Room-temperature ground-state lasing from long-wavelength InAs quantum dots on InAlGaAs/InP(311)B

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Quantum dot (QD) lasers have been intensively studied for the low threshold-current, low-chirp and temperature-insensitive operations. Because most of their active layers are InAs self-assembled QDs on GaAs substrates, the lasing wavelengths are limited in the range from 1.0 to 1.3 μm. To apply the lasers in optical fiber communication systems, emission in the 1.55-μm range is strongly required. InAs QDs on InP substrates, instead of GaAs substrates, are attractive for the longer wavelength materials [1]. However there have been few reports on the lasers using the InAs QDs on the InP substrates [2, 3] and they show poor performance at room temperature due to the small optical gain from the QDs having the large variety in the size and low density. Here, we report uniform-sized and high-dense InAs QDs grown on InAlGaAs layers/InP(311)B substrates, and achieve QD-ground-state lasing with a lower threshold current density at room temperature.

We grew InAs QDs on $In_{0.52}Al_{0.29}Ga_{0.19}As$ buffer layer/InP(311)B substrate at 500°C in a molecular beam epitaxy (MBE) chamber. Figure 1(a) shows the atomic force microscopy image of them and (b) shows the room-temperature photoluminescence (PL) from the InAs QDs capped with InAlGaAs layer. The QDs have an average diameter of 30 nm and an average height of 6 nm, and PL peak wavelength is 1.60 μm. Owing to using InAlGaAs buffer and (311)B substrate, the QDs have a very high area density (9×10^{10} cm^{-2}) and a uniform size (PL linewidth of 51 meV), which are advantageous in producing the large optical gain of the QD ground state.

We then fabricated laser structures on the InP(311)B substrate, which consisted of 5-stacked InAs-QD layers as the active region in a 470-nm $In_{0.52}Al_{0.29}Ga_{0.19}As$ wave-guiding layer. The InAs QDs in the laser structure had a PL emission at 1.63 μm, which could be varied by varying the composition of the quaternary compound (InAlGaAs) barrier layer. The lasers were operated under the pulsed current at room temperature.

Figure 2 shows the light-output curve and lasing spectrum of a laser with a 2.08-mm-long and 50-μm-wide stripe, whose facets are coated with high reflectivity (HR). The threshold current density of the laser was 380 A/cm^2 and the lasing wavelength was 1.63 μm. This is the first demonstration of ground-state lasing at room temperature in long-wavelength QD lasers on InP substrates. We measured the threshold current densities and lasing wavelengths of the lasers with different long cavities at room temperature (Fig. 3). All lasers had uncoated facets. Even with a short cavity length of 0.72 mm without HR coating, the lasing still occurred at the ground state transition of QDs. From the mirror loss of 16.7 cm^{-1} and the internal loss of 3.6 cm^{-1} for the 0.72-mm-cavity laser, we estimated the maximum modal gain of the ground state to be around 20 cm^{-1}. It is two times larger than that in the QD lasers on GaAs substrates. Achieving lower threshold lasing in long-wavelength QD lasers on an InP substrate indicates that the QD lasers can be applied to fiber communication systems that have longer wavelengths of up to 1.6 μm, which is the wavelength range used for wavelength-division-multiplexing optical communication.

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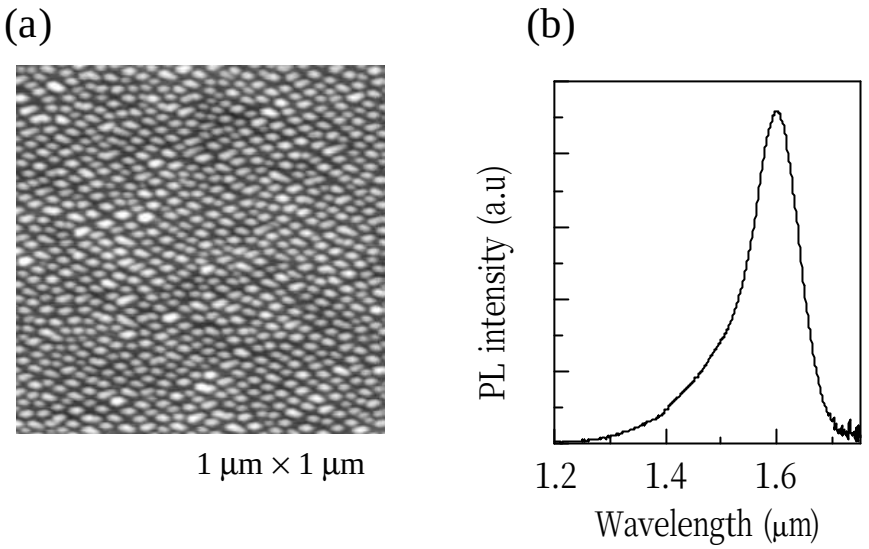

Fig. 1. (a) Atomic force microscopy image of InAs QDs on InAlGaAs buffer/InP (311)B substrate. (b) Photoluminescence from the InAs QDs capped with InAlGaAs layer.

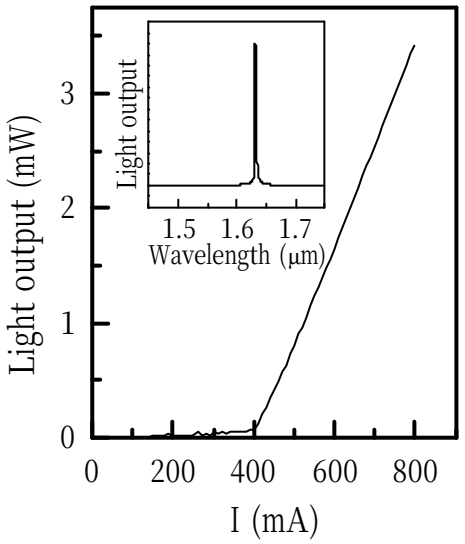

Fig. 2. Light-output curve of a HR coated laser with 2.08-mm-long and 50-μm-wide stripe at room temperature. Inset is its lasing spectrum.

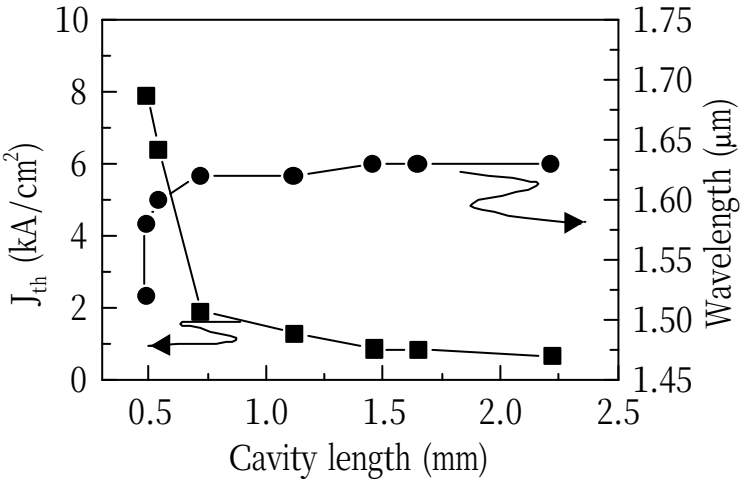

Fig. 3. Threshold current density and lasing wavelength at room temperature as a function of cavity length.