Epitaxy and Characteristics of Resonant Cavity LEDs at 650 nm*

Kang Yuzhu(康玉柱)†, Li Jianjun(李建军), Ding Liang(丁亮), Yang Zhen(杨臻), Han Jun(韩军), Deng Jun(邓军), Zou Deshu(邹德恕), and Shen Guangdi(沈光地)

(Beijing Optoelectronic Technology Laboratory, Beijing University of Technology, Beijing 100124, China)

Abstract: Resonant-cavity light-emitting diodes (RCLED) at 650 nm wavelength were grown by metal organic chemical vapor deposition. In order to improve the interface quality and reduce the device voltage, an AlGaInP material system has been chosen to grow the top DBRs. The emission properties of the RCLED were characterized by measuring PL and EL spectra. The average emission power of the device is 0.5 mW at 20 mA and 2.2 V, and its spectrum full width at half maximum is about 10 nm.

Key words: RCLED; MOCVD; PL spectrum; EL spectrum
DOI: 10.1088/1674-4926/30/5/054005 **PACC:** 7850G; 7855; 7860F

1. Introduction

With the development of optical fiber networks, short-range optical communication technology based on cheap POFs (plastic optical fibers) has developed rapidly[1, 2]. Compared with conventional LEDs, RCLEDs have many advantages such as higher output power, lower divergence of the output beams, better temperature stability and a narrower spectrum width[3]. Basically, an RCLED consists of three parts: a microcavity with an MQW active region and two parallel DBRs, which surround the microcavity[4]. According to the Purcell effect[5], the optical mode density in a microcavity will be redistributed. Some modes will be enhanced, and others will be inhibited. So the spontaneous emission in a microcavity can be preferentially directed to the emitting surface by an appropriate design of the structure, which will lead to a higher light extraction efficiency and a narrower optical spectrum.

For short-range optical interconnections, the RCLED of 650 nm wavelength, which corresponds to the low-loss band of POFs, is the ideal light source[6−8]. Generally, a 650-nm RCLED is fabricated on a GaAs substrate with AlGaInP materials used for the microcavity and $Al_xGa_{1-x}As/Al_yGa_{1-y}As$ used for the DBRs[9]. But due to absorption losses, AlGaAs DBRs are limited to wavelengths longer than 600 nm[10]. In addition, the control of the interface structure between AlGaInP and AlGaAs is difficult. So in this paper, we select an AlGaInP material as the top DBR to improve the RCLED properties.

2. Device fabrication

The schematic structure of our RCLED is shown in Fig. 1. The layers consist of (Ⅰ) 34-pair Si-doped $Al_{0.5}Ga_{0.5}As/AlAs$ n-type bottom DBR layers, (Ⅱ) a 80 nm undoped $(Al_{0.5}Ga_{0.5})In_{0.5}P$ phase match layer, (Ⅲ) an active region composed of three 5 nm wide undoped GaInP quantum wells separated by two 5 nm wide undoped $(Al_{0.5}Ga_{0.5})In_{0.5}P$ quantum barriers, (Ⅳ) an 80 nm undoped $(Al_{0.5}Ga_{0.5})In_{0.5}P$ phase match layer, (Ⅴ) 15-pair Mg-doped $(Al_{0.3}Ga_{0.7})In_{0.5}P/AlInP$ p-type top DBR layers, and (Ⅵ) a 0.5 μm GaP layer for current spreading and Ohmic contact. The device structure was grown by MOCVD (EMCORE Company) on Si-doped 2-inch GaAs substrates at about 700 °C. Gas sources include AsH_3, PH_3, and SiH_4, while liquid sources include TMAl, TMGa, and TMIn. The carrier gas was H_2, which has been purified by a Pd cell. After epitaxy, a ring electrode was formed on the top in order to spread the current towards the center, so that the light could be mainly generated from the center. Then as Purcell effect, most light could be extracted from the aperture located in the center. As a result, the luminous efficacy of the device was improved. The following manufacturing processes were similar to conventional LEDs.

3. Results and discussion

3.1. White reflection spectrum

Because of the importance of the top DBR in this

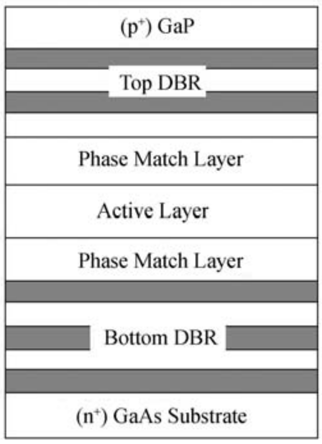

Fig. 1. Schematic structure of the RCLED.

* Project supported by the Science and Technology Plan of the Beijing Education Committee (No. KM200810005002) and the Funding for Academic Human Resources Development in Institutions of Higher Learning under the Jurisdiction of the Beijing Municipality.

