High power AlGaInP laser diodes with zinc-diffused window mirror structure

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The technology of zinc-diffusion to improve catastrophic optical damage (COD) threshold of compressively strained GaInP/AlGaInP quantum well laser diodes has been introduced. After zinc-diffusion, about 20-μm-long region at each facet of laser diode has been formed to serve as the window of the lasing light. As a result, the COD threshold has been significantly improved due to the enlargement of bandgap by the zinc-diffusion induced quantum well intermixing, compared with that of the conventional non-window structure. 40-mW continuous wave output power with the fundamental transverse mode has been realized under room temperature for the 3.5-μm-wide ridge waveguide diode. The operation current is 84 mA and the slope efficiency is 0.74 W/A at 40 mW. The lasing wavelength is 656 nm.

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Since the room-temperature continuous wave (CW) operation was firstly achieved in 1985[1], AlGaInP visible light laser diode (LD) oscillating in the 650-nm wavelength range has attracted much interest as light source for optical information processing systems such as digital video disk (DVD). For rewritable optical disk system (DVD-RW) usage, the output power should be higher than 30 mW. The maximum output power of AlGaInP-based LD is limited by catastrophic optical damage (COD)[2]. When the optical density at the mirror facet reaches a threshold level, COD occurs due to optical-absorption-induced thermal runaway at the laser mirror facet. In recent years, compressively strained quantum well lasers have been widely used because of their superiority in many aspects such as reduction of the threshold current. But one of the disadvantages of this laser structure is the inevitable bandgap shrinkage in the vicinity of laser facet due to the stress release[3], which leads to larger possibility of COD in such LDs. Therefore, it is important to improve the COD threshold to enable high power operation, especially for compressively strained quantum well LDs.

There are several methods to enhance the COD threshold, such as: 1) cleaving and coating lasers in vacuum circumstance, which has the disadvantages of the difficulty in technical realization and the requirement for costly equipment. 2) Passivating the laser facet by some special materials[4]. 3) Coating the laser facet with suitable film[5−7]. 4) Adopting the strain-compensated active layer, which means the strain type of the well and barrier is different to each other[8]. 5) Forming a window mirror structure in the vicinity of the laser facet[2,9]. LDs with window structure are made by simultaneously enlarging the bandgap near the facet and keeping that of the other region along the cavity unchanged. Because of the wider bandgap in the vicinity of the facet, light can go out with little optical absorption.

In this letter, COD threshold of compressively strained AlGaInP LDs is dramatically improved by adding a Zn-diffused window mirror structure. As a consequence, the output power of the fundamental transverse mode is also improved to be higher than 40 mW.

Figure 1 shows a schematic structure of the AlGaInP dual-channel ridge waveguide LDs with window mirror structure. The epitaxial growth of the laser was carried out by one-step metal organic chemical vapor deposition (MOCVD) technique using a 15° misoriented GaAs substrate. The resulted structure consists of a Si-doped n-GaInP buffer layer, a Si-doped n-AlGaInP cladding layer, the undoped compressively strained multi quantum well (MQW) active layers, a Zn-doped p-AlGaInP first upper cladding layer, a Zn-doped p-GaInP etching-stopper

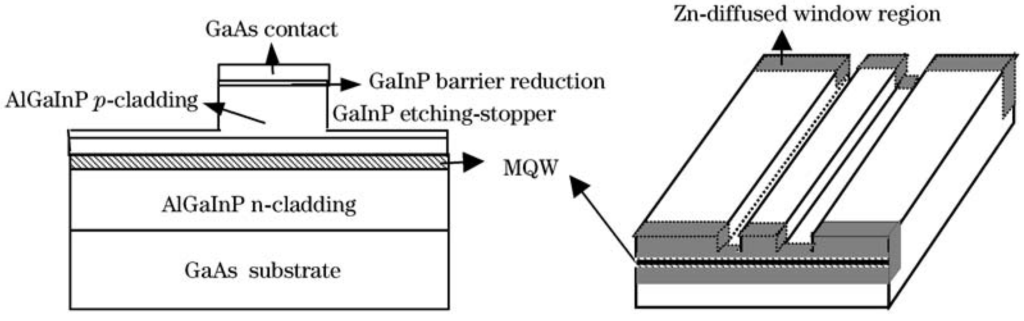

Fig. 1. Schematic structure of the AlGaInP LD with window mirrors.

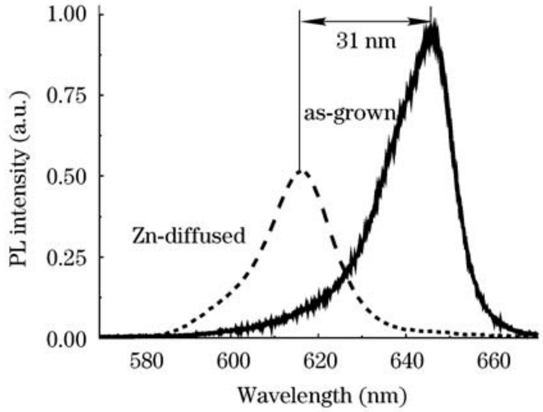

Fig. 2. Room temperature PL spectra of GaInP/AlGaInP QW for the as-grown (solid line) and Zn-diffused (dashed line) samples.

layer, a Zn-doped p-AlGaInP second upper cladding layer, a Zn-doped p-GaInP barrier reduction layer, and a Zn-doped p-GaAs contact layer.

