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1.5 µm InAs/InGaAsP/InP quantum dot laser with improved temperature stability

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Abstract. Temperature characteristics of InAs/InGaAsP quantum dot (QD) lasers synthesized on InP (001) substrate are presented. The lasers demonstrate high temperature stability: a threshold current characteristic temperature as high as 205 K in the temperature range between 20 to 50ºC was measured. Lasing wavelength of 1.5 µm was achieved by covering QDs with 1.7 monolayers of GaAs.

1. Introduction

Quantum dot (QD) lasers are of great interest owing to 3D confinement leading to a number of device improvements [1]. 1.3 µm InAs/GaAs QD lasers are already close to their maturity. For example, temperature insensitive threshold current at room temperature (RT) has been demonstrated for such lasers [2]. A significant interest exists in studying devices with 1.5 µm lasing emission, which is the key wavelength for telecom applications. However, this is beyond the ability of GaAs-based laser diodes with pseudomorphic QDs. At the same time, InAs QDs formed on an InP substrate are typically characterized by much longer wavelength emission (see e.g. [3]) because of twice lower lattice mismatch in this material system compared to the InAs/GaAs combination. Recent advances in synthesis of InAs QDs on InP substrates allowed to reach 1.5 µm laser generation. However, so far these lasers have poor temperature stability. To the best of our knowledge, the highest characteristic temperature of threshold current was reported to be 135 K in the 200-300K temperature interval [4]. The characteristic temperature estimated above room temperature is 106K [5] or even lower.

In the present work, we report on 1.5 µm InAs/InGaAsP/InP QD lasers that have improved temperature stability of threshold current (and external differential efficiency) compared to previously reported results.

2. Experiment details and results

A laser heterostructure was grown by metal organic vapour-phase epitaxy (MOVPE) on an InP (001) substrate. An active region comprised 5 layers of 1.65 monolayer (ML) InAs QDs, which surface density was estimated as $4.2 \cdot 10^{10}$ cm^{-2} per layer [6]. Each QD layer was covered with 1.7 ML GaAs

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and separated from each other by 60 nm $In_{0.83}Ga_{0.17}As_{0.38}P_{0.62}$ (Q1.08) spacers. The active region was positioned in the centre of a 450 nm thick Q1.08 waveguide, confined by *n*- and *p*-type InP claddings.

Using standard post-growth techniques, the structure was processed into 2 µm wide ridge waveguides of 1-4 mm lengths. The devices were soldered *p*-side up onto heatsinks. No facet coatings were deposited. Measurements were performed in a pulsed pumping regime (5 µs and 150 Hz) in 20-50ºC temperature range.

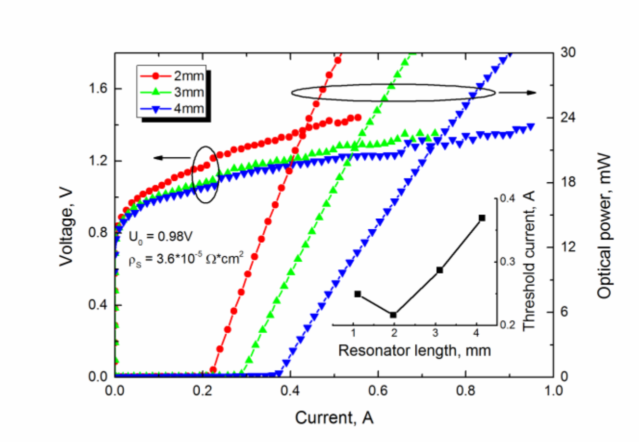

Figure 1. Voltage and optical power versus bias current at 20ºC for 2, 3 and 4-mm-long QD lasers. Output power corresponds to both facets. Inset: threshold current *vs.* resonator length.

In Figure 1, current- voltage and light-current characteristics of 2, 3 and 4 mm-long samples measured at 20ºC are presented. Their turn-on voltage and specific series resistance were estimated as 0.98 V and $3.6{\cdot}10^{-5}$ Ω·cm^2, respectively. The threshold current (I_{th}) versus resonator length dependence is presented in inset of Figure 1. The smallest I_{th} of 215 mA was found in 2-mm-long device. The lasers with resonator length in the 2-4 mm interval demonstrate lasing wavelength close to 1.5 µm, which corresponds to the QD ground state transition. At the same time, the lasing line is blue-shifted to 1.45 µm in 1 mm-long devices. This is accompanied by a strong rise in threshold current density from 5.4 kA/cm^2 (in 2-mm device) to 11.2 kA/cm^2 in 1 mm device.