† Corresponding author. Email: YuzhuK@emails.bjut.edu.cn

Received 27 September 2008, revised manuscript received 3 December 2008

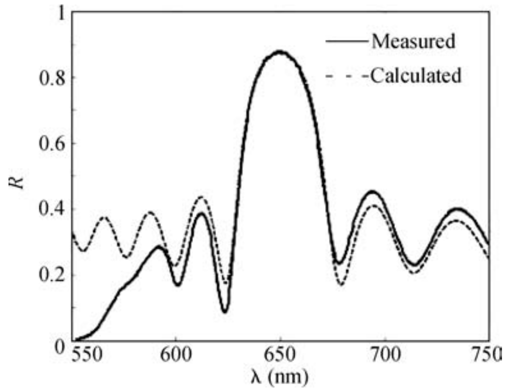

Fig. 2. Calculated and measured reflection spectrum of 15 pairs of AlGaInP/GaInP DBRs.

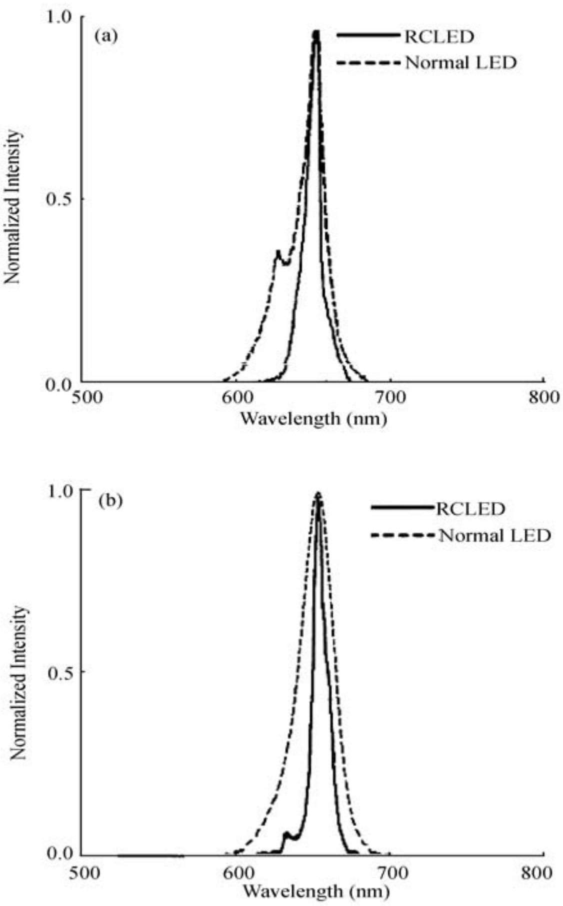

Fig. 3. (a) PL spectrum and (b) EL spectrum of the RCLED and the normal LED.

experiment, a 15-pair AlGaInP/AlInP DBR layer was grown separately. The white reflection spectrum of this DBR is shown in Fig. 2. The reflection curve peak is at 650 nm, which meets the requirements of the experimental design. Also shown in Fig. 2 are the simulation results calculated from the transfer matrix method[11], in which the dispersion relation of the $Al_xGa_{0.5-x}In_{0.5}P$ material[12] is estimated by

$$n(E, x) = \sqrt{\frac{E_0 E_d}{E_0^2 - E^2} + 1}, \qquad (1)$$

where $E_0 = 3.39 + 1.216x$, $E_d = 28.07 + 3.373x$, $E = 1240/\lambda$ (eV), and λ is the wavelength (unit: nm), respectively. The

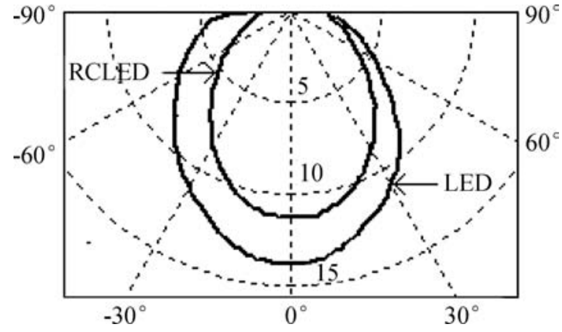

Fig. 4. Far-field strength as a function of angle of the RCLED and the traditional LED.

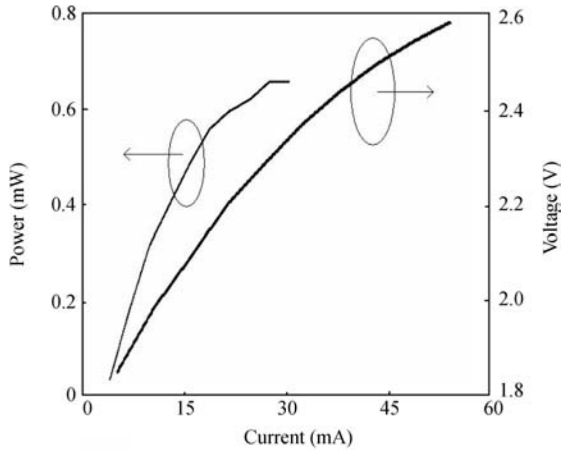

Fig. 5. Voltage–current and power–current characteristics of the device.

calculated and measured curves are basically the same. The difference between theory and experiment stems from the measurement sensitivity at shorter wavelength.

