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Long Photon Lifetime from Microdisk Cavity Laser with Type II GaSb/GaAs Quantum Dots

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1. Introduction

In recent years, the GaSb/GaAs quantum dot (QD) structures have attracted great interest due to their type II band alignment and intrinsically different properties compared to the well-known InAs/GaAs QD system. The type II band alignment accommodates spatially indirect transitions in which the interface properties will drastically influence the optical and electrical properties [1]. In this study, we demonstrated a compact microdisk cavity laser made of type II GaSb/GaAs QDs on GaAs substrate. The lasing action was obtained from a 3.9 µm diameter microdisk with a low threshold. The longer photon lifetime from type II microdisk laser was also observed, compare to type I lasers.

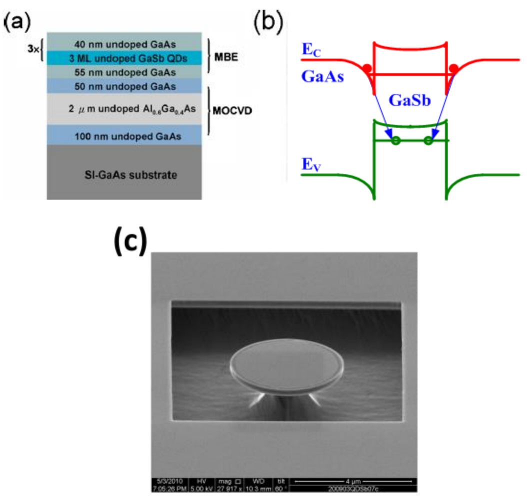
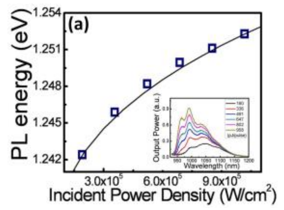


Fig. 1 (a) The illustration of a layer structure with the GaSb/GaAs QD epiwafer and (b) the type II band alignment image of the GaSb/GaAs QD epiwafer . (c) The SEM image of a microdisk cavity with a diameter of 3.9 µm.

2. Results and discussions

The microdisk cavities were fabricated from a 225-nm thick GaSb/GaAs QD layer. Fig. 1(a) shows the layer structures of the GaSb/GaAs QD epiwafer. Figure 1(b) shows the type II band alignment image of the GaSb/GaAs QD structure. The area density of GaSb QDs is around 4.53×10^{10} cm^{-2}. Fig. 1(c) shows the SEM image of a microdisk cavity with diameter of 3.9 µm. The microdisk cavities were then optically pumped by using an 850 nm wavelength laser at normal incidence with a 1.5% duty cycle and a 30 ns pulse width. Before measuring the optical properties of microdisk cavities, the photoluminescence (PL) from the GaSb/GaAs QD wafer was first characterized. The PL spectrum shows a blue shift as the pump power increases, which is one of the key characteristics of type II gain material. The peak position for the principal PL peak of this QD wafer versus the pump power density is shown in the Fig. 2(a). The black curve is a fitting curve based on the following relation: (PL peak energy) $=1.29912+0.00023(\text{power density})^{1/3}$. This relation between energy and power density can be explained by the band bending effect due to excited carriers and had been reported. Time-resolved photoluminescence (TRPL) measurement were performed with the sample excited by an 860nm pulse laser operating at 1MHz. The temporal resolution of the setup is limited by the 40 ps laser pulse width. As shown in Fig. 2(b) we compared the photon lifetime between the type I InAs QDs and GaSb QDs. The GaSb QDs show a long decay performance than that of the type I InAs QDs. Such a long photon lifetime of GaSb QDs emission is attributed to the reduced spatial overlap between wave functions of the electrons and holes and it confirmed again that the GaSb QDs belong to type II band structure. [2].



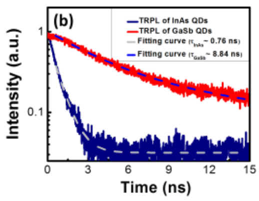


Fig. 2 (a) The PL spectrum from the GaSb/GaAs QD layer with different incident pump powers at temperature of 150 K. The inset shows the measured PL peak energy (squares) and the fitting curve for PL peak energy with a cube-root dependence of the power density. (b) The comparison of time-resolved PL between type I InAs QDs and type II GaSb QDs.

The blue curve in Fig. 3(a) illustrates the lasing spectrum from a microdisk laser with 3.9 µm diameter at 150 K temperature. The lasing peak appears at a wavelength of 968.2 nm. The inset of Fig. 3(a) is the light-in-light-out (L-L) characteristics of this laser, which are shown with a red curve. It was found that the laser has a low threshold power of 450 pJ/pulse. The linewidths of the lasing mode at various pump powers are also marked with blue circles. A linewidth narrowing was observed as the incident pump power increases, confirming the lasing action from the GaSb/GaAs QD microdisk. The quality factor of the microdisk cavity is approximately 5300, which was estimated from the ratio of resonant peak wavelength to linewidth at transparence (i.e., Q ~ $\lambda/\Delta\lambda$). The lasing mode is a first-order WGM mode in the microdisk cavity, which is verified by the three-dimensional finite-element method (FEM) simulation.

As shown in Fig. 3(b), we fit the data with the single-exponential function, obtaining the photon lifetime of GaSb QDs PL emission is about 8.84 ns and the photon lifetime of microdisk lasing is about 1.045 ns. This behavior is attributed to the cavity enhancement. We could estimate Purcell factor is approximately 8 because of the spontaneous emission enhancement in the microdisk cavity.

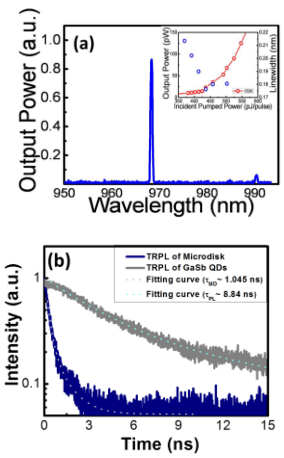


Fig. 3 (a) The lasing spectrum from a microdisk laser at 150 K. The inset: The L-L curve, the linewidth (circles) of the laser, and its threshold behavior were observed. (b) TRPL decay curve of microdisk cavity and GaSb QDs PL emission.

3. Summary

A GaSb/GaAs QD microdisk laser with 3.9 µm diameter has been demonstrated. The blue shift in PL peak with increasing pump power was observed for the type-II QD structure. The longer photon lifetime from type II microdisk laser was also observed, compare to type I lasers. The lasing at 968.2 nm wavelength with a low threshold was achieved at 150 K and the photon lifetime of lasing is shorter than the photon lifetime of photoluminescence from GaSb QD due to the cavity enhancement.

4. Reference

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