Wavelength Fine-tuning Flexible Photonic Crystal Rods Laser

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ABSTRACT

In this study, a flexible photonic crystal laser was demonstrated with InGaAsP nano rods on a polydimethylsiloxane (PDMS) substrate. The InGaAsP nano-rods content 4 quantum wells which are designed for 1.55 μm communication wavelength. The lasing action was observed around 1550nm which is a band-edge emission at high-symmetry Γ-point of photonic crystals. One of advantages of the flexible laser is the fine-tuning of optical properties by manipulating its geometry. In this work, we observed the lasing wavelength can be controlled by increasing photonic crystal lattice extension. The lasing wavelength was linearly red-shift up to 6 nm as the lattice extension percentage increased to 2.2%. The wavelength tuning rate is approximately 2.69 nm for 1 % lattice extension. Those geometric fine-tuning properties indicate the flexible photonic crystal laser can be applied as a compact tunable light source in photonic crystal integrated circuits or biomedical sensors.

Keywords: Photonic crystals, flexible lasers, nanorod lasers

1. INTRODUCTION

Photonic crystal lasers have been developed and integrated with optical functionality or optoelectronic components as wavelength–scale coherent light sources. However most of the reported photonic crystal lasers are implanted on a hard substrate and the optical properties are not adjustable once the structures are fabricated [1] [2]. We have demonstrated microdisk lasers on flexible substrate in the previous work [3] [4]. In this work, we demonstrated the flexible square-lattice photonic crystal band-edge rods lasers on a polydimethylsiloxane (PDMS) substrate.

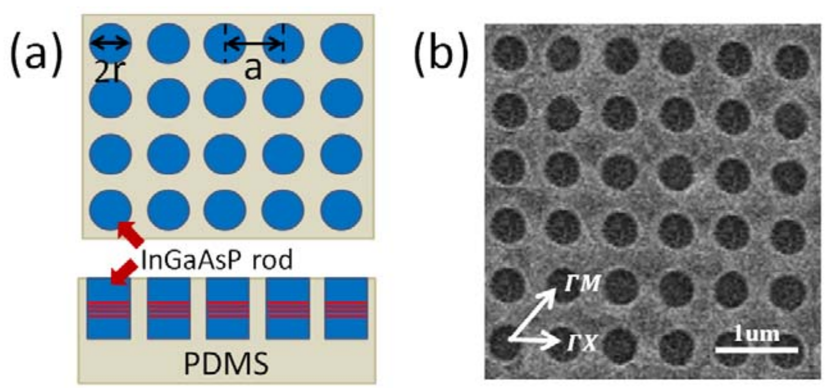

Figure 1. (a) Top-side and cross-section illustration of the photonic crystal square-lattice rods structure. (b) The SEM image of the fabricated photonic crystal rods.

2. FABRICATION

The square-lattice structure was formed by a 240 nm thick InGaAsP rods on a PDMS substrate. Fig. 1(a) show 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

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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 square-lattice rods 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).

3. CHARACTERIZATION 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 which was 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 is around 1601 nm. The threshold power shown in fig. 2(b) is about 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.

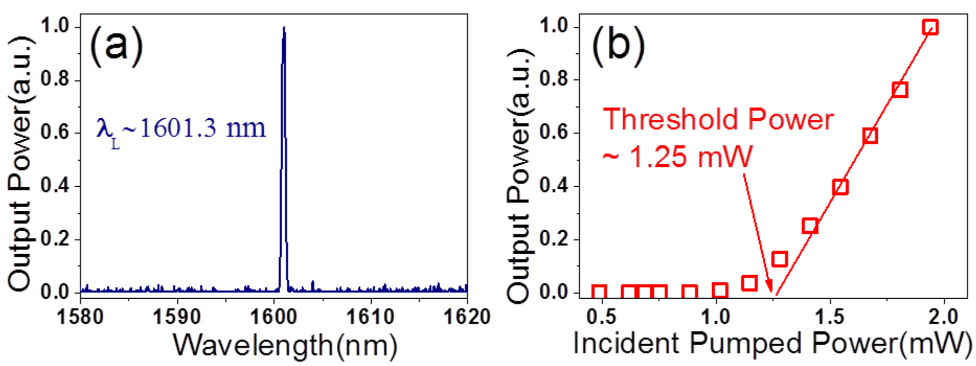

Figure 2. (a) The lasing spectrum from a square lattice photonic crystal band edge rods laser on a flexible PDMS substrate. (b) The L-L curve from the laser.

