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Parity-Time Symmetry breaking in First-order Distributed Feedback Lasers

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Abstract: It is of fundamental significance to effectively manipulate the cavity resonant modes in laser physics. Recent explorations of parity-time symmetry provide an opportunity to realize stable single-mode lasing by strategically structuring gain and loss in the laser cavity. Here we experimentally report, for the first time, high-output single-mode lasing with relatively low threshold current in first-order distributed feedback cavities with broken parity-time symmetry structure.

Introduction

Laser, light amplification by stimulated emission of radiation, is of great significance to many important fields like communications, medicine and defense. How to realize single-mode operation through spatial and spectral control of the cavity is one of the primary goals of laser design. Recently, inspired by the concept in quantum physics and thanks to the equivalence of Schrödinger equation vs wave equation, parity-time symmetry (PT-symmetry) [1] was proposed and demonstrated experimentally in optics [2] to reach single-mode operation [3,4] in laser systems via delicately arranged gain and loss in resonators. However, to the best of our knowledge, the performance of these reported PT-symmetric lasers has the usual hallmarks of first and demanding lab-level demonstrations (here low output with high consumption), which although fostering very interesting physics, still remain far from real-world applications.

Our research mainly focuses on the implementation of single-frequency PT-symmetric lasing on a distributed feedback (DFB) platform due to its potential high yield and thus lowered cost for monolithic integration in photonic integrated circuits (PICs). Following our recent work in 2021[5] on PT-symmetric third-order DFB lasers that can realize commercial level single-mode lasing output, this study, as an extension, experimentally demonstrates, for the first time, higher power emission at lower consumption in PT-symmetric first-order DFB lasers benefiting from lower metallic absorption losses and dielectric radiation losses compared to third-order designs.

Principle and Design

Fig. 1(a) is the sketch of the proposed PT-symmetry DFB laser structure. It is a standard ridge waveguide composed of a dielectric grating with two metallic gratings on its lateral sides. The grating periods are both 240 nm with a $f=0.5$ duty-cycle suited to operate at 1550 nm. By bringing an additional shifted gain/loss modulation to a conventional refractive Bragg grating structure, the potential can be turned into a PT symmetric condition, notably for a phase shift of $\pi/2$ between the gain and refractive index modulations, when real and imaginary parts of the material index respectively obey even and odd profiles in a unit cell [inset in Fig. 1(a)]. Fig. 1(b) shows a tilted micrograph of the fabricated first-order PT-symmetric DFB laser structure.

Results

A typical light-current characteristic of our first-order PT-symmetry DFB laser with the cavity length around 1.5

mm is presented in Fig. 2(a), the lasing threshold I_{th} is around 20 mA with an output power at $I=200$ mA of nearly 20 mW per (cleaved) facet. The measured typical emission spectra in Fig. 2(b) shows a neat single mode lasing with a Side Mode Suppression Ratio (SMSR) clearly over 50 dB. Our achievement validates the PT-symmetry strategy for use in single-mode DFB lasers with expected characteristics such as feedback immunity of high interest notably in PICs.

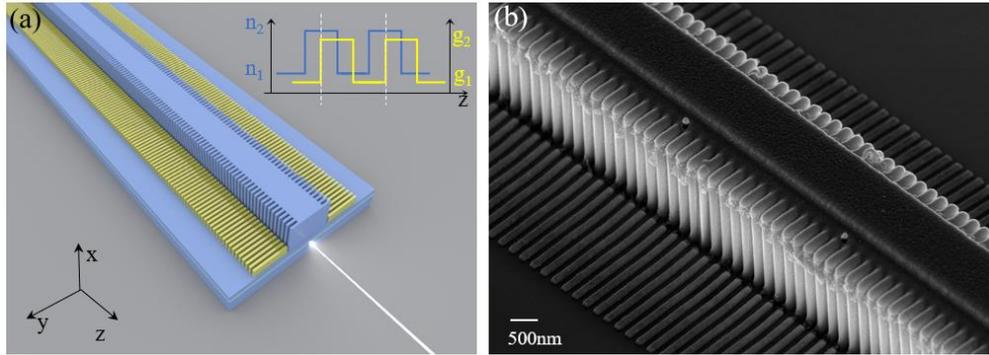


Fig.1. (a) Sketch of PT-symmetry DFB laser, blue (dielectric) and yellow (metallic) gratings are shown; the inset depicts the condition for PT symmetric potential. (b) SEM side view of a fabricated first-order PT-symmetry DFB laser.

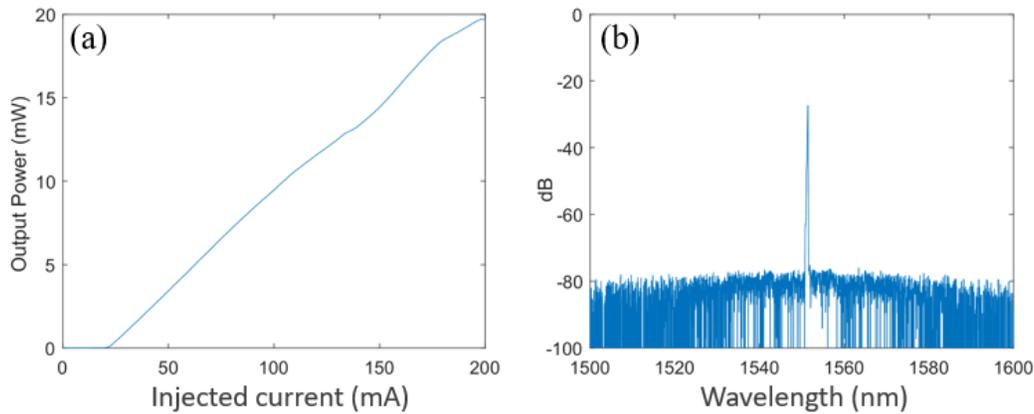


Fig. 2 Typical (a) Light–current characteristic and (b) Emission spectrum measured by first-order PT-symmetry DFB lasers.

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