Realization of Extended Ultrabroadband Quantum-Dash Laser Emission using Postgrowth Intermixing

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Abstract: We demonstrate a widened ultrabroad-stimulated emission in InAs/InAlGaAs quantum-dash laser using the postgrowth lattice-intermixing technique. The 100nm wavelength blue-shifted device exhibits larger lasing bandwidth (~41nm) than as-grown laser (~25nm) with a spectral ripple of <1dB.

1. Introduction

Inhomogeneous broadening gain spectrum due to carriers' localization in noninteracting self-assembled quantum dot (Qdot) or quantum dash (Qdash) has experimentally been proven to show superior performance than its quantum well (QW) counterpart [1]. Extensive research yield impressive results, such as, low room-temperature threshold current [2], wide tuning range at bias currents ten times lower than those required in QW lasers [3], and ultrabroadband stimulated emission [4]. These unique features of self-organized technology have led to the realization of broad interband lasers that can find wide applications in optical telecommunication, various sensors detecting chemical agents, atmospheric or planetary gases, high-precision optical metrology and spectroscopy, biomedical imaging, and pump sources for erbium-doped solid-state lasers.

Spatially selective bandgap engineering of QW, wire, dash and dots, has been a subject of intense research since it is a simple and cost-effective technique for the fabrication of advanced photonics devices, especially photonic integrated circuits (PICs) [4]. In addition, technology of self-assembled Qdot and Qdash is more pronounce in bandgap tuning due to their large interface area to volume ratio with the surrounding barriers [5].

In this paper, we demonstrate wavelength tuning of an inhomogeneous InAs/InAlGaAs QDash laser using the impurity free vacancy disordering (IFVD) technique. With moderate degree of intermixing, whereby the Qdashes with varying size and composition are subjected to different interdiffusion rates, broad lasing linewidth is preserved. Similar to the as-grown (AG) broadband laser, the 100 nm bandgap tuned laser exhibits ultrabroad stimulated emission with larger wavelength coverage of ~ 85 nm at a center wavelength of ~ 1.54 µm.

2. Experiment

The Qdash laser structure was grown by molecular beam epitaxy on (100) oriented InP substrate. The active region consists of four sheets of 5 monolayer InAs dashes, each embedded within a 7.6 nm thick compressively strained $In_{0.64}Ga_{0.16}Al_{0.2}As$ quantum well and a 30 nm thick tensile strained $In_{0.50}Ga_{0.32}Al_{0.18}As$ barrier [4]. A 475 nm layer of SiO_2 was deposited on samples using plasma enhanced chemical vapor deposition prior to rapid thermal annealing at 750ºC in nitrogen ambient for one minute. Photoluminescence (PL) spectroscopy was performed at 77 K using a 980 nm diode laser as an excitation source. Broad area lasers with 50 µm wide oxide stripes were fabricated from the intermixed Qdash samples. A fresh 200 nm thick SiO_2 layer was deposited and a 50 µm contact window was defined using a 10% buffer HF-based chemical etching. In order to maximize the gain, the optical cavity was aligned along the [011] orientation which is perpendicular to the dash elongation direction. A p-metal contact consisting of Ti-Au layers was defined using electron beam evaporation and lift-off process. The samples were thinned down to ~150 µm and n-metal contact of Au-Ge-Au-Ni-Au layers was evaporated on the back side of the samples. After cleaving the sample into bars with different cavity lengths, the non-coated facet lasers were tested on a temperature controlled heat sink at 20ºC with the epitaxial p-side-up mounting configuration. Current injection was performed under pulsed operation at 0.2% duty cycle with a 2 µs pulse width.

3. Results and Discussion

Carriers localized in different dot/dash, resulting in a system without a global Fermi function and exhibiting an inhomogeneously broadened gain spectrum, have shown interesting phenomena of lasing spectra [4, 6]. This unique feature of dot/dash can be well studied from the evolution of state-filling spectroscopy in both as-grown and intermixed Qdash-in-well at 77 K under different excitation power densities [fig. 1 (a)]. At low excitation below 3 W/cm^2, the ground state emissions of 1.57 µm and 1.50 µm are dominant in the as-grown and the intermixed samples, respectively. The nearly symmetric PL spectra are broadened with increasing optical excitation densities in both samples without significant presence of different excited energy states. The PL linewidth of intermixed samples increases up to 111 nm (61 meV), which is significantly larger than that of as-grown samples (94 nm or 47 meV) at the power excitation density of 1500 W/cm^2. The broadening of the spectra is due to the contribution of multiple transition states [4]. However, carrier localization in Qdash becomes evident when the intermixed samples show a larger change of full-width-half-maximum (ΔFWHM ~ 47 nm) as compared to the as-grown sample (ΔFWHM ~ 18

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nm) under the power excitation density of 1500 W/cm^2 [inset of fig. 1 (a)]. This shows the effect of different interdiffusion rates in the Qdash nanostructures with varying composition, geometry and size, as pictured by the atomic force microscopy images in Fig. 1(b), in producing a more uniform distribution of energy levels across the dash active medium. The presence of these non-interacting Qdash with wider distribution of energy levels will contribute to larger FWHM in PL spectra.

