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Wavelength Fine-tuning of Photonic Crystal Rods Laser on a Flexible Substrate

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1. Introduction

Photonic crystal (PhC) lasers have been developed and integrated with functionality optical or optoelectronic components as wavelength–scale coherent light sources. However most of reported PhC lasers are implanted on a hard substrate and the optical properties are not adjustable once the structures are fabricated [1] [2]. In this work, we demonstrated flexible square-lattice photonic crystal band-edge rods lasers on a polydimethylsiloxane (PDMS) substrate.

2. Fabrication

The photonic crystal square-lattice structure was formed by a 240 nm thick InGaAsP rods on a PDMS substrate. Fig. 1(a) shows the illustration of the structure. In fabrication, the photonic crystals were implemented in a 240 nm thick InGaAsP layer on the InP substrate. The InGaAsP layer consisted of four strained InGaAsP quantum wells (QWs) with an emission peak at 1.55 μm. A silicon-nitride (SiN_x) layer and a polymethylmethacrylate (PMMA) resist were deposited on the epitaxial wafer for the dry etching processes and electron-beam lithography. The triangular-lattice air holes were defined on PMMA by electron-beam lithography. Followed by RIE and ICP dry etching processes, the patterns were transferred to the SiN_x layer with CHF_3/O_2 mixture gases at 20℃ and further to the QWs layer with Cl_2/N_2 mixture gases at 160℃. After that, we bonded the QWs layer to a 260 μm thickness PDMS substrate. The structure was formed by removing the InP substrate with HCl solution. The scanning electron microscope (SEM) picture of fabricated PCs is shown in Fig. 1(b)

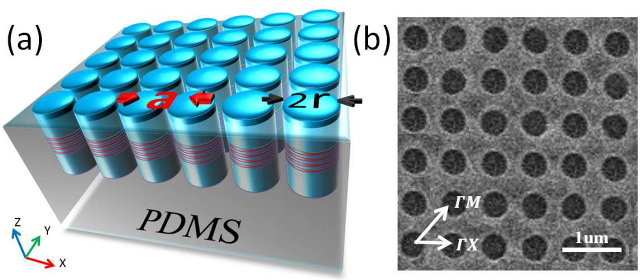

Fig. 1(a) The illustration of a square-lattice photonic crystal band edge laser on a PDMS substrate. (b) The SEM image of the fabricated structure.

3. Measurement and Discussion

The devices were then optically-pumped at room temperature by using an 850 nm wavelength diode laser at normal incidence with a 1.5% duty cycle and a 30 ns pulse width. The pump beam was focused on the devices by a 100x objective lens. The pumped beam spot size is approximately 2 μm in diameter. The output power from the lasers was collected from the top of the structures by a multi-mode fiber connected to an optical spectrum analyzer. The structure achieves lasing with a low threshold power. Fig. 2(a) shows a lasing spectrum from the photonic crystal band-edge rods laser with 705 nm lattice constant. The lasing wavelength was observed around 1601 nm. The light-in light-out (L-L) curve of this laser is show in Fig. 2(b). The threshold power is approximately 1.25 mW. To confirm the optical modes of the band-edge laser, the structures with different lattice constants were optically-pumped and the lasing wavelengths were recorded. The normalized frequency of the lasing modes is about 0.441.

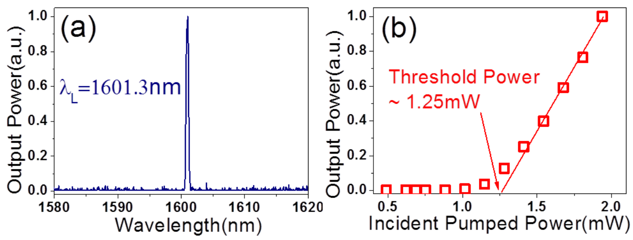

Fig. 2(a) The lasing spectrum from a square lattice photonic crystal band edge rod laser on a PDMS substrate. (b) The L-L curve from the laser.

To understand the lasing modes, the corresponding band structure for TE-like modes are calculated with plane-wave expansion (PWE) method. The band structure is shown in Fig. 3(a). The band-edge lasing modes are likely to occur around the high-symmetry points of the band structure. The flat dispersion curve near the band-edge implies a low group velocity of light and strong localization. Compared the measurement with the simulation, the lasing mode of 0.441 normalized frequency corresponds to the second Γ band-edge point. Furthermore, we have analyzed the photonic crystal structure with finite-element method (FEM). Fig. 3(b) shows the calculated H_z mode profile of the Γ band-edge mode, which is the observed lasing mode.

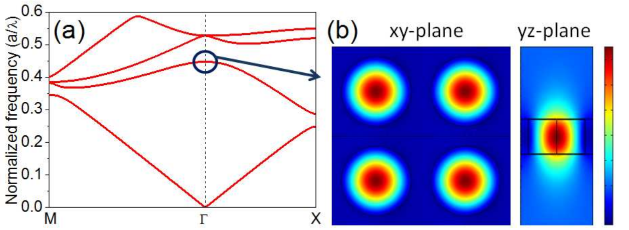

Fig. 3(a) The band structure of the square-lattice photonic crystal with 0.37 r/a ratio calculated with the 2D PWE method. The lasing mode is shown with a black circle. (b) The H_z field mode profile of the Γ band-edge mode.

After characterizing the band-edge laser on a flat surface, we extended the photonic crystals along the Γ-X direction with a homemade stage. Fig. 4(a) show the illustration of lattice extension. The arrows indicate the direction of lattice extension. Under the same pumping conditions and pumping power, the fabricated structure achieved lasing at various extending lattice constant. Fig. 4(b) shows the lasing wavelength red-shifted as the extending percentage was increased.

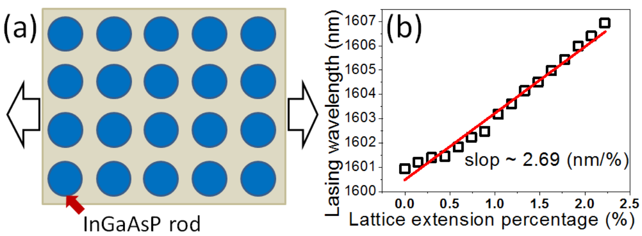

Fig. 4(a) The illustration of the lattice extension. (b) The lasing wavelength red-shift as the extension percentage is increased.

The lasing wavelength of the photonic crystal lasers strongly depends on its geometry. The red-shift implies that the geometry of the laser would be changed when the structure is extended. We observed that the lasing wavelength increase linearly with the extension ratio of photonic crystal lattices. The lasing wavelength tunability of the flexible photonic crystals is approximately 2.69 (nm/%). The shift is attributed to small lattice distortion of photonic crystals on the flexible substrate.

4. Conclusions

In conclusion, the square-lattice photonic crystal band-edge laser on a flexible PDMS substrate was demonstrated. The lasing action was achieved around 1550 nm wavelength with a threshold power. The observed lasing mode was identified to be around the symmetry point Γ of the second photonic crystal band by comparing experimental results with 2D PWE simulation. The lasing action of the extended photonic crystal lattices was also observed at various lattice extension percentages. The lasing wavelength was red-shifted as the lattice extension percentage was increased, and the red-shift in wavelength is dominated by the lattice extension along the Γ-X direction.

References

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