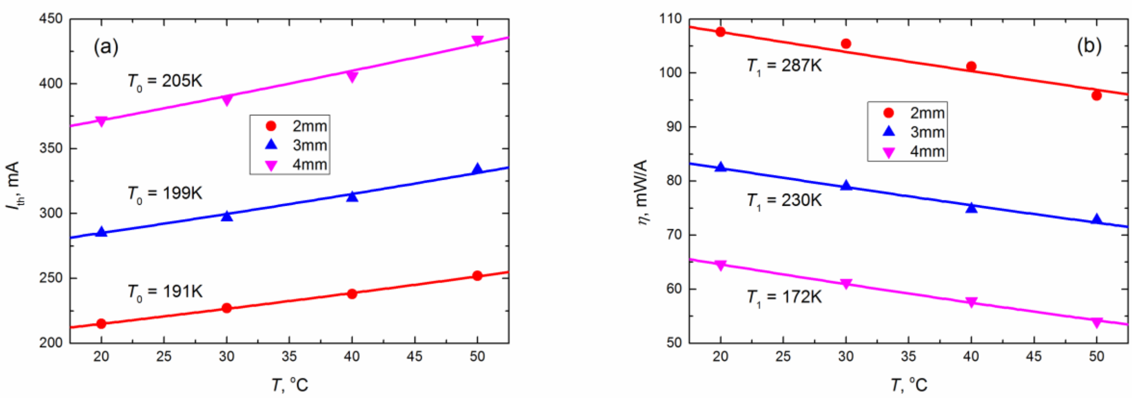

Figure 2. Temperature dependencies of threshold current I_{th} (a) and external differential efficiency η (b) of 2, 3 and 4 mm long lasers. Solid lines are fittings to exponential function (see description in the text). External differential efficiency corresponds to both facets.

Figure 2 shows temperature dependencies of the threshold current I_{th} (a) and the external differential efficiency η (b) of the lasers under study. Characteristic temperatures T_0 of the threshold current and T_1

of the external differential efficiency were extracted from fitting of the experimental data to exponent functions $I_{th} = I_0\exp(T/T_0)$ and $\eta = \eta_0\exp(-T/T_1)$, correspondingly. High values of T_0 and T_1 were reached for this type of lasers. For example, 4 mm long device demonstrates T_0 of 205 K and T_1 of 172 K in the 20-50ºC temperature interval. We attribute this improvement of the temperature characteristics to reduced aspect ratio of grown QDs [6] as well as high carrier localization energy, which is achieved by using InGaAsP (Q1.08) barriers.

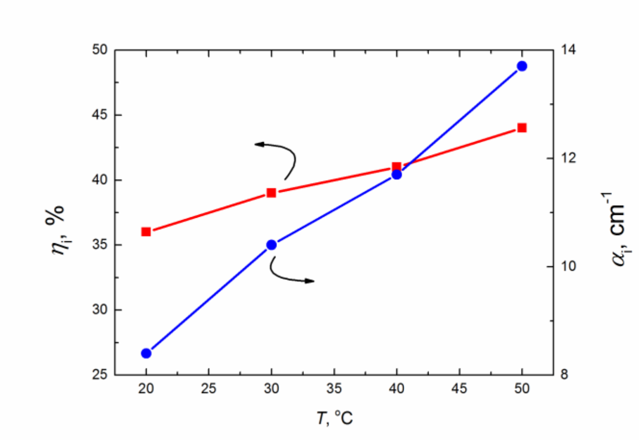

Figure 3. Temperature dependencies of internal differential quantum efficiency η_i and internal losses α_i.

Temperature dependence of internal differential quantum efficiency η_i and internal losse α_i was also extracted (see Figure 3). A standard procedure was used to determine η_i and α_i from inverse external efficiency versus cavity length dependence. The samples are characterized by a moderate value of internal losses (about 8 cm^{-1}) at room temperature. However, the α_i rapidly grows with temperature by one quarter per 10 centigrade. The value of η_i is rather low at room temperature (~ 36%). This can probably be attributed to a large inhomogeneous broadening of QDs, i.e. only part of QDs contributes to lasing. As temperature rises, η_i slightly increases to 44% at 50ºC.

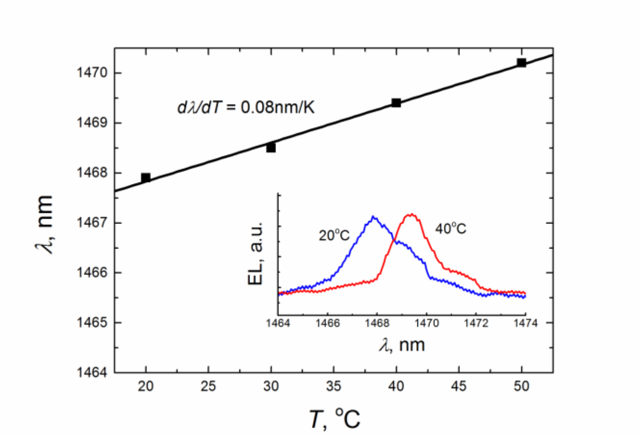

Figure 4. Emission wavelength versus ambient temperature for QD laser having length of 1 mm. Solid line represents a linear fit to the data. Inset shows emission spectra slightly above the threshold at 20 and 40ºC.

For 1-mm-long device a low temperature-induced shift of lasing line was observed, see Figure 4. The temperature coefficient was estimated to be 0.08 nm/K, whereas it typical values in InP-based QD lasers is about 0.4 nm/K (e.g. see [7]). This can be explained by proximity of the ground state optical gain to its saturated value in this device that leads to a strong counteraction between a blue shift of lasing line caused by thermally activated escape of carriers and its red shift due to band gap shrinkage with temperature.

In conclusion, we have studied 1.5 μm InAs/InGaAsP/InP QD lasers grown by MOVPE. Owing to reduced QDs aspect ratio, as a result of capping QDs with thin GaAs layer, and considerably high localization energy, we have achieved high temperature stability of threshold current and differential efficiency in pulsed regime: in the 20-50ºC interval, the 4 mm-long device is characterized by T_0 of 205 K (to the best of our knowledge, this is the highest characteristic temperature ever reported for 1.5 μm QD laser grown on InP) and T_1 of 172 K.

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