Near-field measurement of quantum dot broad area laser diodes by utilizing near-field scanning optical microscope: Effects of the linewidth enhancement factor on filamentation

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Abstract—Near-field scanning optical microscopy (NSOM) studies of broad area laser diodes (BALD) with different structures of quantum dot (QD) and quantum well (QW) were performed. The values of $\alpha$-factor for the two types of BALD were measured as 0.6 (QD) and 2 (QW), respectively. Near-field measurements show that the filamentation in the BALD is closely related to the $\alpha$-factor. Moreover, the high resolution (<100 nm) of NSOM provides a detailed mapping of the BALDs output from the active region.

Keywords-component: quantum dot; broad area laser diode; near-field scanning optical microscope

I. INTRODUCTION

In the past several years, quasizero dimensional system, especially self-assembled semiconductor quantum dot (QD) grown by using the Stranski-Krasstanow (S-K) mode has been investigated from a fundamental physics point of view and for the potential applications to a device. The previous investigations have predicted that the QD laser should have higher gain, lower threshold current density, and higher thermal stability compared with other quantum structure, which are due to the atomic-like density of state in the QD system [1].

It is well known that the filamentation in the broad area laser diodes (BALD) is closely related to the linewidth enhancement factor ($\alpha$-factor) [2]. While normal $\alpha$-factor in the multiple-quantum well (MQW) structure are 2–4, it is expected and calculated that $\alpha$-factor in QD are under 1. This means that the filamentation in the BALD with QD structure would be delayed until higher current level.

In this study, we have experimentally investigated the different of near-field between QD- and QW-BALD samples by utilizing near-field scanning optical microscope (NSOM). $\alpha$-factor in the QD-BALD was measured to be around 0.6, while in the QW around 2. From NSOM measurement, it is clearly observed that the extent of filamentation is strongly related to the $\alpha$-factor. It was observed that the BALD with QD kept single mode beam under higher current level than the BALD with QW. This study experimentally supports theoretical predictions that the linewidth enhancement factor is strongly related to the filamentation of BALDs.

II. EXPERIMENTAL DETAILS

A. Device fabrication

Two different BALD structures were grown by a molecular beam epitaxy. The QD-BALD is self-formed during alternate supply of precursors by using the atomic layer epitaxy (ALE) technique. For the QD active layer, 3 InAs-QD/InGaAs/GaAs layers and 3 InAs-QD/GaAs layers are used. The active layer was sandwiched by 18 periods of Al$_{0.3}$Ga$_{0.7}$As (2 nm)/GaAs (2 nm) for the separate-confinement layer (SCL). The cladding layers outside the n- and p-SCL were n- and p-Al$_{0.35}$Ga$_{0.65}$As (1.52 $\mu$m, 3 × 10$^{18}$/cm$^3$). Finally, p-GaAs (400 nm, 2 × 10$^{19}$/cm$^3$) was grown as cap layer for the ohmic contact [3].

The QW-BALD active region consists of four periods of a 3 nm thick 0.5 % compressively strained InGaAs well and 20 nm lattice-matched InGaAsP (1.25 $\mu$m-Q) barrier. The stack of QW/barrier was sandwiched in a 20 nm thick inner InGaAsP (1.25 $\mu$m-Q) bounding separate-confinement heterostructure layer [4].

B. Near-field scanning optical microscope measurement

Collection mode NSOM system is used to study the near-field scanning image as a function of bias current for the BALDs with different structures of QD and QW. Probe tip is mounted on an x-y-z piezo, which is scanned relative to the sample. Simultaneous shear-force measurements provide an independent measure of the surface topography to maintain a fixed proximity (~10 nm) between tip and sample. The laser emission was collected through a ~80 nm diameter aperture, resulting in <100 nm spatial resolution.
III. RESULTS AND DISCUSSION

Near-field scanning images of the active region are obtained by collecting the electroluminescence (EL) as the tip is scanned across the surface. In Fig. 1, a set of $30 \times 7 \mu m$ images centered around the active region of the QD- and QW-BALD samples are shown as a function of bias current. White regions represent areas emitting the most light, while darker regions represent areas emitting less light. A single-mode near-field scanning images from the QD-BALD sample are shown at $I < I_{th}$, $I = I_{th}$, and $I > I_{th}$ in Fig. 1(a). At the below threshold current, a broad emission distribution is observed. It is note that many carriers do not contribute to the lasing mode. However, the vertical- and lateral-mode narrows when the laser is driven above threshold, and that no filamenting is observed. On the other hand, multi-mode near-field scanning image from the QW-BALD sample is shown above threshold in Fig. 1(b).

Transverse-mode behavior can be extracted from cross sections of these spatial maps. The transverse cross sections of the emission of the BALD samples are plotted in Fig. 2. Note in QW-BALD sample, above threshold, we see a significant separation of the mode. On the other hand, the QD-BALD kept single mode beam under higher current level than the QW-BALD. Marciante et al. have reported that the $\alpha$-factor is a significant element affecting the filamentation and that it appears slowly, as the $\alpha$-factor is smaller [2]. Unfortunately, there have been no experimental reports to prove this theoretical assertion. However, we have experimentally investigated the effect of the $\alpha$-factor on filamentation by using NSOM. This result show another evidence that QD structure might be more adequate for high power laser diodes with single mode beam characteristics.

IV. CONCLUSION

We have fabricated QD- and QW-BALD samples for the epi-structures having different values of $\alpha$-factor. The $\alpha$-values of lasers for the QD structure and for the QW structure were about 0.6 and 2, respectively. From near-field measurement, it is clearly observed that the extent of filamentation is strongly related to the $\alpha$-factor. It was observed that the BALD with QD kept single mode beam under higher current level than the BALD with QW.

REFERENCES