Highly-Strained InGaAs/GaAs Single-Quantum-Well Lasers Grown by Molecular Beam Epitaxy*

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Abstract: Highly stained InGaAs/GaAs Quantum Wells (QW) are grown by using molecular beam epitaxy. The room-temperature photoluminescence (PL) peak wavelength as long as 1160nm is obtained from QW with the In composition of 38% and the well width of 6.8nm. The full-width at half-maximum of the PL peak is 22meV, indicating a good quality. InGaAs/GaAs QW ridge-waveguide lasers with emission wavelength of 1120nm are demonstrated. For 100-μm-wide ridge-waveguide lasers with a cavity length of 800μm, the kink-free output power up to 200mW is achieved with the slope efficiency of 0.84mW/mA under the continue-wave operation. For 10μm-wide ridge-waveguide lasers, the lowest threshold current density of 450A/cm^2 and the characteristic temperature of 90K are obtained.

Key words: InGaAs; molecular beam epitaxy; high strain; quantum well laser

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1 Introduction

Strained InGaAs/GaAs Quantum Wells (QWs) are widely used as active layers for GaAs-based devices. Laser diodes emitting at 980nm are used for pumping the Er-doped fiber amplifiers[1,2]. Longer wavelengths have found increasing interest to be used in pumping lasers, the replacement of Nd∶YAG lasers, for Pr-doped fiber amplifiers or short-distance optical fiber communications. For these applications, a high In composition in QW is necessary. However, In composition is generally limited to 0.25 due to the surface segregation of In atoms[3]. High strain is introduced in the structure to increase the In composition. The strain affects not only the defect formation but also the In incorporation during the growth[4,5]. When the strain exceeds a critical value, the InGaAs layer starts to relax due to the formation of misfit dislocations[6], and the growth mode changes from two-dimensional (2D) to three-dimensional (3D)[7]. Even when the strain is less than the critical value, defects can be formed, which are the remainders of InAs-rich clusters created due to the excess In supply[5]. This cluster formation also limits the In incorporation into the InGaAs layers. Though many methods have been adopted to extend the wavelength of InGaAs QW laser[8—11] such as using a surfactant, a high growth rate and a low growth temperature, it is still difficult to obtain the lasers with the wavelength exceeding 1060nm. Compared with Metal-Organic Chemical Vapor Deposition (MOCVD)[10], Molecular Beam Epitaxy (MBE)

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has some unique advantages to grow highly strained quantum wells[12], including in-situ monitoring of the growth mode, accurate control of the layer thickness and composition, lower growth temperature, super-high vacuum, etc. This paper describes the growth of highly strained $In_xGa_{1-x}As/GaAs$ QW laser by using MBE. The lasing wavelength of 1120nm has been achieved.

2 Experimental Procedures

The growth was carried out in a VG-80H MKII MBE system. Metallic Ga, In and Al were used as the source materials. Be and Si were used as p and n dopants, respectively. As_2 was supplied from a cracker source. The laser structures were grown on n-type GaAs (100) 4°-off substrate. There is a 6.5-nm-thick InGaAs strained layer sandwiched between two 100-nm-thick GaAs guide layers in the active layers. The cladding layers were 1.5μm-thick n- and p-type $Al_{0.35}Ga_{0.65}As$ layers with doping concentration of 4×10^{17} and 5×10^{17} cm^{-3}, respectively. A 0.5μm-thick n-GaAs buffer layer and 0.2μm-thick p^+-GaAs cap layer were also incorporated. Photoluminescence (PL) characteristics were measured by using an Ar^+ laser and a Ge detector. In compositions could be determined by simulating the measured X-ray rocking curves.

