The 27th Iranian Conference on Optics and Photonics (ICOP 2021), and the 13th Iranian Conference on Photonics Engineering and Technology (ICPET 2021).
University of Sistsn and Baluchestan, Zahedan, Iran, Feb. 2-4, 2021

کد مقاله: A-۱۰-۱۷۵۶-۱

تحلیل عددی فاکتور کیفیت برای لیزر میکرو دیسک مبتنی بر GaAs در طول موج ۱۵۵۰ نانومتر

نیما شریفی، حمید واحد

دانشکده‌ی مهندسی برق و کامپیوتر، دانشگاه تبریز، تبریز، ایران

Nima.sharifi97@ms.tabrizu.ac.ir , Vahed@Tabriz.ac.ir

چکیده- ما در این مقاله به بررسی فاکتورهای کیفیت در لیزرهای میکرودیسک طراحی و شبیه‌سازی شده به روش سه بعدی FDTD می‌پردازیم. تاثیرات اندازه‌ی شعاع میکرودیسک و عرض موجبر خروجی لیزر را بر روی فاکتور کیفیت در ناحیه‌ی فعال لیزر مورد بررسی قرار می‌دهیم. نتایج حاصل نشان می‌دهد که در شعاع ۱۴ میکرومتر و عرض موجبر ۱ میکرومتر بالاترین میزان فاکتور کیفیت را خواهیم داشت که در حدود ۲۱۳۴/۴ می‌باشد.

کلید واژه- لیزرهای میکرودیسک، روش تفاضل محدود حوزه‌ی زمان (FDTD)، فاکتور کیفیت (Q-Factor)

Numerical analysis of Quality Factor for microdisk laser based on GaAs at wavelength 1550 nm

Nima Sharifi, Hamid Vahed

Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran
Nima.sharifi97@ms.tabrizu.ac.ir , Vahed@tabrizu.ac.ir

Abstract- In this paper, we investigate the quality factors in multi quantum wells (QWs) microdisk lasers, that's it designed and simulated by the three-dimensional finite-difference time-domain (3D FDTD) method. We examine the effects of microdisk laser diameter and laser output waveguide width on the quality factor in the active region of laser. The results show that when the microdisk laser with a diameter of 14µm and a waveguide width of 1µm, at wavelength 1550nm, our quality factor is maximized. We found the mode quality factor about 2134.4.

Keywords: Microdisk lasers, FDTD, Quality factor, GaAs, Waveguide.

The 27th Iranian Conference on Optics and Photonics (ICOP 2021)
The 12th Iranian Conference on Photonics Engineering and Technology (ICPET 2021)
University of Siastan and Baluchestan, Zahedan, Iran, Feb. 2-4, 2021.

1. Introduction

Semiconductor lasers have been widely used in various fields rapidly, such as large-scale integrated device and long-distance optical fiber communication systems. In the field of semiconductor lasers, enhancing the quality and efficiency of laser output light is one of the facing serious challenges for researchers in this field [1,2]. Although, there have been some limitations, but semiconductor lasers are more commonly used in optical chips and integrated circuits [3,4]. The advantage of using Gallium Arsenide (GaAs) as substrate in these lasers is the robustness of its structure and its low cost, which multiplies the motivation of researchers to use this structure in semiconductor lasers [4]. Accordingly, the use of this substrate accelerates studies and advances in optical telecommunication systems and integrated circuits [5,6].

Usually, GaAs/InP wafer bonding technology is used to fabrication of GaAs based laser at wavelength 1.55 µm which is also of high cost and high complexity [7]. At other work, researchers fabricated GaAs/AlGaAs microdisk lasers with diameter about 2 µm at temperatures 80ºK [8]. Also, InAs/InGaAs quantumdots based lasers with GaAs substrate is fabricated [9,10]. Recently, the microcavity lasers have attracted attention because of high quality factor (Q-factor), easy integration and low cost [11,12].

In this paper, we investigate the structure of 1.55µm InGaAs/InGaAsP-based multi quantum well (MQW) laser on InP layers, which are located on a GaAs substrate. To improve the laser efficiency at telecommunication wavelength (1.55µm), select the laser cavity shape in circles and use the three-dimensional (3D) finite-difference time-domain (FDTD) method to investigate and simulate the structure and laser quality factor. We study the dependence of the quality factor on the diameter of laser cavity (d) and the output waveguide width (w) of the laser.

2. Device Structure

The schematic structure of microdick laser epilayers is illustrated in Fig. 1. GaAs, low-temperature InP and high-temperature InP buffer layers with thickness of 300nm, 15nm and 1100nm, respectively, were sequentially placed on the substrate and hardened by heat. 500nm coating layer of n-InP is grown on it. The laser active region consisting of 5 series of 5nm InGaAs and 10nm InGaAsP are encapsulated between two 100nm and 90nm InGaAsP layers. Finally, InP cladding layer and InGaAs contact layer is grown with thickness of 1500nm and 200nm, respectively.

