Dynamic regulating of single-mode lasing in ZnO microcavity by piezoelectric effect

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Realizing single-mode-lasing output while being able to dynamically select and regulate a specified resonant mode could bring revolutionary impact for laser technology, on-chip data communication, and optical sensing/switches. Here, we demonstrate a single-mode lasing achieved by the piezoresistive and piezoelectric polarization synergistic effect on an epoxy-encapsulated ZnO microresonator. Based on relative shifts of gain spectrum and the resonant wavelength, the lasing mode in a hexagonal ZnO rod can be selected and regulated dynamically within a certain range. The relationship between the corresponding applied strain and the tunable refractive index is analyzed in depth and discussed systematically. Our studies open up exciting avenues for constructing optical mode-phase modulator, high-sensitive optical switches and color-perceived optical sensing.

Introduction

Since A. Einstein proposed the theory of stimulated emission in 1917 [1], the development of lasers has drawn much attention due to their vast applications in defense, medical treatment, and communication technology. The traditional laser cavities can confine and select a large number of resonant modes by utilizing the confining dimension of the cavity [2–5]. Laser emission at multiple frequencies will not only result in the group-velocity dispersion-induced temporal pulse broadening and false signaling, but also be subject to mode competition-dependent random fluctuations and instabilities. Achieving the stable single-mode lasing output is an effective strategy to avoid these series of problems, which is also of fundamental importance for various scientific and technological applications. In the last few decades, much effort has been devoted to enforcing single-mode operation, such as the construction of distributed Bragg reflector (DBR) mirrors or distributed feedback (DFB) gratings [6–8], reduction of cavity size for enlarging free spectral range (FSR) [9–11], coupled-resonant cavities through Vernier effect [12–14], spatially varied optical pumping [15,16], and parity-time symmetry breaking [17–19]. However, these approaches are applicable to pre-designed cavity configurations and highly rely on complex microfabrication technology. Also, reducing the cavity size to expand the FSR will suppress the acquisition of optical gain, which not only leads to the increase in optical loss, but also causes the increase in lasing threshold. Therefore,

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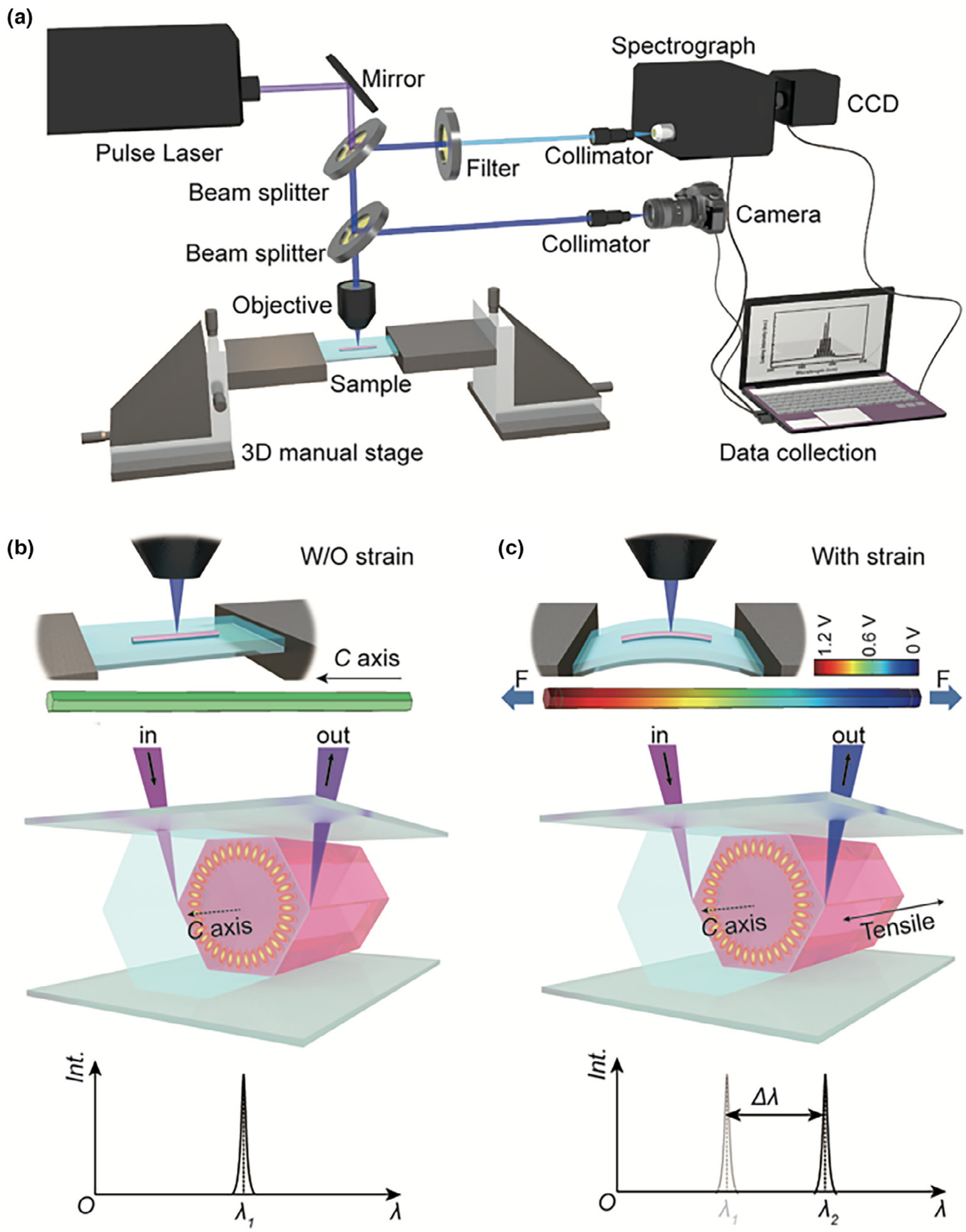

FIGURE 1

Optical path system and proposed mechanism for dynamic modulating lasing mode in ZnO microcavity. (a) The entire optical path diagram. (b) Schematic view of the excited WGMs in ZnO microcavity without applied strain by a focused Nd:YAG laser. The lasing wavelength is assumed to be at λ_1 (purple light). (c) Schematic view of the excited WGMs in ZnO microcavity under an applied tensile strain along the *c* axis, where the lasing mode will redshift from λ_1 to λ_2 (blue light). Piezopotential distribution in a ZnO microrod is simulated by a finite-element analysis method (COMSOL).

it is urgent to develop a simple method to achieve single-mode lasing and realize the regulation of lasing mode dynamically.

Previous explorations on the piezoresistive effect and piezoelectric polarization effect dependence of optical bandgap [20–22] and refractive index [23,24] offer a practicable strategy for dynamically tuning gain region and mode position, which is expected to realize lasing mode modulation. ZnO is an ideal gain medium for designing UV laser devices [25–28] because of its wide direct bandgap (3.37 eV) and high exciton binding energy (60 meV). In addition, the non-centrosymmetric hexagonal wurtzite ZnO micro/nanostructures not only provide a natural configuration for optical oscillations [29–32], but also offer a theoretical support for the existence of the piezoelectric polarization effect under mechanical perturbations [33–36]. As early as 1967, Vedam et al. [23] reported the effect of the pressure-induced polarizability on refractive index is greater than that caused by the increased number of dispersion centers per unit volume in the wurtzite-structural crystals, opening a door to dynamically modulate the lasing mode by utilizing the piezoelectric polarization effect. Combined with the method of controlling lasing mode output through reducing the resonator size to modulate the FSR, it is expected to obtain single-mode lasing while

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