3.2. PL spectrum and EL spectrum analysis

Figure 3 shows a comparison between the EL and PL spectra of an RCLED and a conventional LED. The FWHM of the conventional LED is 20 nm, while the FWHM of the RCLED is less than 10 nm. If the number of the pairs of the top DBR would be further increased, the peak would be even narrower[13].

3.3. Far-field divergence angle

Figure 4 shows the far-field divergence angle of a RCLED and a normal LED without encapsulation in polar coordinates. The angle is about 56° and 48° for the normal LED and the RCLED, respectively. This makes the RCLED device well suited for optical communication.

3.4. Current-voltage and power-current characteristics

Figure 5 shows the forward voltage and the light output power as a function of the injected current. The voltage and the output power increase as the current increases, but the output power saturates at 0.65 mW. At 20 mA, the output power is 0.5 mW and the forward voltage is 2.2 V. Compared with the results of Ref. [14], the operating voltage is almost the same but the output power is 0.2 mW higher. Compared with the result of Ref. [15], although the output power is 1 mW less, the forward voltage is 0.5 V lower. If some measures of current confinement were adopted, such as the lateral sidewall oxidation technology[16], the output power would be further improved.

4. Conclusion

650-nm resonant cavity light emitting diodes with AlGaInP top DBRs were made. The results indicate that AlGaInP top DBRs have the advantage of better interface quality and lower voltage. The average emission power of the device is 0.5 mW at 20 mA, 2.2 V, and its FWHM is about 10 nm.

References

[1] Bulters G M. Recent developments in polymer optical fiber (POF) transceivers. Proceedings of the 9th International Conference on Transparent Optical Networks, 2007: 54

[2] Chiou S W, Lee Y C, Chang C S. High-speed red RCLEDs and VCSELs for plastic optical fiber application. Proc SPIE, 2005, 5739: 129

[3] Delbeke D, Bockstaele R, Bienstman P. High-efficiency semiconductor resonant-cavity light-emitting diodes: a review. IEEE J Sel Top Quantum Electron, 2002, 8(2): 189

[4] Hunt N E J. Resonant cavity light-emitting diodes. Proc SPIE, 1997, 3002: 50

[5] Purcell E M. Spontaneous emission probabilities at radio frequencies. Phys Rev, 1946, 69: 681

[6] Moens E, Vervaeke M, Meuret Y. Realistic opto-mechanical modeling of plastic optical fiber coupling systems. Proc SPIE, 2008, 6992: 69920X

[7] Guina M, Orsila S, Dumitrescu M. Light-emitting diode emitting at 650 nm with 200-MHz small-signal modulation bandwidth. IEEE Photonics Tech Lett, 2000, 12: 7

[8] Dumitrescu M M, Saarinen M J, Guina M D. High-speed resonant cavity light-emitting diodes at 650 nm. IEEE J Sel Topics Quantum Electron, 2002, 8: 2

[9] Vilokkinen V, Sipila P, Melanen P. Resonant cavity light-emitting diodes at 660 and 880 nm, Mater Sci Eng B, 2000, 74(1–3): 165

[10] Schneider R P, Lott J A. InAlP/InAlGaP distributed Bragg reflectors for visible vertical cavity surface emitting lasers. Appl Phys Lett, 1993, 62(22): 2748

[11] Dumitrescu M, Vilokkinen S V. Resonant cavity light-emitting diodes: modeling, design, and optimization. Proc SPIE, 2000, 4068: 597

[12] Tanaka H, Kawamura Y, Asahi H. Refractive indices of $In_{0.49}Ga_{0.51-x}Al_xP$ lattice matched to GaAs. J Appl Phys, 1986, 59: 3

[13] Bockstaele B D. Resonant-cavity light-emitting diodes: a review. Proc SPIE, 2003, 4996: 74

[14] Tsai C L, Chou Y L, Lin R M. An alternative method to fabricate the planar-type resonant-cavity light-emitting diodes by using silicon oxide for short-reach communications. Mater Sci Semicond Proc, 2007, 10: 235

[15] Wei Jiyong, Huang Baibiao, Qin Xiaoyan. Epitaxy and characterization of short wavelength resonant cavity LEDs. J Opt Laser, 2005, 16: 11

[16] Wang Z W, Su Y K, Huang C Y. The fabrication and characterization of InGaAs oxide-confined resonant-cavity light-emitting diodes grown on GaAs substrate. IEEE Conference on Electron Devices and Solid-State Circuits, 2007: 217