3 Results and Discussion

The surface segregation of In atoms strongly affects the In incorporation into a strained InGaAs layer. The segregation can be suppressed by changing the growth conditions, such as by lowering the growth temperature, increasing the growth rate or V/III ratio. However, low growth temperature or high growth rate will result in an insufficient migration of In and Ga atoms on the growth surface, which is the reason for bad quality. In our growth, the optimum growth temperature and growth rate for InGaAs layers with In composition around 30% are 460℃ and 1μm/h, respectively. After growing the well layer, but before the substrate temperature is increased to the required growing temperature, a 2nm-GaAs layer is grown at the same temperature of 460℃ to obtain the GaAs and AlGaAs of good quality. The 2nm-layer can reduce the segregation of In atoms to following layers.

Highly strained InGaAs/GaAs QWs with an In composition over 30% are more sensitive to surface quality than that with a low In composition[9]. The surface quality of the interface, on which the highly strained InGaAs/GaAs QWs are grown, affects not only the quality of QW but also the In incorporation in the QW. Poor surface quality can cause a transition from 2D to the 3D growth mode. Poor surface quality is described as an interface that contains some areas, which may include some uneven parts of the degraded surface, so that the migrating In atoms can be preferentially incorporated at hillocks where they are bonded to fewer neighbors and thus can partly relax. Furthermore, the areas around the threading dislocations may be plastically relaxed and the migrating In atoms be preferentially incorporated into the relaxed area. To improve the surface quality of the interface, considering the poor quality of GaAs grown at a low temperature and high V/III ratio, the transition time of the growth temperature and the V/III ratio before growing the InGaAs layer should be as short as possible.

Figure 1 shows typical PL spectra from highly strained QW samples at room temperature. The PL peak wavelength of 1160nm has been achieved. The In compositions in these two samples are 32% and 38%, respectively. The corresponding strains are 2.24% and 2.65%, respectively. Despite of high strain, the PL peak intensities of highly strained QWs are comparable with that of a 980nm-InGaAs/GaAs QW. The full-width at half maximum (FWHM) of PL peaks are 13meV and 22meV, respectively, indicating a good quality.

Figure 2 shows the schematic of highly strained InGaAs/GaAs QW ridge-waveguide lasers. The laser structures are formed by using the

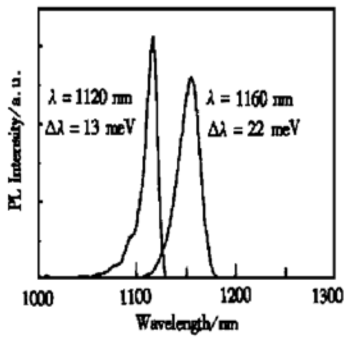

FIG. 1　Room Temperature PL Spectra of Highly Strained InGaAs/GaAs QWs

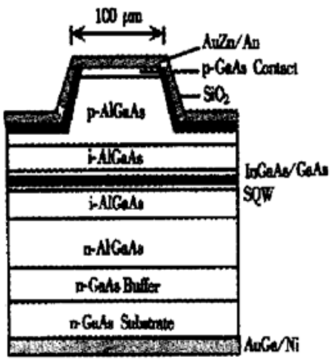

FIG. 2　Schematic Structure of InGaAs/GaAs QW Ridge-Waveguide Laser

standard photolithography and wet-chemical etching techniques. Conventional AuZn and AuGe/Ni metallisation are used for the p- and n-type contacts. Highly reflective [(HR), 90%] and antireflective [(AR), ~ 5%] optical films are applied to the rear and front laser facets. The fabricated devices are mounted junction-side up on the copper heatsinks.

Figure 3 (a) shows the room temperature *L-I* characteristic of a 100μm × 800μm ridge-waveguide laser under continue-wave operation. The kink-free output power is up to 200mW with the slope efficiency of 0.84mW/mA (The maximum output power is limited by the measurement system). The peak emission wavelength is 1120nm at room temperature (Fig. 3(b)). The operation voltage and series resistance are relatively high. It is perhaps due to the unoptimized doping profile of AlGaAs cladding layers and GaAs cap layer. Figure 4 shows the dependence of the threshold current density on the reciprocal cavity's length of a 10μm × 800μm ridge-waveguide laser. An increase of the threshold current density with the decreasing of cavity length can been seen. The lowest threshold current density is $450A/cm^2$. The temperature dependence on the threshold current of this laser is shown in Fig. 5. The threshold current increases from 65 to 142mA when the temperature rises from 20 to 100℃. The resulting characteristic temperatures (T_0) are approximately 90 and 70K, respectively, at the operation temperature below or above 75℃. The threshold current density is relatively high compared with that of 980nm InGaAs/GaAs QW lasers, as is partially due to the unoptimized laser structure. Through the optimization of the thickness and Al composition of AlGaAs cladding layers, improved performance is achieved as anticipated. T_0 can be further improved by reducing the thickness of GaAs guide layers to suppress the carrier leakage.