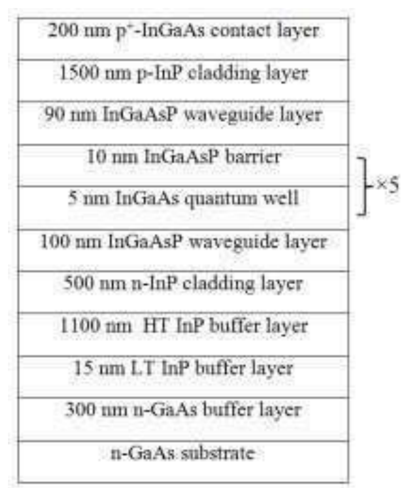

Fig. 1: Schematic structure of the microdisk laser epilayers

Figure 2. show the schematic structure of microdisk Laser based on multi QWs with an output waveguide at 1.55µm. The laser cavity is surrounded by a layer of benzocyclobutene (BCB) and 200nm nitride (SiNx). The diameter of the cavity, the output waveguide width, and the height of the cavity are denoted by the letters d, w, and h, respectively.
The refraction index of air, BCB, SiNx, and active region are 1, 1.54 [13], 2.0 and 3.4, respectively. The refractive indexes of GaAs and InP material

are selected 3.34 and 3.17. The simulation wavelength is set to be 1550nm and propagated by a megnatic dipole source. The number of mesh points per wavelength and the simulation time are set to 0.1 and 1500fs, respectively. The mode Q-factors are investigated from the Q analysis in center of waveguide.

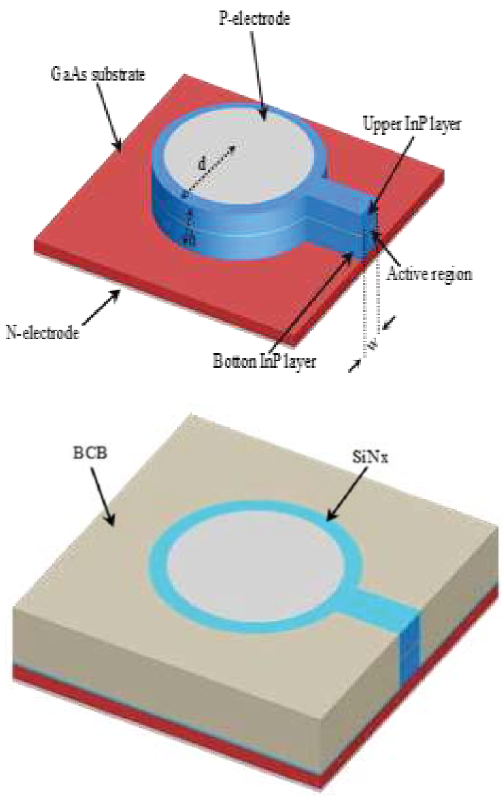

Fig. 2. schematic diagram of the microdisk laser cavity (upper picture) and the device model of the microdisk laser cavity (lower picture).

2.1. Results and Discussion

Firstly, we study the quality factor with respect to the diameter of microdisk cavity. Figure 3 show the Q-factor as a function of the microdisk cavity which is a microdisk laser on GaAs substrate when the etching depth (h), width of waveguide (w), wavelength (λ) and simulation time are 3.87µm, 1µm, 1550nm and 15000fs, respectively. As the diameter increases from 8µm to 14µm in this laser Q-Factor shows an increasing trend from about 1231 to 2134.4, When the Diameter increases from 14µm to 18µm, the Q-Factor decreases in the output quality factor to 1203.2. Finally, the Q-factor reaches the maximum value 2134.4 at the diameter of microcavity at 14µm.

After examining the results obtained for the Q-factor versus the diameter of microdisk laser cavity and selecting the microdisk laser with diameter of 14µm is the highest laser output quality factor. We resize the output waveguide width in this laser, to evaluate the quality factor as a function of the waveguide width. The waveguide widths are set to be 0.5, 1, 1.5, 2, 2.5, 3µm, and the results are shown in Fig. 4. In this case, by increasing the waveguide width from 0.5µm to 1µm, the quality factor increases from about 1320.8 to 2134.4, and by resizing the waveguide width to 3µm, the relative decrease in the simulated microdisk laser output quality factor reaches to about 1002.8. Figure 4 show the maximum Q-factor is obtained for the waveguide width 1µm.

