High Power Coupled Large Cavity Lasers and Multi-active Light Emitting Diodes*

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Abstract

For increasing laser diode (LD) output power, improving laser beam quality and enhancing the light emitting diode (LED) brightness, the coupled large optical cavity semiconductor lasers and multi-active LEDs with tunneling-regenerated current transport have been presented and experimented. Both the external and differential quantum efficiency and both the LD's output power and the LED's brightness are together increasing approximately with the number of the active regions. The very high power LDs and the very high brightness LEDs working in the low injecting current and also the fundamental mode stimulated light with good beam quality have been achieved in our laboratory.

1. Problem and Physical Mechanism

High power semiconductor InGaAs/GaAs LDs and high brightness AlGaInP LEDs have been extensively paid attention(1,2) due to their very wide and important applications. The problems of traditional LDs to obtain high output power are the lower catastrophic mirror damage (COD) level at high light power density, electro-thermal destroy under high injecting current and worse light beam quality due to thin line-like active region which results in strong diffraction(3, 4, 5), as shown in Fig.1a. The brightness of the traditional LEDs is limited by two facts (6, 7) : 1. Large leakage current because of small band offset between active region and p-confining layer. 2. Due to the dopant Zn diffusion during the growth, non-radiation recombination occurred in the interface of active region and p-cladding layer which is indirect band gap material. Overheat caused by non-radiation recombination would decrease the quantum efficiency and then the brightness of LEDs. The schematic energy diagram is shown in Fig.1b.

Novel multi-active region tunneling regenerated LDs and LEDs are presented(8, 9, 10) that after recombination in the former active region, the electron will tunnel through the tunnel junction into next active region and then recombination again. Thus the inner quantum efficiency will increase with the number of active regions. Through proper design, separated active regions will couple into a uniform large optical cavity in the novel LDs, and the laser beam emit uniformly from a large area

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edge as shown in Fig.2, not a line for traditional LDs. Then the diffraction effect of traditional LDs is lessened by emitting from an area and the COD level of novel LDs is enhanced due to reduced light power density passing the large edge area. For LEDs, due to high inner quantum efficiency, the injection current can be much reduced compared that of the traditional LEDs. Then the leakage current and heating will lessen.

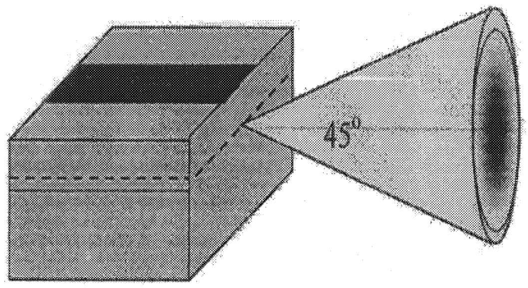

Fig.1a sketch map of traditional LD

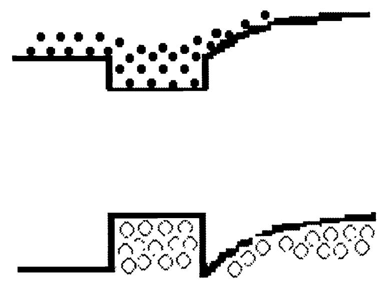

Fig.1b Energy band diagram of traditional heterostructure AlGaInP LEDs

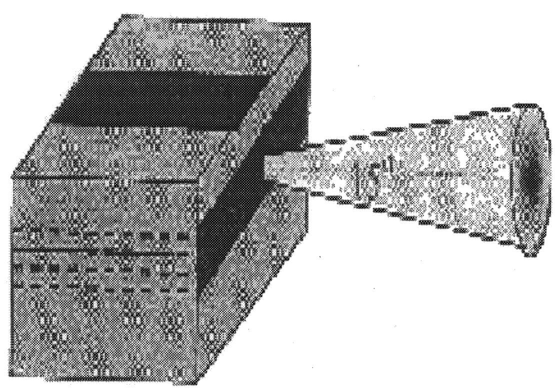

Fig.2 Coupled large optical cavity of novel LDs

2. Fabrication and Structure Properties

Both InGaAs/GaAs QW LD and AlGaInP LED epitaxial layer structure were grown by low-pressure MOCVD on n-GaAs substrate. The (100) GaAs substrate was oriented at 2° off the <110> direction for LDs while 15° for LEDs. TMGa, AsH_3, PH_3, TMAl, TMIn were used as precursors. SiH_4 diluted in hydrogen and liquid CCl_4 were used as donor and acceptor dopants respectively for reversed GaAs tunnel junction that is sandwiched between the two active regions. Ti/Au and Au/Ge/Ni were used as p-type and n-type contact materials respectively. The sizes of the novel LDs and LEDs are 100 μ m *600 μ m, 300 μ m*300 μ m respectively.

