Characterization of wavelength tunable quantum dot external cavity laser (QD-ECL) for 1.3-μm waveband narrow line-width coherent light source

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1. Introduction

The expansion of wavelength division multiplexing (WDM) channels increases usable wavelength bands and optical frequency resources. Therefore, we have recently focused on thousand-band (T-band) and O-band (1.00–1.26 μm and 1.26–1.36 μm, respectively) for optical communications because optical frequency resources greater than 10 THz can be employed at these wavebands [1, 2]. It has been anticipated that these wavelength bands will be used for metro/access photonic networks and as optical interconnects in datacenters [3]. To increase the frequency utilization efficiency for data transmission, coherent communication technology has also been intensively investigated worldwide. One of the essential components for realizing a coherent communication system is a narrow line-width wavelength tunable coherent light source. It is well known that a narrow spectrum line-width of less than a few hundred kHz is required to achieve a quadrature amplitude modulation (QAM) format [4]. In the near future, it is believed that coherent communication technology will be applied to the T- and O-bands of photonic transport systems to achieve optical communications with ultra-high bit-rates and capacities.

A self-assembled quantum dot (QD) laser diode fabricated on a large-diameter GaAs wafer has attracted considerable attention as a T-band or O-band light source as it offers low cost, low power consumption, and high performance. Therefore, we have considered a QD structure to be one of the most promising candidates among optical gain media for lengthening the operating wavelengths of light sources. Additionally, we have proposed a novel sandwiched sub-nano separator (SSNS) growth technique for obtaining high-quality and high-density QD optical gain media operating in the T- and O-bands [2].

Based on these considerations, it is easy to project that a narrow line-width wavelength tunable QD laser will become an essential component for constructing WDM and coherent communication systems operating in the T- and O-bands. Therefore, in this study, we developed and characterized a narrow line-width wavelength tunable InAs/InGaAs QD external cavity laser (QD-ECL) using the SSNS growth technique for O-band operation.

2. Fabrication of wavelength tunable QD-ECL using SSNS growth technique

Self-assembled InAs QD structures were grown on (001)-oriented n-type GaAs substrates using solid-source molecular-beam epitaxy (MBE). Recently, we proposed a novel InAs/InGaAs QD structure using an SSNS growth technique [2]. According to this technique, a sandwiched GaAs thin film was used to modify the surface conditions of the quantum well (QW) under the QD structure. Fig. 1(a) shows an atomic force microscope (AFM) surface image of the 2.76-ML InAs QD fabricated on a 10-ML In0.15Ga0.85As QW using the SSNS growth technique. A 3-ML (0.85-nm) GaAs thin film was used as the SSNS structure. We confirmed that the SSNS technique would largely suppress the giant dot structures, achieving an ultra-high QD density of approximately 8.0 × 1010/cm2.

To develop a 1.3-μm waveband QD optical gain chip, a multi-stacked InAs/InGaAs QD as an active-region was formed on the GaAs substrate. Fig. 1(b) is a cross-sectional image of the fabricated optical gain chip consisting of the 7-stacked InAs/InGaAs QD structure fabricated using the SSNS growth technique. Additionally, carrier-doped quantum dots were further grown on the InGaAs QD structure to adjust the emission wavelength. The thickness of the GaAs spacer layers in the InGaAs quantum well was optimized to obtain the desired emission wavelength at 1.3 μm.

3. Experiment and Characterization

A self-assembled quantum dot (QD) laser diode fabricated on a large-diameter GaAs wafer has attracted considerable attention as a T-band or O-band light source as it offers low cost, low power consumption, and high performance. Therefore, we have considered a QD structure to be one of the most promising candidates among optical gain media for lengthening the operating wavelengths of light sources. Additionally, we have proposed a novel sandwiched sub-nano separator (SSNS) growth technique for obtaining high-quality and high-density QD optical gain media operating in the T- and O-bands [2].

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To develop a 1.3-μm waveband QD optical gain chip, a multi-stacked InAs/InGaAs QD as an active-region was formed on the GaAs substrate. Fig. 1(b) is a cross-sectional image of the fabricated optical gain chip consisting of the 7-stacked InAs/InGaAs QD structure fabricated using the SSNS growth technique. Additionally, carrier-doped quantum dots were further grown on the InGaAs QD structure to adjust the emission wavelength.
1.5-μm AlGaAs cladding layers were grown at 540 °C. A ridge-type waveguide structure was fabricated with an electrode width of 3.4 μm and a waveguide length of 1950 μm. Fig. 2(a) shows the setup of the fabricated QD-ECL. The temperature of the QD gain chip was fixed at 300 K using a thermo-electric controller (TEC). One of the cleaved facets of the QD optical gain chip had an anti-reflection (AR) coat for the 1.3-μm waveband. An external cavity was constructed with a cleaved facet of the QD optical gain chip and a half-mirror (reflectance: 60%), where the total cavity length was as small as approximately 40 mm. We also used a narrow band-pass filter (bandwidth: <0.4 nm) and an etalon filter (free spectrum range: 100 GHz) to select a single optical mode for the lasing. As seen in Fig. 2(b), a compact bench-top coherent light source module was successfully developed for the wavelength tunable QD-ECL.

3. Characterization of narrow line-width wavelength tunable QD-ECL.

Fig. 3 shows the dependence of the threshold current on the lasing wavelength tunable InAs/InGaAs QD-ECL. The authors would like to thank the staff of Koshin Kogaku Co., Ltd. and Sevensix, Inc. Thanks are due to Prof. H. Sotobayashi of Aoyama Gakuin Univ., the staff of the Photonic Device Laboratory, Dr. A. Kanno, and Dr. I. Hosako of NICT.

References