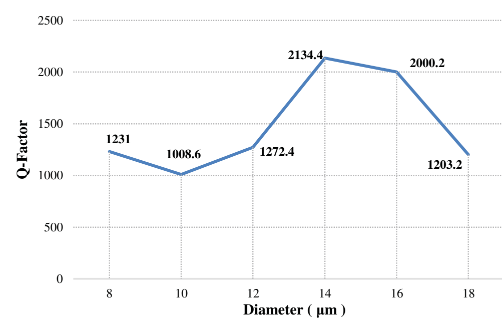

Fig. 3. Q-factor with respect to the diameter of microdisk cavity

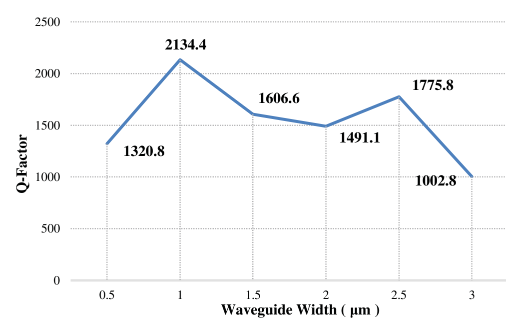

Fig. 4. The tendency of mode Q-factor with the waveguide width

2.2. Conclusion

In cunclusion, we design and improve the 1550 nm multi QWs microdisk laser on the GaAs substrate with the InGaAs / InGaAsP-based active region by the three-dimensional time-domain finite-difference method (3D FDTD) of laser output quality factors. We investigated and simulated different output waveguide widths with the highest microdisk laser output quality factor of 14μm with a diameter of the laser cavity 14μm and an output waveguide width 1μm. This slider can perform better than others in the field of electric chips and integrated circuits.

References

[1] H. Ron, K.W. Mai, M.A. Horowitz, The future of wires, Proc. IEEE, Vol. 89, No. 4, pp. 490–504, 2001.

[2] J.A. Davis, R. Venkatesan, A. Kaloyeros, M. Beylansky, S.J. Souri, K. Banerjee, K.C. Saraswat, A. Rahman, R. Reif, Interconnect limits on gigascale integration (GSI) in the 21st century, Proc. IEEE, Vol. 89, No. 3, pp. 305–324, 2001.

[3] K.F. Yarn, W.C. Chien, C.L. Lin, C.I. Liao, Direct growth of high-quality InP layers on GaAs substrates by MOCVD, Act. Passive Electron. Components, Vol. 26, No. 2, pp. 71–79, 2003.

[4] J.H. Jang, G. Cueva, D.C. Dumka, W.E. Hoke, P.J. Lemonias, P. Fay, I. Adesida, The impact of a large bandgap drift region in long-wavelength metamorphic photodiodes, IEEE Photon. Technol. Lett., Vol. 13, No. 10, pp. 1097–1099, 2001.

[5] H.Q. Zheng, K. Radhakrishnan, H. Wang, K.H. Yuan, S.F. Yoon, G.I. Ng, Metamorphic InP/InGaAs double-heterojunction bipolar transistors on GaAs grown by molecular-beam epitaxy, Appl. Phys. Lett., Vol. 77, No. 6, pp. 869–871, 2000.

[6] F.E. Ejeckam, C.L. Chua, Z.H. Zhu, Y.H. Lo, M. Hong, High-performance InGaAs photodetectors on Si and GaAs substrates, Appl. Phys. Lett., Vol. 67, No. 26, pp. 3936–3938, 1995.

[7] V.M. Ustinov, A.E. Zhukov, GaAs-based long-wavelength lasers, Semicond. Sci.Technol., Vol. 15, R41-R54, 2000.

[8] U. Mohideen, W. S. Hobson, S. J. Pearton, F. Ren, R. E. Slusher, GaAs/AlGaAs microdisk lasers, Applied Physics Letters, Vol. 64, No.15, pp. 1911, 1994.

[9] L.Y. Karachinsky, T. Kettler, I.I. Novikov, Metamorphic 1.5 μm-range quantum dot lasers on a GaAs substrate, Semicond. Sci. Technol., Vol. 21, pp. 691–696, 2006.

[10] S.R. Bank, H.P. Bae, H.B. Yuen, L.L. Goddard, M.A. Wistey, T. Sarmiento, J.S. Harris, Low-threshold CW 1.55-μm GaAs-based lasers, Proc. OSA/OFC, pp. 1646–1648, 2006.

[11] Xing Ma, Jun Wang, Zhuo Cheng, Zeyuan Yang, Haiyang Hu, Wei Wang, Haiying Yin, Yongqing Huang, Xiaomin Ren, Numerical analysis of the output waveguide design for 1.55μm square microcavity lasers directly grown on GaAs substrates, Physica E: Low-dimensional Systems and Nanostructures, Vol. 101, pp. 157–161, 2018.

[12] Wei Wang, Jun Wang, Zhuo Cheng, Zeyuan Yang, Haiying Yin, Xing Ma, Yidong Zhang, Ming Yang, Haiyang Hu, Yongqing Huang, Xiaomin Ren, Numerical analysis of the electrically pumped 1.3 μm InAs/InGaAs quantum dot microdisk lasers on silicon with an output waveguide, Physica E: Low-dimensional Systems and Nanostructures, Vol. 108, pp. 404–410, 2019.

[13] N.A.M. Yahya, W.H. Lim, K.D. Dambul, H. Ahmad, R. Zakaria, F.R. Mahamd adikan, Fabrication and characterization of a dual layer multiple refractive index benzocyclobutene polymer platform for integrated optical devices, Opt. Mater., Vol. 34, No. 11, pp. 1735–1741, 2012.