Broad area laser characterization further provides evidence of a multi-state emission as shown in fig. 2. The light-current (*L-I*) curve of the Qdash laser (L=500 μm) yields a current density (J_{th}) and slope efficiency of 2.1 kA/cm^2 and 0.423 W/A, respectively [Fig. 2(a)]. Measuring the temperature dependent J_{th} over a range of 10-60 ºC, reveals the temperature characteristic (T_o) of 56.5 K. This result is comparable to the T_o range (50-70 K) of the equivalent QW structure. In fig. 2 (b), only the ground state lasing with the wavelength coverage of ~15 nm is observed below injection of 1.5xJ_{th}. This broad lasing spectrum suggests there is collective lasing from Qdashes with different geometries. At $J > 1.5$ x J_{th}, the bistate lasing is evident. The simultaneous lasing from both transition states [7] is attributed to the relatively slow carrier relaxation rate and population saturation in the ground state in low-dimensional quantum heterostructures. The bistate lasing spectrum is progressively broadened with increasing carrier injection up to a wavelength coverage of 85 nm at $J = 4$ x J_{th}, which is larger than that of AG (~76 nm) [4], as shown in fig. 3. A center wavelength shift of 100 nm and an enhancement of the broadband linewidth are achieved after the intermixing. The inset of fig. 3, showing the FWHM of the broadband laser with injection, further proves that multimode lasing emission [6] from Qdashes of different geometries occur before a supercontinuum broad lasing bandwidth, where a ripple of wavelength peak fluctuation of less than 1 dB, is achieved.

4. Conclusion

In conclusion, wavelength tuned broad interband lasers has been fabricated utilizing the process of IFVD to promote group-III intermixing in InAs/InAlGaAs dash-in-well structure. The intermixed lasers exhibit higher internal quantum efficiency, lower threshold current densities and larger broad lasing spectra. Bandgap shift of 100 nm has been measured from the intermixed lasers with center wavelength of ~1.54 μm as compared to AG lasers with center wavelength of ~1.64 μm. Our results indicate a highly attractive wavelength trimming and selective bandgap tuning method, well suited for planar, monolithic Qdash integration of optoelectronics components.

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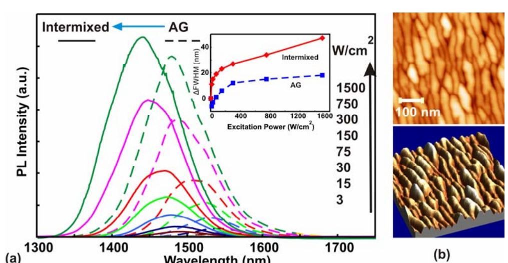

Fig. 1(a) The PL spectra of both AG and intermixed samples with varying optical pumping levels. The inset shows the corresponding changes of FWHM. (b) 2D (top) and 3D (bottom) view of AFM images of InAs QDashes.

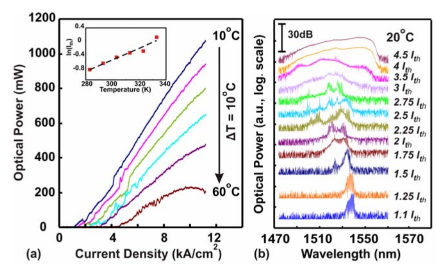

Fig. 2 (a) *L-I* characteristics of the 50 x 500 μm^2 broad area Qdash laser at different temperatures. Up to ~1 W total output power has been measured at J = 5.5 x J_{th} at 20ºC. (b) The lasing spectra above threshold condition are acquired by an optical spectrum analyzer with resolution of 0.05 nm.

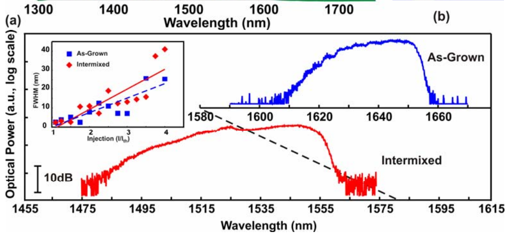

Fig. 3 The bandgap-tune of broadband quantum dash laser from 1.64 μm to 1.54 μm center wavelength. The lasing coverage increase from 76 nm to 85 nm after intermixing process. The inset shows the FWHM of the broadband laser in accordance to injection above threshold up to J = 4 x J_{th}.

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