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1.3-μm-Wavelength Quantum-Dot Lasers for Temperature-Stable High-Speed Direct Modulation

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Abstract: Low-driving-current temperature-stable 10-Gb/s modulation under fixed driving condition was realized in 1.3-μm-wavelength quantum-dot lasers. For further improvement of modulation characteristics, increased modal gain was also confirmed with antimony-mediated high-density quantum dots.

1. Introduction

Recently, quantum-dot (QD) lasers [1] have been paid much attention because some of their theoretically predicted unique characteristics have been realized owing to the progress in crystal growth technology. Using InAs QDs on GaAs substrates, we can make 1.3-μm-wavelength lasers for optical fiber communication. The drastically improved temperature stability by introducing p-doping to the QD active layers [1-7] is one major advantage of QD lasers compared with conventional quantum-well lasers in the 1.3-μm wavelength range. We have made first demonstration of temperature-stable 10-Gb/s operation using p-doped InAs QD lasers [4] and improved the characteristics so far [5, 7].

In this paper, we describe our recent activities on 1.3-μm-wavelength QD lasers. We have realized low-driving-current temperature-stable 10-Gb/s operation. We also observed the increase in modal gain using antimony-mediated high-density QDs.

2. Low-driving-current 10-Gb/s operation

In QD lasers, strong damping originated from the carrier capture process to the QDs mainly limits the modulation bandwidth [8]. When the threshold gain of the laser is near the maximum modal gain of the ground state of the QDs, carriers occupy most of the ground states under lasing condition. This makes effective carrier capture time longer. Therefore, to realize high-speed modulation, sufficiently high maximum modal gain compared with threshold gain of the laser is required. Based on rate-equation analysis, we have clarified that 10-layer-stacked structure and optimized threshold gain, which is equal to the sum of the internal loss and the mirror loss, of around 15 cm^{-1} is necessary for 10-Gb/s modulation in the case of the dot density with 3 x 10^{10} cm^{-2} [9]. To obtain low driving current, it is essential to choose short cavity length and to set the facet coating for satisfying optimum threshold gain condition.

According to our theoretical analysis, we fabricated 200-μm long lasers with 10-layer-stacked QDs as the active layers. P-type doping was applied to the QD active layers to suppress temperature dependence. To obtain optimum threshold gain for 10-Gb/s modulation, both facets were high-reflection coated with the reflectivity of 81% [7]. The threshold current

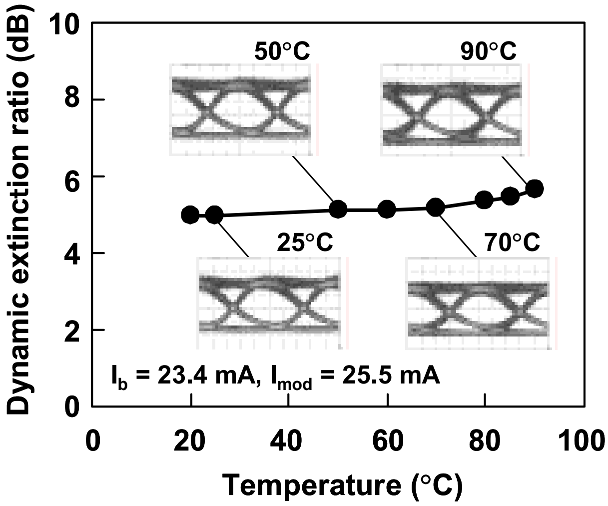

Fig. 1 Temperature dependence of dynamic extinction ratio under 10-Gb/s modulation with fixed driving condition. Insets are eye patterns at 25, 50, 70, and 90°C.

was as small as 2.2 mA at 25°C and the characteristic temperature was 300K between 20 and 50°C. We also obtained output power of more than 5 mW up to 90°C under 40 mA injection current. Fig. 1 shows temperature dependence of dynamic extinction ratio under 10-Gb/s modulation of this laser with fixed driving condition. The bias current was 23.4 mA and the modulation current was 25.5 mA_{pp}. We obtained dynamic extinction ratio of more than 5dB between 20 and 90°C. As shown in the insets of Fig. 1, we obtained clear eye openings although slight degradation was observed at higher temperatures. Using this QD laser and a receiver with an electric dispersion compensator, error-free transmission over 300-m-long multimode fiber between 25 and 80°C was also achieved under fixed driving condition [10].

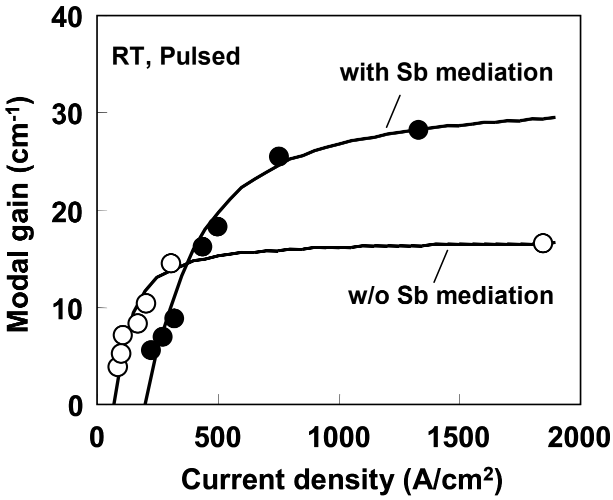

Fig. 2 Current density-gain characteristics of 5-layer-stacked QD lasers with and without Sb mediation.

3. Increased modal gain using high-density QDs

To improve the modulation characteristics further, it is necessary to increase the modal gain of QD active layers [9]. One effective way is to increase the dot density so that various efforts such as graded composition strain reducing layer [11] and antimony (Sb) mediation in the growth procedure [12] have been made. We have investigated Sb irradiation on the GaAs surface just before the InAs QD growth using MBE system and succeeded in growing high-density QDs with 6 x 10^{10} cm^{-2} [13]. This is twice as high as the density without Sb mediation. Using the 5-layer-stacked Sb-mediated high-density QDs, we fabricated broad area lasers [14]. Fig. 2 shows the relationship between current density and modal gain evaluated from measured threshold current densities of the lasers with different cavity structures at room temperature. We clearly observed increase in the modal gain by utilizing Sb-mediated high-density QDs. This result indicates that Sb mediation is a promising way to improve the modulation characteristics in InAs QD lasers.

4. Summary

We have realized low-driving-current temperature-stable 10-Gb/s operation of 1.3-μm-wavelength QD lasers between 20 and 90°C. We have also shown increase in modal gain using Sb-mediated high-density QD active layers. The temperature stable opration of QD lasers is promising for future 1.3-μm-wavelength uncooled light sources and further improvement will be expected.

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