Since the optical properties of the photonic crystals depend strongly on the geometry, we expected the lasing wavelength could be manipulated when the photonic crystal lattices are extended in the PDMS substrate. After characterizing the band-edge laser on a flat surface, we extended the device along the Γ-X direction on a homemade extending stage. The illustration of lattice extension is shown in fig. 3(a). The arrows indicate that the lattice is extended along Γ-X direction. Fig. 3(b) is the picture of a homemade extending stage. The sample was fixed on the stage by clamps and we controlled the lattice extension percentage by rotating the knob. Under the same pumping condition and pumping position, the fabricated structure achieved lasing at various extending lattice constant. Fig. 4 shows the lasing wavelength red-shifted as the extending percentage was increased.

In experiment, we observed that the lasing wavelength increase linearly with the extension ratio of photonic crystal lattices. Within the extension ratio between zero to 2.5 %, the lasing wavelength was shifted approximately 7 nm. 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.

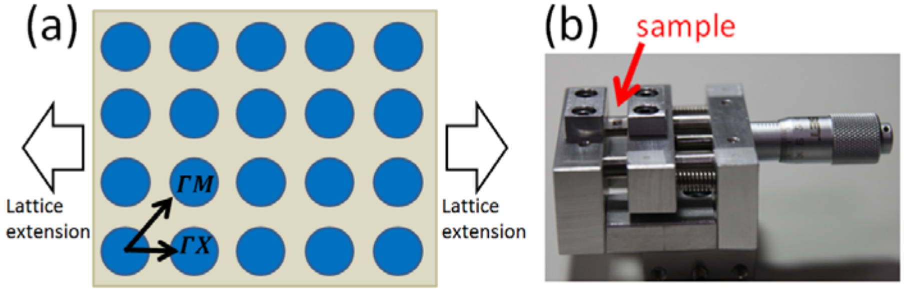

Figure 3. (a) The illustration of the direction of lattice extension. (b) The homemade extending stage. The lattice extension percentage is adjusted by the knob.

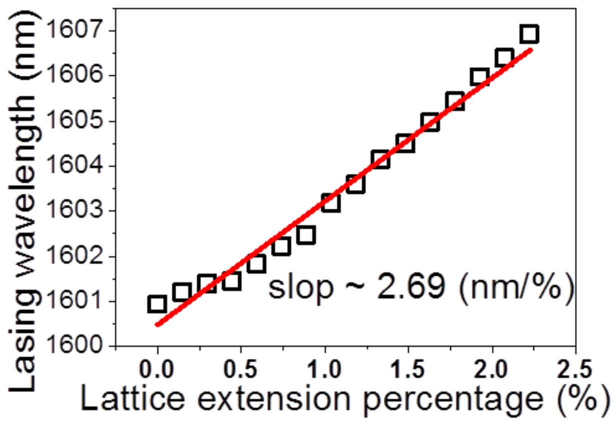

Figure 4. The lasing wavelength red-shift as the extension percentage is increased. The lasing wavelength was linearly red-shift up to 6 nm as the lattice extension percentage increased to 2.2%.

4. SUMMARY

In summary, the band-edge lasing action from the rod-based photonic crystals on a flexible PDMS substrate was demonstrated. The lasing wavelength was observed at 1601.3 nm with a low threshold. 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. The wavelength tunability of the flexible photonic crystal band-edge lasers is approximately 2.69 (nm/%).

REFERENCES

[1] M. Imada, S. Noda, A. Chutinan, T. Tokuda, M. Murata, and G. Sasaki, "Coherent two-dimensional lasing action in surface-emitting laser with triangular-lattice photonic crystal structure," Appl. Phys. Lett., 75, 316–318 (1999)

[2] L. Ferrier, O. El Daif, X. Letartre, P. R. Romeo, C. Seassal, R. Mazurczyk and P. Viktorovitch, "Surface emitting microlaser based on 2D photonic crystal rod lattices," Optics Express, Optics Express, 17, 9780-9788 (2009)

[3] M. H. Shih, K. S. Hsu, W. Kuang, Y. C. Yang, S. K. Tsai, Y. C. Liu, Z. C. Chang, and M. C. Wu, "Compact optical curvature sensor with a flexible microdisk laser on a polymer substrate", Optics Letters **34**, 2733 (2009).

[4] M. H. Shih, K. S. Hsu, Y. C. Wang, Y. C. Yang, S. K. Tsai, Y. C. Liu, Z. C. Chang and M. C. Wu, "Flexible compact microdisk lasers on a polydimethylsiloxane (PDMS) substrate", Optics Express **17**, 991-996 (2009).