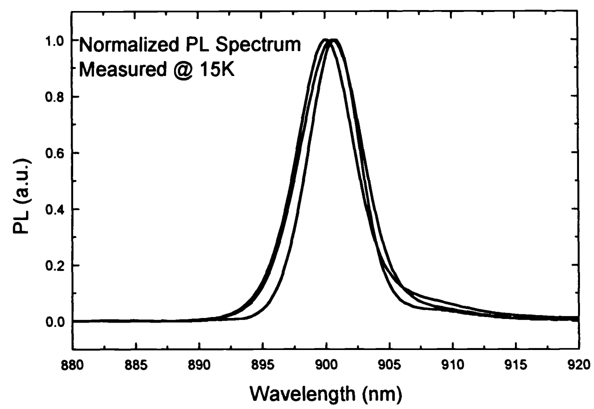

Fig.3 the PL result of novel LDs with three active regions

	FWHM	Peak WL
upper	5.46nm	900.0nm
middle	5.91nm	900.6nm
bottom	4.85nm	900.9nm

Table 1 the detail data of PL result of Fig.3

Fig.3 is the photoluminescence (PL) spectrum at 15K of novel semiconductor laser with three active regions. Each quantum well active region was measured by etching down the upper one. The data in table 1 illuminate that the minimum FWHM is 4.85nm and maximum difference of peak wavelength is 0.9nm, which means that the good quality and uniformity of the three quantum wells and makes sure to get coherent optical gains.

One of the key to realize the novel LD is to get high quality tunnel junction. GaAs tunnel diode was fabricated using carbon as p-type dopant which is with very low diffusion coefficient and high doping concentration. Current-Voltage curves of the devices at the temperature of 77K and 300K were measured and the typical one is shown in Fig.4.

3. Device Performances

3.1 Performance of LD

The novel laser diodes with different number of active regions have been fabricated and their output power, slope efficiency and quantum efficiency were measured as shown in Fig.5. With increasing the number of active regions, the output power, slope efficiency and quantum efficiency increases linearly approximately. The output power of four active regions LD achieved nearly 5W at 2A.

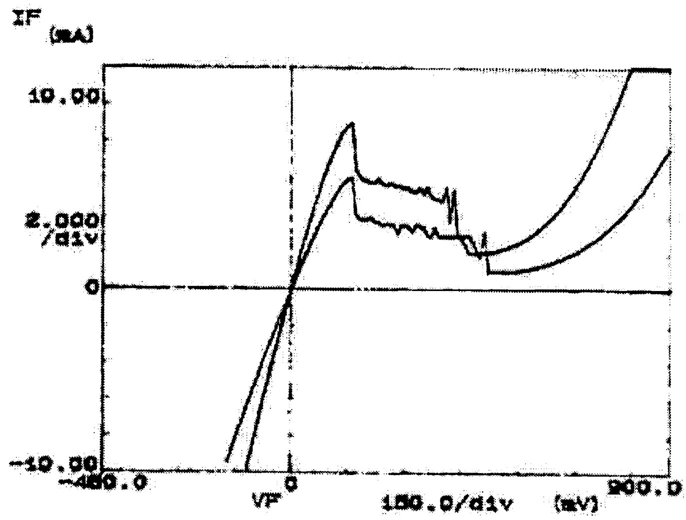

Fig.4 The typical I-V curve of GaAs tunnel junction at 77K and 300K

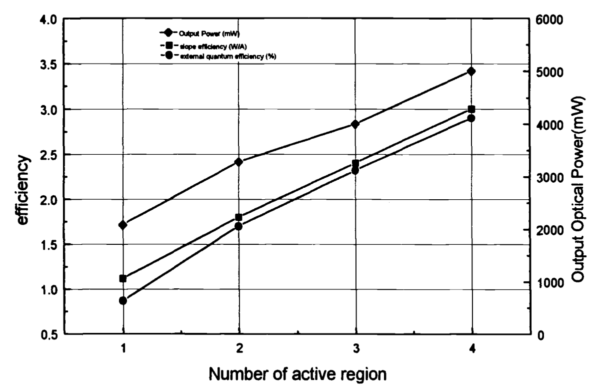

Fig.5 The influence of the number of active region on the novel laser power and efficiency

Based on the deep study of novel LD's waveguide behavior, a design was presented that enhanced couple of light in sub-active region and decreased optical absorption loss of tunnel junction. High quality material is indispensable. Fig. 6 is the far field divergence result. The size of LD is 100*700μm, the threshold current density is 586A/cm^2 and the perpendicular divergence of uncoated LD is only 15° .

