Temperature-Stable (Wavelength ~ 1μm) InAs/GaAs Quantum Dot Light-Emitting Diode

Shiang-Feng Tang [a], Shih-Yen Lin [a], Si-Chen Lee [a] and Chi-Chou Tsai [b]

[a] *Department of Electrical Engineering, and Graduate Institute of Electronic Engineering, National Taiwan University, Taipei, Taiwan, Republic of China*

[b] *Graduate Institute of Mechatronics, Huafan University, Taipei, Taiwan, Republic of China*

Corresponding Author e-mail: sclee@cc.ee.ntu.edu.tw

Abstract

The InAs/GaAs quantum dot (QD) edge light emitting diode (LED) emitting at a wavelength of 1 μm has been fabricated which exhibits very small wavelength shift of 0.22 nm/K and the full width at half maximum (FWHM) broadening shift of 0.04 nm/K. Detailed temperature characteristics over a range from 20 to 300 K are presented.

1. Introduction

For the last decade, the light-emitting devices operating at the important 1.3 and 1.55 μm fiber-communication wavelengths widely utilized InGaAs/GaAs/AlGaAs and InP/InGaAsP material systems [1-3]. Recently, InAs/GaAs QD laser can also be tuned to 1.3 μm [4] and provides alternative laser source for fiber communication. The development of infrared data transport technology in short distance, low-cost, temperature insensitive, and easy-to-use wireless communication application such as personal digital assistants (PDAs), digital camera, mobile phones, the light emitting diode using strained $In_xGa_{1-x}As$ quantum well (QW) on GaAs operating around 980 nm [5] can well be utilized which can be detected by silicon, germanium, or InGaAs detectors. Strain compensated InGaAs/GaAsP/InGaP 980 nm emitting diode is used as pump laser for erbium-doped fiber amplifier. High power, single-mode operation, with frequency stability and high reliability is required for this application [6].

Strained layer epitaxy is one effective method to fabricate self-assembled zero dimensional (0D) InAs / GaAs quantum dots. The 7 % lattice mismatch between the epitaxial InAs and GaAs induced the Stransky-Krastanov growth mode [7]. The temperature-dependent current-voltage (I-V) curves and spectra of QD LED are measured in detail. The resulting curves are often referred to as the ideality factors and light-current (L-I) curves. In this paper, the self-assembled InAs/GaAs QD LED was grown by VG-80 solid-source MBE. A temperature-insensitive characteristics of the QD LED is demonstrated.

2. Experiments

The device was grown by solid-source molecular beam epitaxy. A 500 nm-thick and n-doped $2 \times 10^{18}cm^{-3}$ GaAs buffer layer was grown on (001) ~ $1 \times 10^{18}cm^{-3}$ Si-doped GaAs substrate at 580 °C, followed by 500 nm-thick $Al_{0.5}Ga_{0.5}As$ which was doped to $1 \times 10^{18}cm^{-3}$ at higher grown temperature of 610 °C and two period of 5 nm GaAs/ 5 Å $Al_{0.5}Ga_{0.5}As$ were deposited when the temperature was ramping down to 580 °C. Note that the two periods of superlattice is designed to decrease the mobility of injection electrons from the n-contact under forward bias leading to entrapping of electrons in the InAs QDs for increasing optical-radiative transition probability. Subsequently, three period of undoped 2 ML InAs QD / 30 nm thick GaAs layers were grown at 500 °C. The InAs dots were grown under the arsenic shutter closed condition and the growth rate was 0.25 ML/sec. Increasing temperature from 500 to 610 °C, 500 nm-thick (Be-doped 5×10^{18} cm^{-3}) $Al_{0.5}Ga_{0.5}As$ barrier layer were grown. Finally, the 500 nm-thick GaAs contact layer (1×10^{19} cm^{-3}) was grown at 580 °C. The InAs/GaAs QD edge emiting diode was patterned by standard photolithography and the device active area is 10 μm × 1 mm. Au / Ge / Ni and Au were deposited on the bottom n-type, and Au / Be and Au on the top p-type GaAs layer, then annealed at 410℃ for 60 sec to form ohmic contacts. Fig. 1(a) displays the cross section transmission electron micrograph (XTEM) of the three periods InAs/GaAs QD layers. It is clear that no vertical alignment of QDs is observed indicating that the 30 nm thick GaAs spacer layer is thick enough to release the strain and no threading dislocations on the GaAs surfactants. The schematic device structure of the QD LED is shown in Fig. 1(b).

