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High-frequency short-pulse generation with a highly stacked InAs quantum dot mode-locked laser diode

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Abstract

A high frequency pulse and a short pulse were generated by a quantum dot (QD) mode-locked laser diode (MLLD). We adopted a highly stacked QD structure using a strain-compensation technique in the active region of QD MLLD to fabricate a short-cavity MDDL. The tow section MLLD structure was fabricated with a cavity length of 500 µm. This laser exhibited lasing with a threshold current of approximately 40 mA. The spectrum of this laser has a well-defined and wide range longitudinal mode. A short pulse approximately 1 ps in width was observed in the interference measurement using a Michelson interferometer.

1. Introduction

Generation of high-frequency and ultrashort optical pulses with mode-locked laser diodes is of great interest for a wide range of applications, including optical data communication, radio over fiber, metrology, and imaging [1,2]. The mode-locked laser diode (MLLD) with a semiconductor quantum dot (QD) in the gain and saturable absorber (SA) region can be expected to realize a high-frequency and ultrashort optical pulse. In this case, the cavity length of the MLLD should be short because the cavity length determines the repetition rate. High-density QDs are required to satisfy this condition from the perspective of having sufficient gain and saturable absorption. We developed a strain-compensation technique to fabricate a highly stacked InAs QDs layer on an InP(311)B substrate [3]. In this scheme, since the tensile strain from InAs was canceled out by the compressive strain from the InGaAlAs embedding layer, the number of stacking layers can be increased without any degradation of the crystal quality. In this study, we fabricated an MLLD wherein the highly stacked QDs were used for both gain and SA media.

2. Experimental results and discussion

The laser structures were grown on a n-InP(311)B substrate by molecular beam epitaxy [4]. After thermal cleaning, the n-InAlAs bottom cladding layer, active layer, p-InAlAs upper cladding layer, and p-InGaAs contact layer were grown. In the active layer, InAs QDs were grown by self-assembly and were capped with a 20 nm-thick InGaAlAs strain-compensation layer. In this study, we adopted 15 InAs QDs layer stacking to fabricate the laser structure. For example, the surface morphology of highly stacked InAs QDs are shown in Fig 1 where uniform and high-density QDs were formed.

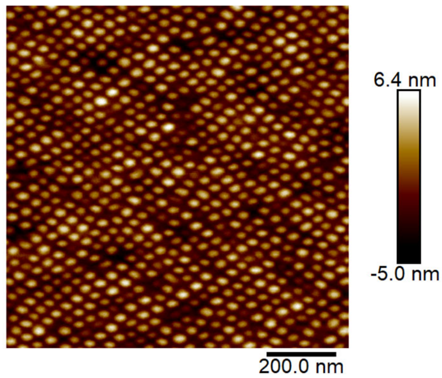

Fig. 1 Atomic force microscope (AFM) image of highly stacked QDs structure.

After the growth of the laser structure, the ridge waveguide structures were fabricated by UV lithography, dry-etching, and metal evaporation. In this process, we fabricated two-section upper p-side electrodes that can bias the gain region and the SA region independently. The ridge waveguide was cleaved with a 50-µm length, and one facet was coated with a high-reflection dielectric mirror. The schematic of the laser structure is shown in Fig 2.

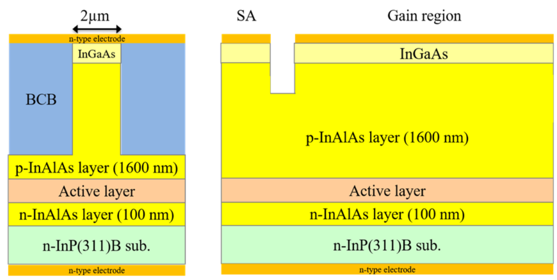

Fig. 2. MLLD structure

Figure 3 shows the current–light output (I–L) characteristic of this QD-MLLD with no bias in the SA region. Although the threshold current was estimated at approximately 40 mA, the I–L curve was significantly different from the typical LD. Figure 4 shows the lasing spectrum at a current of 80 mA in the gain region (without bias in SA). A well-defined and wide range longitudinal mode was observed. The separation of the longitudinal mode was approximately 80 GHz, which corresponds to the frequency calculated from the cavity length. Thereafter, this output was introduced in a Michelson interferometer to evaluate the existence of the pulse and the pulse width.

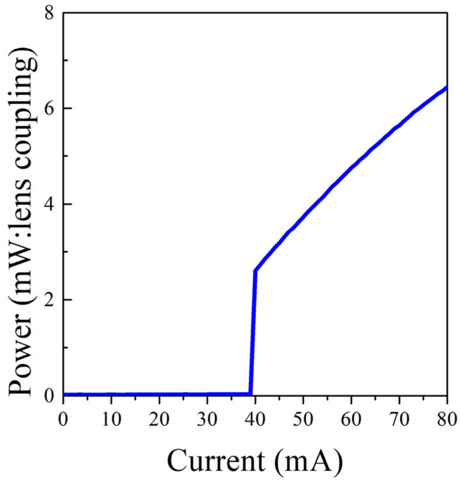

Fig. 3. I–L characteristics of QD-MLLD

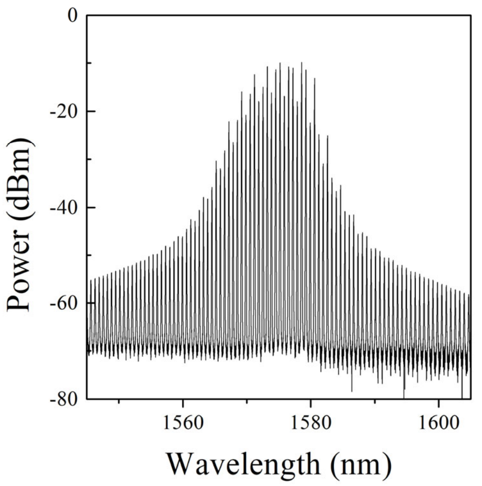

Fig. 4. Lasing spectrum of QD-MLLD

The observed delayed interference signal is shown in Fig. 5. A fitting curve, assuming Gaussian distribution, is used to envelope the interference signal, and it shows 1 ps full-width at half maximum. The repetition rate of each pulse was approximately 80 GHz, which is in good agreement with the separation of the longitudinal mode. Although the cavity length is short, the threshold current of 40 mA is sufficiently small, and the output power is several milliwatts, which means that the QDs density is sufficiently high. Therefore, we can reduce the cavity length to less than 500 μm, and a higher repetition rate is expected in the ultra-short cavity QD-MLLD.

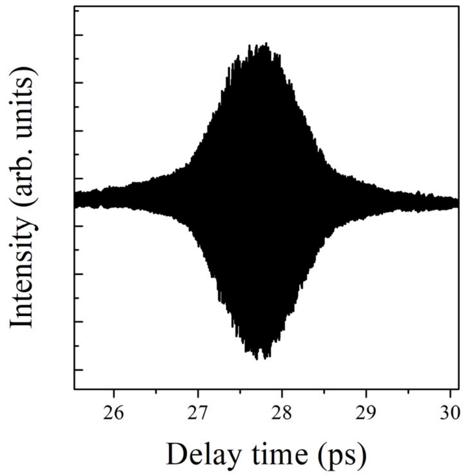

Fig. 5. A delayed interference signal of QD-MLLD evaluated by Michelson interferometer.

3. Conclusions

We have developed the MLLD which includes highly stacked QDs and demonstrate the generation of high frequency optical pulse at 1550 nm wavelength region. The pulse width of approximately 1ps and 80 GHz repetition rate were obtained in this MLLD.

Acknowledgements

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