Temperature-Insensitive pulse and 120°C CW Operation of 1550nm-Band p-doped InAs/InGaAlAs Quantum Dot Lasers on InP(311)B Substrate

Ryota Yabuki(1), Atsushi Matsumoto(2), Ryumi Katsuhara(1), Siim Heinsalu(1), Koichi Akahane(2), Yuichi Matsushima(1), Hiroshi Ishikawa(1), and Katsuyuki Utaka(1)

(1) Faculty of Science and Engineering, Waseda University, Tokyo 169-8555, Japan
(2) National Institute of Information and Communications Technology (NICT), Tokyo 184-8795, Japan
E-mail: ryota0000@akane.waseda.jp

Abstract: We fabricated 1550nm-band, p-doped, InAs/InGaAlAs quantum-dot (QD) lasers on an InP(311)B substrate. The device showed extremely high temperature stability and lasing up to 120°C was confirmed under CW condition. © 2022 Ryota Yabuki

1. Introduction

In recent years, the rapid increase in Internet traffic due to the proliferation of smart devices such as smartphones and tablet PCs has created an urgent need for ultra-high-speed, high-capacity photonic networks. Especially, traffic growth in access networks, data centers and B5G wireless systems are explosively growing for higher levels than in other networks. In order to construct such ultra-high-speed and large-capacity photonic networks, high-performance photonic devices are desired. In any case, low cost, low power consumption and high temperature stability are also definitely required under the necessity of close positioning and dense integration of such photonic devices and electronic devices like large-scale integrated circuits (LSIs).

From these aspects, quantum dots (QDs) are highly promising materials for high-performance optical devices because of their delta-functional density of states [1], and a lot of groups have reported that advanced optical devices such as laser diodes (LDs) and semiconductor optical amplifiers (SOAs) based on QD structures exhibited high performance, including high thermal stability, low threshold, wide operating bandwidth and ultra-fast response [2-4]. For the above applications, a higher value of characteristic temperature T_0 is desired. One method to improve the temperature characteristics is to adopt p-type modulation doping, which has already been reported in many papers applied to 1.3-μm band QD-LDs [5,6]. Although extremely high T_0 and virtually temperature-insensitive operation around room temperature have been reported in the 1.3-μm band, there have been few reports on extremely high T_0 performances for 1550nm-band QD-LDs [7], especially using p-doped structures [8].

In this paper, a 1550nm-band, p-doped ridge-type QD-LDs with 14 QD layers were fabricated, where the QD wafers were grown on InP(311)B substrates by molecular beam epitaxy (MBE) using the strain compensation technique [9]. It was demonstrated that the fabricated QD-LDs exhibited temperature-insensitive characteristics with an infinite characteristic temperature $T_0 = \infty$ K up to 50 °C in 1550nm-band for practical ridge-type structure, for the first time to our best knowledge, and 120 °C CW operation was obtained.

2. Structure and fabrication process

The QD epitaxial wafer used in our experiments was grown on InP(311)B substrates by MBE with strain compensation techniques. The layer structures are as follow: a 150-nm n-InAlAs cladding layer lattice-matched to an InP substrate, 14 layers of InAs QD layer and 20-nm InGaAlAs spacer layer, a 1.6 μm p-InAlAs cladding layer, and a 100 nm p^+-InGaAs contact layer. For the p-type doping, the QD layers were doped with beryllium (Be) atoms in the InGaAlAs spacer layers by modulation delta-doping method with a doping concentration of 1×10^{18} cm^{-3}. The QD-LDs were fabricated in a ridge waveguide structure of 3.5 μm width. After the ridge structure formation by inductively-coupled-plasma reactive-ion-etching (ICP-RIE), a SiO_2 layer was deposited by chemical vapor deposition (CVD) and opened by photolithography, then Ti/Pt/Au films were evaporated for p- and n-type electrodes by electron beam evaporator. In this experiment, high-reflection (HR) coatings with two sets of multi-layers of TiO_2/SiO_2 for threshold and light output controls. Three types of the QD-LDs were fabricated: 1) CL/CL with a length of L = 750 μm, 2) HR/CL with L = 1000 μm and 3) HR/HR with L = 950 μm.

3. Measurement and results

Figs 1 shows the temperature dependence of the threshold current densities under pulsed condition for the three QD-LD structures of HR/HR, HR/CL and CL/CL. As the increase of facet reflectivity by HR coating for one and both facets from CL/CL to HR/CL and HR/HR QD-LDs, the threshold current densities were decreased by mirror loss reduction. For all the cases, the threshold current densities tended to display the minimums around room

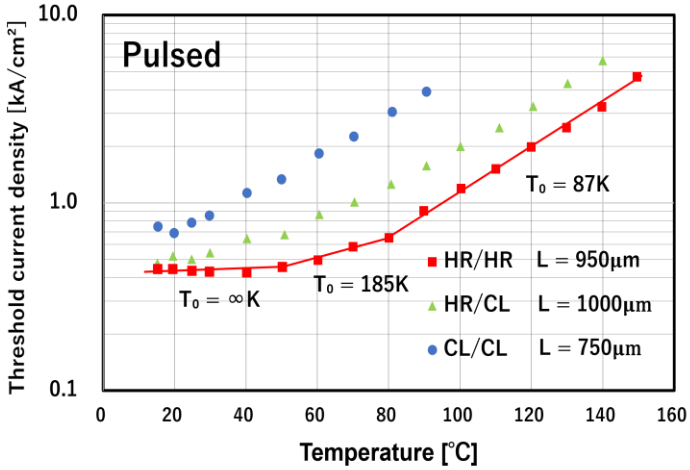

Fig 1. Temperature characteristics of the threshold current densities for the QD-LDs with CL/CL, HR/CL and HR/HR structures under pulsed condition.

