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A method to obtain ground state electroluminescence from 1.3 μm emitting InAs/GaAs quantum dots grown by molecular beam epitaxy*

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1.3 μm emitting InAs/GaAs quantum dots (QDs) have been grown by molecular beam epitaxy and QD light emitting diodes (LEDs) have been fabricated. In the electroluminescence spectra of QD LEDs, two clear peaks corresponding to the ground state emission and the excited state emission are observed. It was found that the ground state emission could be achieved by increasing the number of QDs contained in the active region because of the state filling effect. This work demonstrates a way to control and tune the emitting wavelength of QD LEDs and lasers.

Keywords: quantum dots, electroluminescence, state filling effect
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Self-organized In(Ga)As/GaAs quantum dots (QDs) have attracted much attention for their unique physical properties and potential applications.[1−4] Particularly, 1.3 μm emitting In(Ga)As QDs have caused great interest in recent years because of technologically important applications.[5−8] Room temperature 1.3 μm emitting QD lasers have been reported recently.[9,10] However, it was found that the emitting wavelength of QDs was strongly influenced by growth conditions and device structures, therefore many efforts have been made to make extended wavelength emission and to achieve ground state emission.[11−13]

Experimental results showed that 1.3 μm region emission could be achieved by covering InAs QDs with $In_xGa_{1-x}As$ cap layer.[14] We have reported a systematic study of the influence of $In_xGa_{1-x}As$ ($0.0 \leq x \leq 0.3$) cap layer on the structural and optical properties of InAs QDs grown on GaAs (100) substrates.[15] In this paper, we report the growth of 1.3 μm region emitting InAs QDs by molecular beam epitaxy (MBE) and the fabrication of QD light emitting diodes (LEDs). EL spectra of QD LEDs have been studied at different temperatures and injection current intensities. By comparing the EL spectra of QD LEDs with different device lengths, i.e. active region lengths, we propose a method to obtain ground state electroluminescence from InAs/GaAs QDs.

The samples were grown on n^+GaAs (100) substrates using the VG V80H MKII MBE system. The epitaxial growth sequence of the samples was as follows: firstly a 500 nm n^+GaAs buffer layer was grown at 600°C, then a 1500 nm $n^+Al_{0.4}Ga_{0.6}As$ cladding layer and a 200 nm $Al_xGa_{1-x}As$ (x=0.4–0.3) composition graded layer followed. 20 cycles of 2 nm $Al_{0.3}Ga_{0.7}As$/1 nm GaAs superlattices were formed to provide better morphology. Then the growth temperature was dropped to 510°C for growth of QDs. A layer of 40 nm GaAs was deposited, followed by cycled deposition of 0.1 ML of In with 20 s interruption under constant As flux. After 25 cycles, a total of 2.5 ML InAs were deposited to form the QDs, and a 3 nm $In_{0.2}Ga_{0.8}As$ cap layer was grown on top of InAs QDs. Three layers of QDs were formed, separated by two 20 nm GaAs layers. A 40 nm GaAs layer followed and then the growth temperature was raised to 600°C. Then 20 cycles of 2 nm $Al_{0.3}Ga_{0.7}As$/1 nm GaAs su-

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perlattices, a 200 nm $Al_xGa_{1-x}As$ (x=0.4–0.3) composition graded layer and a 1500 nm $p^+Al_{0.4}Ga_{0.6}As$ cladding layer were deposited. Finally, a 450 nm $p^{++}GaAs$ contact layer was grown. The growth rates of GaAs and InAs were 1 and 0.1 μm/h, respectively. Edge-emitting QD LEDs were fabricated with width of 200 μm and lengths ranging from 0.2 mm to 5 mm. The details of active region structures are shown bellow as Fig.1.



Fig.1. Schematic scheme of active region structure.

EL spectra were taken on a Nicolet Magna-760 Fourier transform infrared spectroscope. The sample temperature was changeable from 10 K to 300 K and the EL spectra were taken by supplying dc current to the samples.