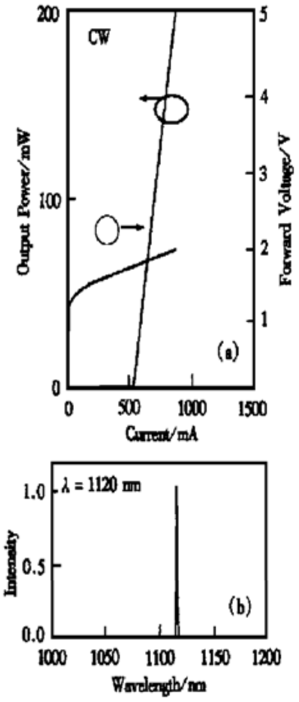

FIG. 3　(a) *L-I* Characteristics and (b) Lasing Spectrum of a 100μm × 800μm Ridge-Waveguide InGaAs/GaAs QW Laser

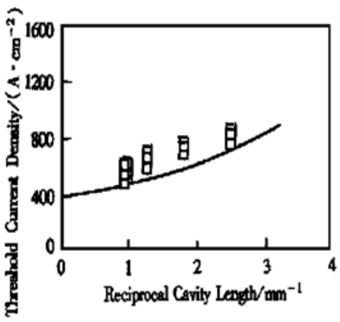

FIG. 4 Dependence of Threshold Current Density on Reciprocal Cavity Length of a $10\mu m\times800\mu m$ Ridge-Waveguide Laser

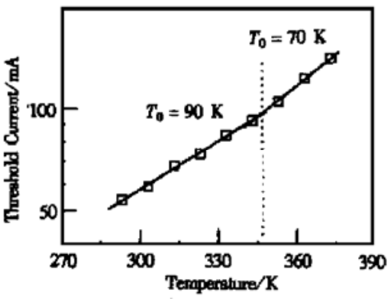

FIG. 5 Temperature Dependence of Threshold Current of a $10\mu m\times800\mu m$ Ridge-Waveguide Laser

4 Conclusion

We have grown highly stained InGaAs/GaAs QWs by MBE. The room-temperature PL peak wavelength of InGaAs/GaAs QW has been extended to be 1160nm with the PL peak FWHM of 22meV. The ridge-waveguide QW lasers with emission wavelength of 1120nm are successfully demonstrated. For 100μm-wide ridge-waveguide lasers with a cavity length of 800μm, the kink-free output power up to 200mW has been achieved under the continue-wave operation with the slope efficiency of 0.84mW/mA. For 10μm-wide ridge-waveguide lasers, the lowest threshold current density is $450A/cm^2$. The characteristic temperature is approximately 90 and 70K, respectively, for the operation temperatures below and above 75℃.

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分子束外延生长高应变单量子阱激光器*

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摘要：采用分子束外延方法研究了高应变 InGaAs/GaAs 量子阱的生长技术．将 InGaAs/GaAs 量子阱的室温光致发光波长拓展至 1160nm，其光致发光峰半峰宽只有 22meV．研制出 1120nm 室温连续工作的 InGaAs/GaAs 单量子阱激光器．对于 100μm 条宽和 800μm 腔长的激光器，最大线性输出功率达到 200mW，斜率效率达到 0.84mW/mA，最低阈值电流密度为 450A/cm^2，特征温度达到 90K．

关键词：InGaAs；分子束外延；高应变；量子阱激光器

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