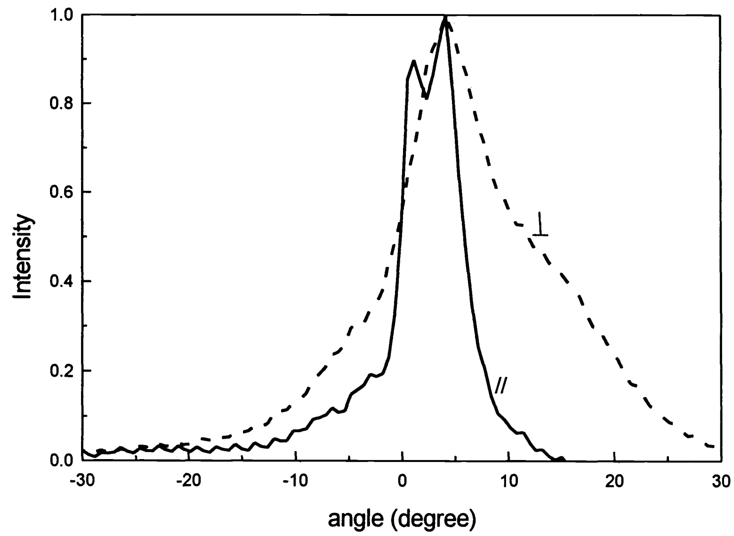

Fig.6 the far field result of novel LD

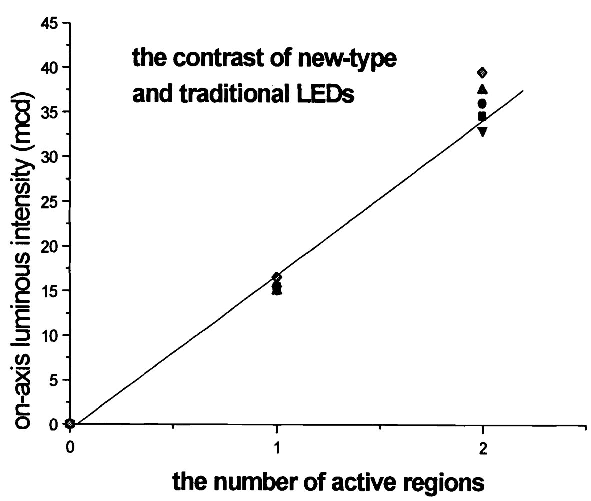

Fig.7 The contrast of brightness of new type LEDs and traditional LEDs

3.2 Performance of LEDs

The similar physical mechanism was applied in AlGaInP LEDs which have many merits as mentioned above. Fig.7 is the luminous intensity contrast results of the traditional and the novel LEDs which were fabricated and tested in the same condition. Novel LED's luminous intensity increases linearly with the number of active regions approximately. Fig.8 is the luminous intensity statistic of two active region 15° encapsulated LED with 3μm GaP current spreading layer at 20mA. The maximum is above 5cd.

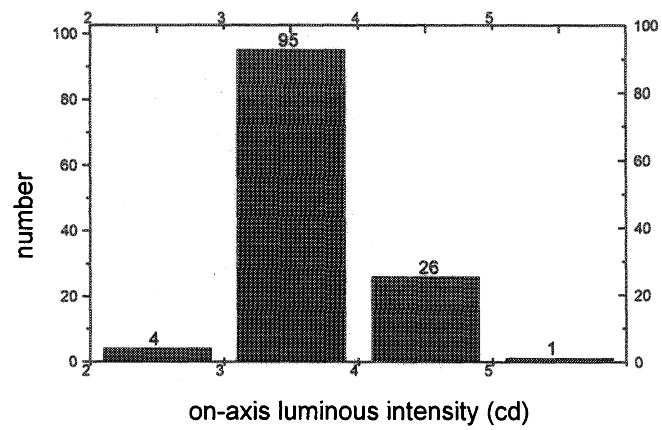

Fig.8 The statistic of novel LEDs

4. Conclusion

Novel coupled large optical cavity LDs and multi-active region tunnel-regenerated LEDs were presented and several experimental results were analyzed. The output power of four active regions LD can achieve 5W and the fundamental mode uncoated LD's perpendicular divergence is 15° . The luminous intensity of two active regions 15° encapsulated LEDs is above 5cd. The devices with high output power at low injection current were realized.

5. Acknowledgement

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