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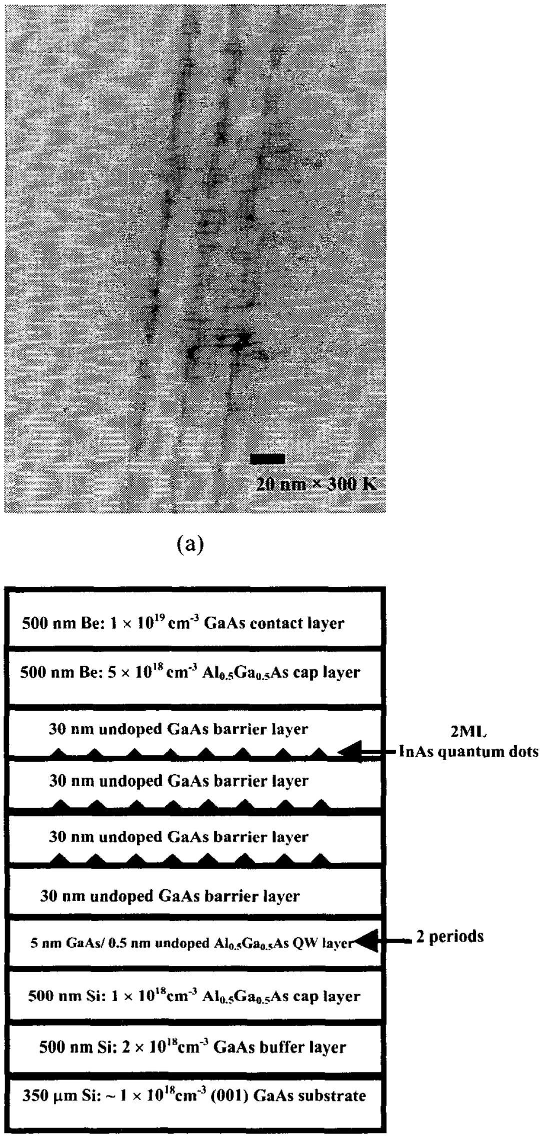


(a)

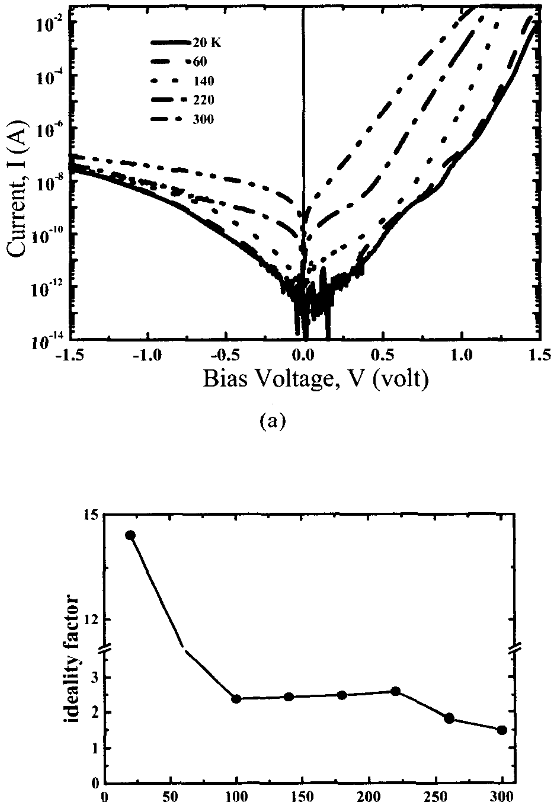
(b)

Fig. 1 The (a) cross section transmission electron micrograph (XTEM) and (b) schematic diagram of three periods InAs/GaAs QD LED.

3. Results and Discussion

3.1 Temperature-Dependent I-V Characteristics

Figures 2(a) and (b) display the temperature-dependent I-V characteristics and ideality factor of three period InAs/GaAs QD LED. In the Fig. 2 (a), as the temperature increases from 20 to 300 K, dark current increases from 84 pA to 13 nA at the negative bias of –0.5V. The ideality factor was calculated at a forward bias of ~ 0.52 V to be 14 (tunneling current is dominant) at 20 K and abruptly dropping down to ~ 2 (G-R current) at the range of 100 to 240 K, then the value approaches to ~ 1.3 (diffusion current limited) as shown in Fig. 2(b). It is demonstrated that the device has low dark current and excellent electrical performance. The series resistance of QD LED is approximately 6 Ω.



(a)

(b)

Fig. 2 The (a) semi-log current-voltage (I-V) curves (b) ideality factor as a function of temperature of InAs/GaAs QD LED.

3.2 Temperature-Dependent EL spectra

Under the driving current of 800 mA peak-amplitude, the temperature-dependent electroluminescence spectrum was shown in Fig. 3. The spectra reveal gaussian distribution due to the transitions of carriers on predominant InAs QDs. The peak-intensities decrease when the temperatures increase from 60 to 300 K due to phonon interaction, leading to non-radiative process.

