Electrically tuned photonic crystal/ liquid crystal laser

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Abstract: The emission wavelength of ultra-small photonic crystal laser is electrically controlled with an applied gate voltage. High quality factor porous-cavity laser design enables strong interaction between strong optical fields and infiltrated liquid crystals.

OCIS codes: 140.3600, 230.3720, 190.2640

Planar photonic crystal (PPC) cavities enable efficient manipulation of light both in space and time. Porous PPC cavity design developed by our group [1] concentrates light into the small air pore in the center of the cavity (Fig. 1), thus enabling strong interaction between light and matter (e.g. liquid) introduced into the small air pore. This interaction results in the change of the emission wavelength of the laser. By monitoring this wavelength shift we can study optical properties of the infiltrated material [2]. On the other hand, by introducing liquid crystals (LC) into the photonic crystal structures [3-5], and by controlling the alignment of LC molecules, we have realized tunable laser sources.

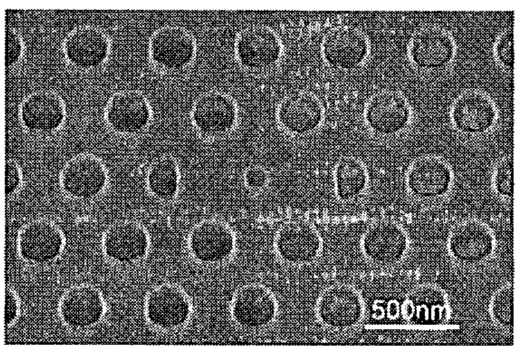

Fig. 1. Fabricated photonic crystal cavity viewed at an oblique angle.

PPC lasers were fabricated in InGaAsP membrane, containing four quantum wells, suspended in the air. Electron beam lithography followed by dry etching is used to fabricate structures. The gas chemistry used to etch InGaAsP, based on $HI/H_2/Ar$, results in smooth and straight sidewalls [1,2]. Using three-dimensional finite-difference time-domain calculations we have estimated quality factor (Q) of our cavity to be better than 21,000. When cavity is immersed in liquids with refractive index of n=1.4 and n=1.6 Q drops to 3,150 and 1,800, respectively.

The LC that we used in our experiment (MLC-6815 from Merck) was chosen based on its low refractive index (n_e = 1.519, n_o = 1.467) in order to achieve reduced lasing threshold (due to higher Q) in the cavity infiltrated with LC. In Fig. 2a we show the PC LC cell used to perform room temperature photoluminescence measurements of our lasers immersed in LC. During the optical pumping of the PC cavities, the refractive index of the LC was changed by application of an electrostatic field between the top ITO electrode and the InP wafer substrate. When the voltage is varied from 0 to 20 V we observe a blue shift of the laser wavelength [5] [Fig. 2b]. This is in good agreement with expected refractive index change in our LC due to applied voltage (from 1.483 to 1.467). Limited tuning range of our laser (1.2 nm) is attributed to the screening effect of the photonic crystal holes: applied electric field is sharply damped in the holes of the PC and therefore alignment of LC is possible only in the layer between the PC membrane and top ITO electrode [5]. Our numerical models predict a tuning range of approximately 1 nm when only the top cladding is aligned, what is in good agreement with the experimental results. The tuning range of the laser can potentially be increased beyond 20 nm by infiltrating the cavity with LCs featuring larger birefringence, increasing the effectiveness of LC alignment with in-plane electrodes, and by controlling the alignment in the holes of the PC.

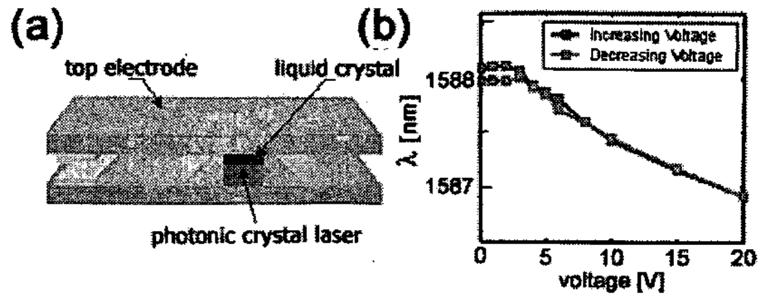

Fig. 2. (a) Cross section of the PC LC cell used in experiment. (b) Lasing wavelength vs. applied voltage

In conclusion, by combining liquid crystals and photonic crystals we have realized the first tunable photonic crystal laser. Our LC infiltrated PC laser also provides a unique opportunity to probe the behavior of LCs confined in nanoscale geometries.

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