstration of high power output from the compressively strained MQW LD lasing at 1.48 μm which is a particular wavelength for pumping Er-doped fiber amplifier. A buried heterostructure was grown by three step MOVPE. The active layer was all quarternary strained MQW structure involving 1.5 % compressive strain in the well layers with separate confinement heterostructure (SCH).[2] The all quarternary InGaAsP/InGaAsP structure is useful for changing the strain maintaining a particular wavelength. Light output versus injection current (L-I) characteristics were measured on 1.5 mm long lasers with anti- and high-reflection (AR and HR) coatings. A maximum output power was as high as 240 mW at 20 °C and the continuous wave (CW) operation was obtained up to 90 °C. The slop efficiency was 0.31 mW/mA. This value is as similar as that of unstrained MQW LDs. However, the saturation power was 20 - 30 % higher than that of the unstrained MQW LD. The output power of the long-wavelength LD is generally limited by the internal loss. For the higher maximum power of the compressively strained MQW LD, it is expected that the internal loss was suppressed by the compressive strain.

4. High Speed Compressively Strained MQW DFB Laser

An extremely high relaxation frequency ($f_r$) in the compressively strained MQW LD has been theoretically predicted.[3] A large differential gain originating from low threshold current due to small hole effective mass provides an improvement of relaxation frequency. In addition, the linewidth enhancement factor (α parameter) is also improved, and then a smaller chirp and a narrower linewidth of lasing spectrum can be expected. We tried to examine these effects of active layer structures of high speed DFB LDs. Two differential strained MQW structures were employed; first was the compressively strained InGaAs/InGaAsP MQW (TSL) structure and other was InGaAsP/InGaAsP MQW (QSL) structure. The number of well was designed to obtain same optical confinement on both structures. The carrier life time is an important parameter for the relaxation frequency. To obtain a high relaxation frequency, the short carrier life time should be combined with a large differential gain which can be obtained on the compressively strained MQW LD. The carrier life time was measured on the unstrained and the two different strained MQW LDs. The smallest carrier life time was obtained on the QSL LD. Therefore, the QSL LD is better to attain the high speed operation compared with the TSL LD. This criterion was experimentally examine. The narrowest chirp width of QSL LD was as small as 0.2 nm.[4]

Compressively strained InGaAs/AlInGaAs MQW LD was fabricated as an another version of the strained MQW LD. An stronger quantum confinementdue to large band offset is expected on this type of MQW structure. A large differential gain was obtained to be $6.53 \times 10^{-16}$ $cm^2$. The slope of resonant frequency against the output power was 3.5 $GHz/mw^{1/2}$. The maximum resonant frequency of 26 GHz is estimated from the maximum output power of 57 mW.[5]

5. Polarization Insensitive Tensile Strained MQW Optical Amplifiers

Polarization insensitive operation of SOA is required for integration with passive and active optical devices having different mode-propagation characteristics. So far, the the propagation mode in the SOA has been controlled by geometric structure of active waveguide such as square shaped waveguide. On the other hand, recently the polarization insensitive optical amplification has been demonstrated on the SOA with a tensile-strained MQW active layer. The strain in the MQW structure can control the mode-gain through the controlled band mixing between the HH and the LH bands. We fabricated the SOAs with tensile-strained MQW structures. Signal gain characteristics were measured on the unstrained, 0.2 %, and 0.4 % strained MQW SOAs. The polarization insensitive amplification was obtained on the 0.2 % tensile-strained MQW SOA with a device length of 350 μm.[6] It is expected that the polarization characteristics of this type of SOA is sensitive to the carrier concentration. This criterion was verified by the measurements of device length dependence of amplified spontaneous emission (ASE) peak intensity for the TE and the TM modes. We found that to achieve the polarization insensitive amplification in the tensile strained MQW SOA both strain and device length should be optimized.[7]

6. Summary

Recent experimental results of improvements of performance on the long-wavelength strained MQW LDs and SOAs are reviewed. In the compressively strained MQW LDs, advantage of performance on the high power, high speed, and spectral stability characteristics were successfully verified. The polarization insensitive optical amplification was accomplished by the tensile strained MQW structure in the SOA.

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