Design of Square Microlasers for Dual-Transverse-Mode Lasing With Tunable Wavelength Intervals

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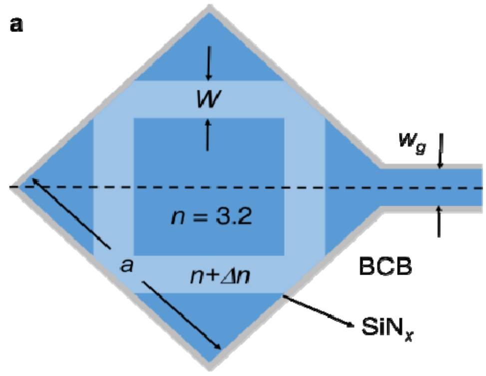
***Abstract*—Square microlasers with a patterned electrode are designed for realizing two-transverse-mode lasing with a tunable wavelength interval. The fabricated microlaser shows the dual-wavelength lasing with the wavelength interval varied with the injection current.**

I. Introduction

Dual-wavelength semiconductor lasers can be used for photonic microwave generation [1]. Recently, we have investigated mode characteristics for square microlasers with an output waveguide connected to one vertex or the midpoint of one side of the square resonator [2]. Single transverse mode and two-transverse-mode operations are realized for the square microlasers. In this talk, we design a square microlaser with a patterned electrode for realizing dual-wavelength lasing with tunable wavelength intervals based on the operation of two transverse modes.

II. Comparison of Microdisk and Microring Lasers

For a microsquare laser with a vertex output waveguide, dual-wavelength lasing with the wavelength interval of 0.56 nm was obtained at the 20-μm-side-length square resonator [2]. In the microsquare resonator connected with a vertex output waveguide, the fundamental and the first-order transverse modes usually have high Q factors for realizing dual-wavelength lasing, because the modes have weak mode field distributions around the square vertices. As the side length reduces from 30 to 10 μm, the simulated mode wavelength interval $\Delta\lambda$ between the fundamental and the first-order transverse modes increases from 0.27 to 1.86 nm (34 to 238 GHz), around the mode wavelength of 1550 nm. To adjust the transverse mode wavelength intervals, we design a square microlaser with a square-ring electrode as shown in Fig. 1(a), to modulate the carrier and refractive index distributions inside the resonator, where a, w_g and W are the side length of the square resonator, the output waveguide width and the electrode opening width, respectively. Assuming the electrode region has a refractive index step Δn relative to the other region for the square microresonator, we calculate the mode wavelength intervals for the square resonator with refractive index $n_0 = 3.2$ confined by 0.2-μm SiN_x and bisbenzocyclobutene (BCB) layers with the refractive indices of 2 and 1.54, respectively. 2D FDTD method is used to simulate the mode properties for the square resonators. The refractive indices of the laser wafer, SiN_x and BCB are set to be 3.2, 2.0 and 1.54, respectively. The spatial steps Δx and Δy are set to be 20 nm, and the time step Δt for the FDTD simulation is set to be 4.33×10^{-17} s according to the Courant condition. The following excitation source is added to one component of the electromagnetic fields inside the resonator $P(t) = \exp[-(t-t_0)^2/t_w^2]\cos(2\pi f_0 t)$. The simulated mode wavelength intervals $\Delta\lambda$ versus Δn are shown in Fig. 1(b) for the square resonators with a = 20 μm, w_g = 1.5μm, W = 2 μm (square symbols), and a = 30 μm, w_g = 2.5μm, W = 4 μm (circular symbols), respectively. The results indicate that as Δn increases from -0.004 to 0.005, the mode wavelength interval $\Delta\lambda$ increases from 0.28 to 1.33 nm and 0.04 to 1.36 nm for the cases with a = 20 and 30 μm, respectively.



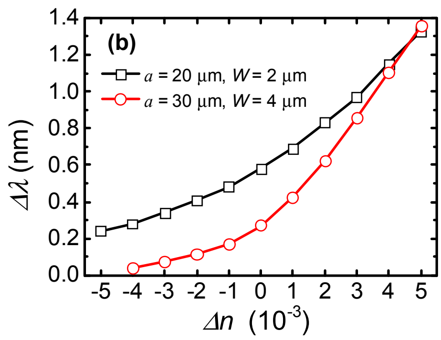


Fig. 1. (a) Schematic of the square microlaser with a square-ring electrode, and (b) the simulated mode wavelength intervals versus Δn for the square resonators with the side length a = 20 μm, w_g = 1.5 μm, W = 2 μm (square symbols), and a = 30 μm, w_g = 2.5μm, W = 4 μm (circular symbols), respectively.