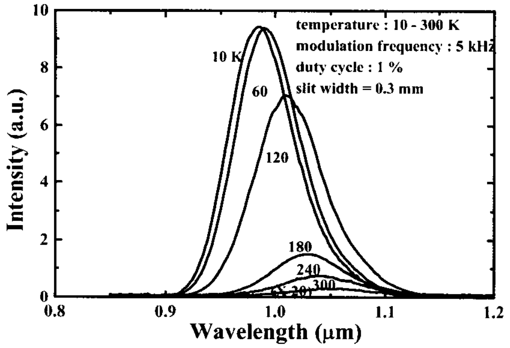
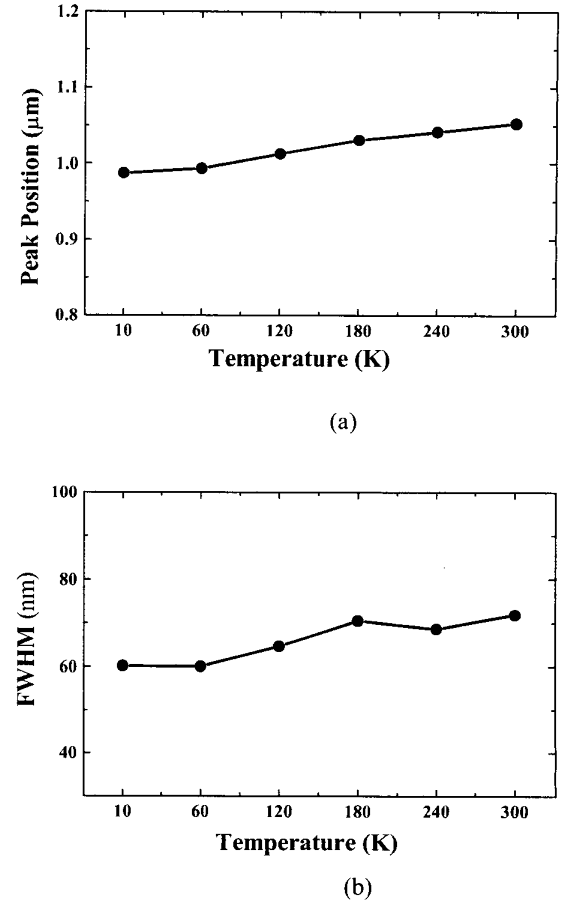


Fig. 3 The EL spectra of InAs/GaAs QD LED as a function of temperature.

The position of peak wavelength and FWHM of the EL spectra are extracted and displayed in Fig. 4 (a) and (b). The position of peak wavelength shifts from 0.99 at 10 K to 1.05 μm at 300 K due to both the energy gap shrinkage of semiconductor and the thermal population of QDs with carriers to higher energy level when increasing temperature [8]. In Fig. 4(b) When the temperature is lower than 60 K, FWHM is almost constant. The phenomenon would indicate that the recombination of carriers is determined primarily by the size distribution of QDs. From 60 to 180 K, the FWHM increases linearly and smoothly due to larger thermal distribution of carriers in different sized QDs. Beyond 180 K, the FWHM even decreases rather than increases until 240 K. It can be explained that the carriers in the QDs would be repopulated to nearby dots via the wetting layer. Hence, the radiative recombination process would tend to occur at the globally lowest conduction band edge, which results in the decrease of FWHM. Operated at the very large temperature range, the wavelength shift and the broadening FWHM are only 0.22 and 0.04 nm/K on average, respectively. These results are comparable to resonant cavity LED [9] and the LED with the surfacing multiplayer dielectric optical filter [10]. The peak intensity as a function of pulsed bias current from 10 to 300 K was shown in the Fig. 5.



(a)

(b)

Fig. 4 The (a) peak wavelength and (b) FWHM of EL spectra versus temperatures of the InAs/GaAs QD LED.

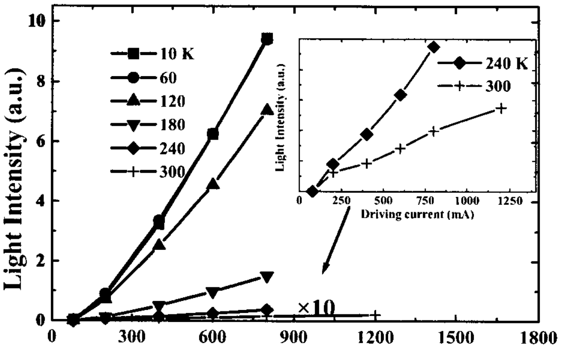


Fig. 5 The L-I curves versus driving currents as a function of temperatures.

The power intensity versus current (L-I) characteristics is essentially linear at the temperature range. In the inset of Fig.5, it is of the same trend when increasing temperature increases from 240 to 300 K. Whereas at 300 K, the driving current exceeding 750 mA, the L-I curve shows the power saturation. These equivalent threshold currents are caused by the parallel constant current leakage path which are independent on temperature. The slopes of L-I decrease with the increasing of temperature. It is probable that non-radiative process at a higher temperature influences the L-I curves.

4. Summary

We have measured the I-V and EL of InAs/GaAs QD LED as a function of temperature to demonstrate the excellent device performance and temperature-insensitivity. The LED emits at a wavelength of 1 μm with the very small wavelength shift of 0.22 nm/K and the full width at half maximum (FWHM) broadening shift of 0.04 nm/K. It is possible to be used as the pump for Er-doped optical fiber amplifier.

5. References

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