temperature, which may be attributed to the combined effects of the temperature-dependent Auger recombination effect in the lower temperature range and the thermal carrier excitation in the higher temperature one. The latter phenomenon was effectively decreased by the p-type doping in the QDs as well as the QD size uniformity specific to the growth on InP(311)B substrates with the strain compensation technique, supplying excessive holes in the valence band and reducing the thermal carrier excitation to higher energy levels in the conduction band. This effect seems more enhanced for the lower threshold device such as HR/HR QD-LD (I_{th} = 14 mA and J_{th} = 0.44 kA/cm^2 at 20 °C) than HR/CL and CL/CL ones, and gave the temperature-insensitive threshold currents with a characteristic temperature of almost infinite and even negative values up to 50 °C for the HR/HR QD-LD. To our best knowledge, this is the first confirmation of the temperature-insensitive threshold characteristics by the p-type doping for 1550nm-band ridge-type QD-LDs. It is also noteworthy that the QD-LD with HR/HR structure indicated an extremely high T_0 value of about 400 K in the wider temperature range up to 80 °C.

The temperature characteristics of the threshold current densities under CW condition are shown in Fig 2 for the

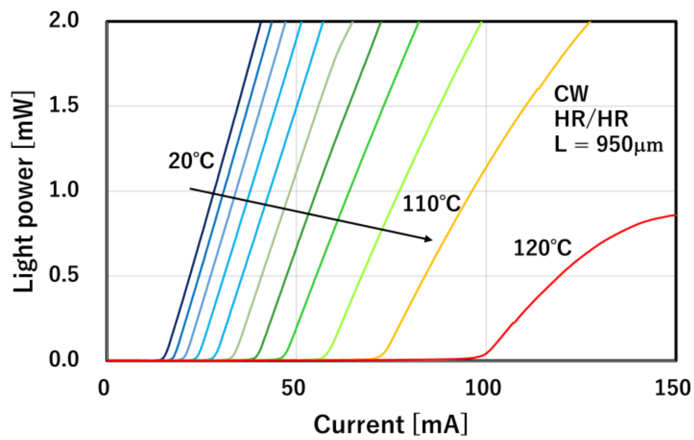

Fig 2. Temperature dependence of current vs. light output characteristics for the QD-LD with HR/HR structure under CW condition.

HR/HR and HR/CL structures. Extremely low threshold currents and threshold current densities were obtained as 16 mA and 0.47 kA/cm^2 for CW condition. Maximum CW operation temperature was up to 120 °C. Also, these results exhibited the remarkably high characteristic temperatures of about 155 K up to 100 °C even under CW condition.

In order to improve the higher output characteristics, the HR/CL structure is effective, and the I-L characteristics at room temperature (20 °C) were measured for the HR/CL QD-LD as well as with HR/HR structure for comparison under pulsed and CW conditions, and the results are shown in Fig 3. The QD-LD with HR/CL displayed the improvement in output light compared to that of the HR/HR with a maximum output power as high as 47 mW and 24 mW under pulsed and CW conditions, respectively.

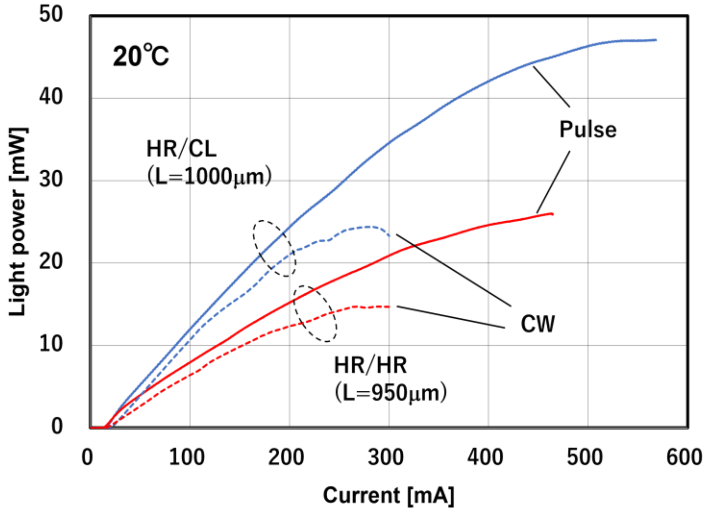

Fig 3. Current vs. light output characteristics for the QD-LDs with HR/CL and HR/HR structures under pulsed and CW conditions.

4. Conclusion

1550nm-band, p-doped, ridge-type InAs/InAlGaAs QD-LDs were fabricated on InP(311)B substrates by MBE with the strain compensation technique with the facets of CL/CL, HR/CL and HR/HR structures. The fabricated QD-LDs exhibited the temperature-insensitive characteristics under pulsed condition, and this superior performance was extended to the high characteristic temperature T_0 of about 155 K up to 100 °C under CW condition for the HR/HR QD-LD. In addition, high output characteristics with a maximum output of 47 mW under pulsed and 24 mW under CW conditions were obtained for the HR/CL.

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5. References

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