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III. Dual-Wavelength Microsquare Lasers

Square resonator microlasers are fabricated using an AlGaInAs/InP laser wafer grown by metal-organic chemical vapor deposition. The microscopic image of a square microlaser with the patterned electrode is shown in Fig. 2(a), which is fabricated by contacting photolithography and inductively coupled-plasma (ICP) etching techniques as in [2]. For a square microlaser with the side length a = 30 μm, the output waveguide width w_g = 2.5μm, and the electrode opening width W = 4μm, we measure the output powers coupled into multiple mode fiber (MMF) and single mode fiber (SMF), and the applied voltage versus the continuous-wave injection current. The results are plotted in Fig. 2(b), which shows the highest powers coupled into the MMF and SMF are 0.44 and 0.11 mW at the current of 73 mA, respectively. The lasing spectrum at the injection current of 90 mA is plotted in Fig. 3(a). The corresponding high resolution spectrum is presented in the inset of Fig. 3(a), which shows the dual-wavelength lasing for two transverse modes. The corresponding wavelength interval and the intensity ratio of the dual-mode around 1563 nm are plotted in Fig. 3(b) as the functions of the injection current. Dual-transverse-mode lasing with the intensity ratio less than 2.5dB is realized from 89 to 108 mA, and the corresponding wavelength interval increases from 0.25 to 0.37 nm (31 to 46 GHz), which is related to Δn from -0.20×10^{3} to 0.70×10^{3} as compared with the results in Fig. 1(b). As marked in the lasing spectrum in the inset of Fig. 3(a), we observe two four-wave mixing (FWM) peaks at 1562.59 and 1563.35 nm resulting from the dual lasing peaks of 1562.84 and 1563.09 nm. In addition, two transverse modes around 1555.3 nm are observed with the intensity of 18 dB less than the main lasing modes.

IV. Conclusions

In summary, we have designed square microlasers with a patterned electrode for inducing refractive index distribution, which can result in two-transverse mode lasing with a tunable wavelength interval. The fabricated square microlasers verifies two-transverse-mode lasing with a tunable wavelength interval. We can expect to realize tunable microwave signal from the microlasers.

References

[1] Y.-H. Lo, Y.-C. Wu, S.-C. Hsu, Y.-C. Hwang, B.-C. Chen, and C.-C. Lin, "Tunable microwave generation of a monolithic dual-wavelength distributed feedback laser," *Opt Express*, vol. **22**, pp.13125-13137, 2014.

[2] H. Long, Y. Z. Huang, Y. D. Yang, L. X. Zou, X. M. Lv, B. W. Liu, J. L. Xiao, and Y. Du, "Mode characteristics of unidirectional emission AlGaInAs/InP square resonator microlasers," *IEEE J. Quantum Electron.*, vol. 50, pp.981- 989, 2014.

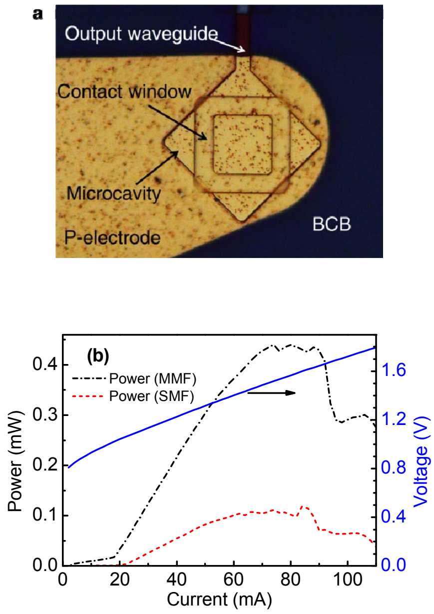

Fig. 2. (a) Microscopic image of the fabricated square microlaser. **(b)** Output powers coupled into MMF (dash dot line) and SMF (dash line), and the applied voltage (solid line) versus the continuous-wave injection current.

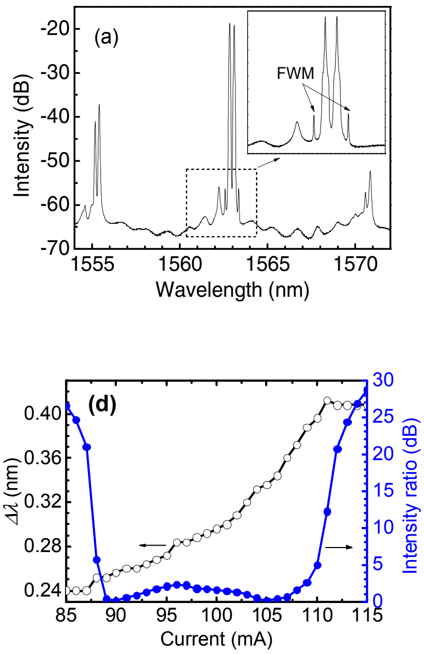

Fig. 3. (a) Lasing spectra at the injection current of 90 mA, and (b) wavelength interval and intensity ratio of the dual-wavelength versus the injection current.