III 族-窒化物量子ドットレーザの発振閾値電流に関する考察

A theoretical study on threshold currents of III-nitride quantum dot lasers

ナノ量子機構 [1] 東大生産研 [2] ○陶 仁春 [1]，荒川 泰彦 [1,2]
NanoQuine[1], IIS. Univ. of Tokyo[2], ○Renchun Tao[1], Yasuhiko Arakawa[1, 2]
E-mail: rctao@iis.u-tokyo.ac.jp

III-nitride semiconductors have been attracting increasing interest in the fields of commercial products, such as laser diodes (LDs). In III-nitrides, InGaN alloys are key materials for green, blue and violet applications. However, the threshold currents of InGaN quantum well (QW) LDs are usually quite large [1]. One of the important factors is the large effective mass of electrons and holes in III-nitrides, which result in larger density of states, slow increasing of Fermi levels, and thus higher injection threshold of carriers. Although the band-mixing effects induced by strain in QWs tend to reduce the effective mass and reduce LDs' threshold, quantum dots (QDs) should be better in terms of injection threshold [2], as the complex strain and three dimensional confinements in QDs could reduce the effects of heavy effective-mass by forming δ-function-like density of states. Considering the larger effective of III-nitrides than III-arsenides, using QDs for low threshold laser applications should be more effective than QW lasers in III-nitrides [3]. So far, comprehensive and comparison studies about these issues of III-nitride QD and QW lasers are still rare. In this study, we report a comparison investigation of III-nitride QD and QW lasers by theoretical simulations. It is found that, with InGaN QDs other than QWs for low-threshold lasers, III-nitrides could be more advantageous than their III-arsenide counterparts.

For both QD and QW lasers, the same ridge-type laser structures are assumed (Fig. 1(a)). The 6×6 k p method is used to calculate the valence bands with effective mass approximation method for conduction bands. Strain and polarization field are also included. We assume $In_{0.2}Ga_{0.8}N/In_{0.02}Ga_{0.98}N$ QDs (Fig. 1(b)), which are of truncated-hexagonal-pyramid shape, with a=10 nm, b=20nm, h=1.5nm, a density of $5 \times 10^{10} cm^{-2}$ and a 0.5-nm-thick wetting layer. To have the same ground state emission energy, the thickness of QWs is set to be 2.0 nm.

The calculated peak modal gain with radiative injection current is shown in Fig. 2. It can been seen that the ratio of transparency current density of single layer InGaN QW laser to InGaN QD laser is about 20, a ratio value much larger than their III-arsenide counterparts (~7 times in ref. [4]). When the total loss is below 10 /cm, an InGaN QD laser with much lower threshold current could be realized. These results show that, for low-threshold laser applications, using InGaN QDs other than QWs could be more advantageous than their III-arsenide counterparts.

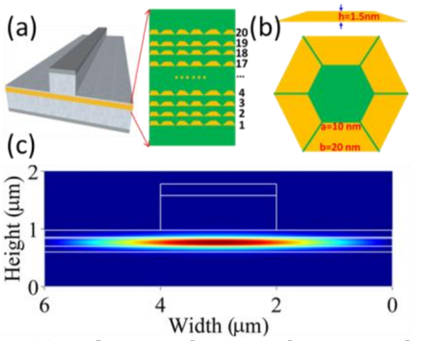

Fig. 1 (a) Ridge-type laser, with 20 periods of active layers; (b) QD parameters; (c) Optical filed profile of fundamental mode.

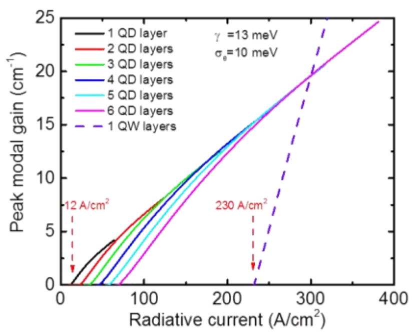

Fig. 2 Peak modal gain vs radiative injection current; with single layer, the transparency density of QD laser is 20 times smaller than QW.

Acknowledgements

The authors thank Satoshi Iwamoto, Munetaka Arita and Teruhisa Kotani for discussions. This work was supported by the Grant-in-Aid for Specially Promoted Research (15H05700) and the NEDO project.

Reference:

[1] S. Nakamura et al., Jpn. J. Appl. Phys. **35**, L74(1996).
[2] Y. Arakawa and H. Sakaki, Appl. Phys. Lett. **40**, 939 (1982).
[3] Y. Arakawa, IEEE J. of Sel. Top. in Quantum. Electron **8**, 823(2002).
[4] W. W. Chow et al., 2015 IEEE Photonics Conference (IPC), TuE1.3(2015).