After MOCVD growth, the window mirror structure was formed in the vicinity of both facets by selective Zn diffusion into the MQW active region. The Zn atoms diffused through the quantum wells (QWs) and stopped at the n-type AlGaInP cladding layer. And the Zn concentration of MQW was estimated about $8\times10^{17}/\text{cm}^3$. The behavior of Zn diffusion in the GaInP active layer was investigated. Figure 2 shows the room-temperature photoluminescence (PL) spectra of the diffused (dashed line) and as-grown MQW structures (solid line). As can be seen from this figure, compared with that of the as-grown MQW, the PL peak of the diffused MQW shifts toward shorter wavelength due to the compositionally disordered MQW and the blue shift is 31 nm, corresponding to 96 meV of bandgap enlargement. In the Zn diffusion process, the amount of the blue shift is related to the Zn concentration of the MQW, but at the same time the diffused Zn atoms serve as the non-radiative recombination centers, which will deteriorate the device performance. So the two aspects should be well balanced. The quality of the diffused MQW material was good as indicated by the full-width at half-maximum (FWHM) of the photoluminescence curves.

After Zn diffusion, a 3.5-μm-wide ridge-waveguide was formed using a selective wet chemical etching technique. The cavity length including the window regions was 600 μm and each window region was 20 μm long. Ohmic contacts were formed with Ti/Pt/Au for the p side and AuGeNi/Au for the n side after the Zn-diffused region was insulated by a SiO_2 layer to prevent the leakage current from flowing into the window region. After cleaving processing, an anti-reflection (10%) coating and a high-reflection (90%) coating were formed on the front and rear facets, respectively. The laser chip was mounted on Si heat sink in a junction down configuration. For comparison, similar LDs without window mirror structure were fabricated with the same process.

All LDs were tested under CW operation at room temperature. Figure 3(a) shows the light output power-current (*P-I*) characteristics of the conventional non-window LD, in comparison with that of the LD with window mirror structure, as shown in Fig. 3(b). In the case of the non-window structure, the COD threshold was lower than 30 mW and averaged at 25 mW. In comparison, the COD threshold of the LD with window structure was improved by about 80%, and reached 45 mW in average.

The threshold current for the window and non-window structure was nearly the same. The external efficiency

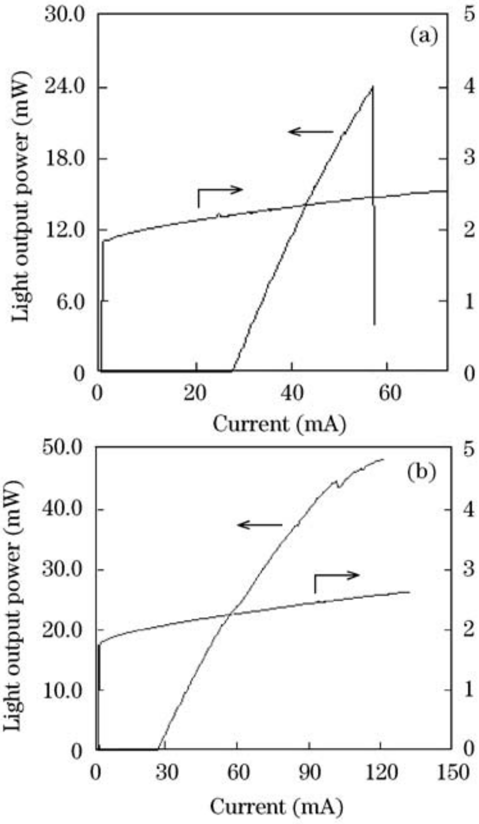

Fig. 3. *P-I* characteristics of LDs without (a) and with (b) window structure.

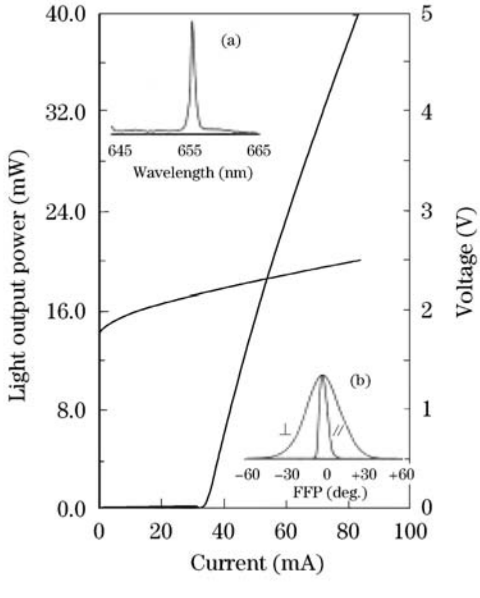

Fig. 4. *P-I* characteristics of LDs with window structure. The insets show the lasing spectrum (a) and FFP (b) at 40-mW output power.

of the window LD was slightly lower than that of the non-window LD, which was maybe due to the waveguide losses of the Zn-diffused window region.

A kink-free *P-I* curve up to 40-mW output power with a lasing wavelength of 656 nm was obtained for the window mirror structure, as shown in Fig. 4. At this output power, the operating current is 84 mA and the slope efficiency is 0.74 W/A. A typical far-field pattern (FFP) is shown in the insets of Fig. 4 and the FWHMs of the FFP for parallel and vertical angles to the junction plane are 11° and 33°, respectively.

In summary, the window mirror structure is effective to obtain a high COD level for the compressively strained AlGaInP LDs. 40-mW CW output power was achieved for the LDs with a window mirror structure by Zn-diffusion induced MQW disordering. In addition, for DVD-RW usage, other requirements such as small beam aspect ratio and high temperature high current operation are also important for this product and these parameters should be improved in future work. Aging experiments of the Zn-diffused LDs are under work now.

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