Figures 2 and 3 show the low temperature EL spectra of two representative QD LEDs. The two QD LEDs were cleaved from the same MBE grown chip after formation of ohm contact. For sample I, the device length is 0.2 mm; for sample II, the device length is 5 mm. There are two obvious peaks in the EL spectra of sample I taken at 100 K. The longer-wavelength emission corresponds to ground state transitions of QDs and the shorter-wavelength emission corresponds to excited state transitions. At low injection current, the intensity of ground state emission is much greater than the intensity of excited state emission. As the injection current increases, the intensity of excited state emission increases rapidly. Excited state emission can be clearly observed when the injection current is 36 mA. At injection current of 250 mA, the intensity of ground state emission approximately remains the same but the intensity of excited state emission further increases. In the EL spectra of sample II, there is only a very weak excited state emission peak when the injection current is 750 mA. The experimental results can be explained by state filling effect. When trapped by QDs, carriers firstly transfer to an excited state, then relax to the ground state, finally make recombination and emit photons.[12,16] For sample I with an active region length of 0.2 mm, most carriers transfer to ground state and emit photons at low injection current. But the ground state will be full at high injection current, so the intensity of ground state emission tends to saturate.[17] More carriers are filled into excited state so that the intensity of excited state emission increases with increased injection current. For sample II with an active region length of 5 mm, it remains to emit ground state emission under different injection current intensities at 77 K. The elimination of excited state emission is attributed to increasing QD numbers. With the much longer active region length, the active region of sample II contains much more QDs than the active region of sample I. Ground state is still not saturated at high injection current and the intensity of ground state emission increases rapidly with increased injection current. The experimental results show that ground state emission is more likely to be achieved in QD-based light emitting devices by increasing the number of quantum dots contained in the active region.

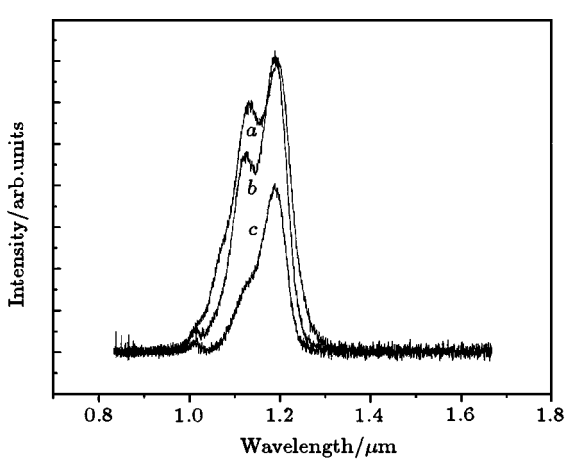


Fig.2. EL spectra of sample I taken at 100K. Injection current: (*a*) 250 mA; (*b*) 36 mA; (*c*) 12 mA.

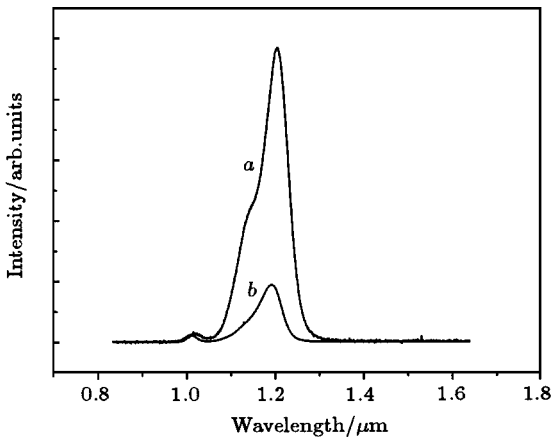


Fig.3. EL spectra of sample II taken at 77 K. Injection current: (*a*) 750 mA; (*b*) 300 mA.

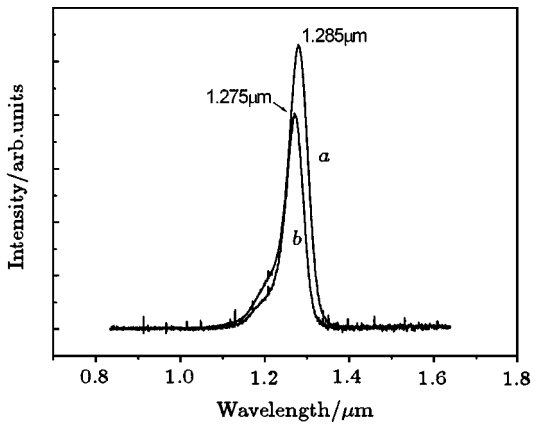


Fig.4. EL spectra of sample II taken at room temperature (290K). Injection current: (*a*) 525 mA; (*b*) 250 mA.

Figure 4 shows the room temperature EL spectra of sample II. Room temperature ground state emission was achieved, and the emission intensity increases with increased injection current. The wavelength of ground state emission shifts from 1.275 μm to 1.285 μm with increased injection current. The redshift is caused by the thermal effect of high injection current. In addition, the EL FWHM of sample II at room temperature is 36 meV, indicating the quantum dot samples have good size uniformity.

In summary, we have fabricated LEDs using MBE grown InAs/GaAs QDs and have studied the EL spectra of the samples. For LEDs with short active region length, the intensity of ground state emission tends to saturate and the intensity of excited state emission increases with increased injection current. For LEDs with long active region length, it remains to emit ground state emission with increased injection current. The experimental phenomena can be explained by state filling effect. We have suggested a method to control and tune the emitting wavelength of QD-based light emitting devices.

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