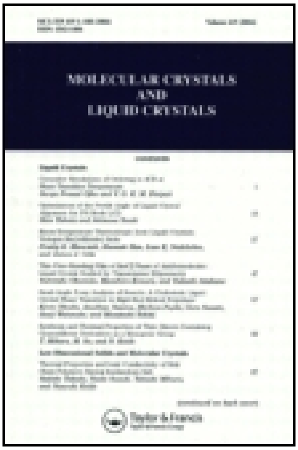

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FLEXIBLE LASERS MADE FROM CHOLESTERIC LIQUID CRYSTAL POLYMERS

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Optically pumped mirrorless laser action has been observed in a dye-doped photopolymerized cholesteric liquid crystal (PCLC) polymer film. At high excitation energy above the threshold, the laser action is observed at an edge of the one-dimensional photonic band of the PCLC herical structure. This PCLC film possesses a mechanical flexibility, and laser action is observed even in a bent film. The helical pitch of the PCLC polymer has no temperature dependence, which is favorable for the laser device application.

Keywords: cholesteric liquid crystal; laser; photonic crystal; stop band

1. INTRODUCTION

Recently, photonic crystals (PCs) which are made from periodic structures with the periodicity in the range of optical wavelength have attracted much attention from both fundamental and practical points of view [1,2]. In the PCs, the propagation of light is inhibited under the Bragg condition, so that optical stop band or photonic band gap (PBG) appears.

Cholesteric liquid crystal (CLC) and chiral smectic liquid crystal such as ferroelectric liquid crystal, which have a periodic helical structure with a periodicity of the optical wavelength, can be regarded as a one-dimensional (1-D) PCs. Recently, the laser actions in these phases have been observed [3–6]. In such materials, 1-D periodic helical structures act as

We would like to show our acknowledgements to Merck KGaA for providing the polymeric cholesteric liquid crystal materials.

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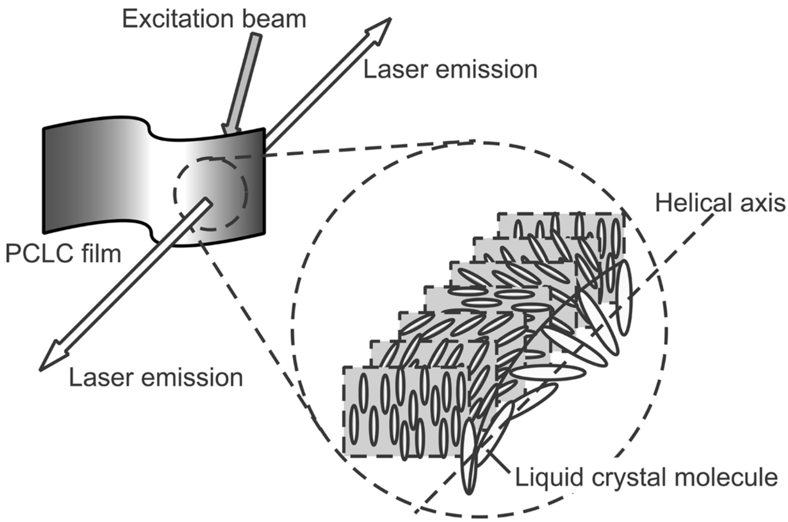


FIGURE 1 Schematic representation of the laser emission of a flexible free-standing film of PCLC and the 1-D periodic helical structure in the PCLC film.

laser cavities and distributed feedback (DFB) laser action was achieved at the photonic stop band edges.

In this study, the fabrication of flexible lasers using photopolymerized CLC (PCLC) films are presented and the influences of the mechanical deformation such as bending of the film on the laser action is also discussed.

2. EXPERIMENTAL

For the fablication of CLC polymer film, two types of photo-polymerizable CLC mixtures (Merck KGaA) were used, which have right-handed helix and reflection bands around 779 nm and 440 nm. The helical pitch of the CLC sample, that is, the wavelength of the optical stop band can be adjusted by mixing these two CLC compounds at a proper ratio. As a laser dye dopant in the CLC, [2-[2-4-(Dimethylamino)phenyl]ethenyl]-6-methyl-4H-pyran-4-ylidene] propanedinitrile, DCM (Exciton) was used. The concentration of the dye was 0.4 wt.-%.

The PCLC film was prepared as follows. The cell is made from two glass substrates which surfaces were coated with a polyimide (Japan Synthetic Rubber, AL1254) and rubbed. The monomer sample was inserted by capillary action into the cell. The gap of this cell was 25 μm. The CLC molecules in this cell align their molecular long axes (director) parallel to the glass plates, that is, the helical axis is perpendicular to the glass substrate. Then UV light irradiation was performed using a Xe lamp to induce the photo-polymerization of the UV-curable CLC monomer. The transmission spectrum measurement was performed using a spectrometer (Shimadzu, UV-3150). Then, glass substrates were removed.

The experimental setup for an emission measurement is shown in the Figure 2. A second harmonic light of Q-switched Nd:YAG laser (Spectra Physics, Quanta-Ray INDI) was used for an excitation, whose wavelength, pulse width and pulse repetition frequency were 532 nm, 8 ns and 10 Hz, respectively. The illumination area on the sample was about 0.2 mm^2. The excitation laser beam irradiated the sample at an angle of about 45° with respect to the cell plate normal. The emission spectra from the dye-doped PCLC film were measured from an opposite side of the cell using a charge-coupled device (CCD) multichannel photodetector (Hamamatsu Photonics, PMA-11) having a spectral resolution of 3 nm. The collecting direction was perpendicular to the cell surface, which is along the helical axis.

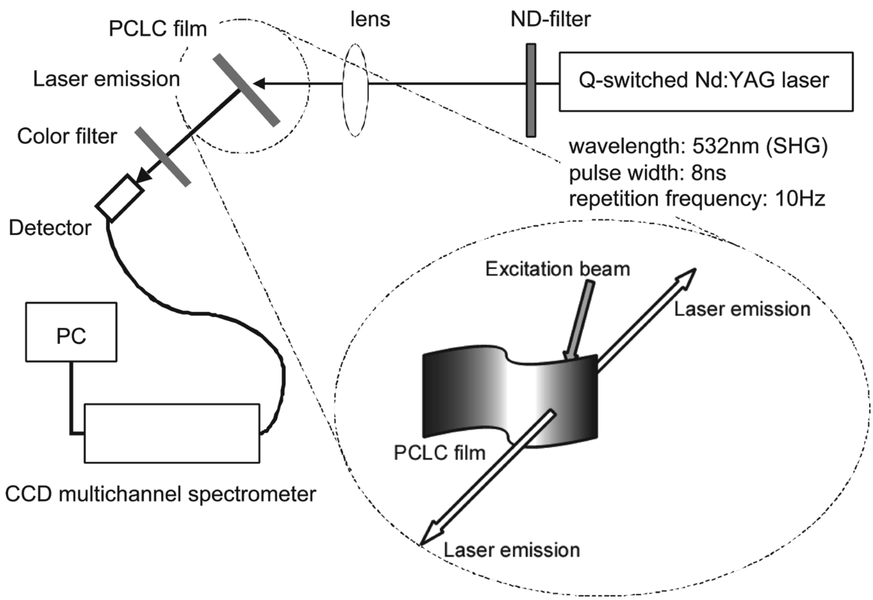


FIGURE 2 Schematic representation of the experimental setup for an emission measurement.

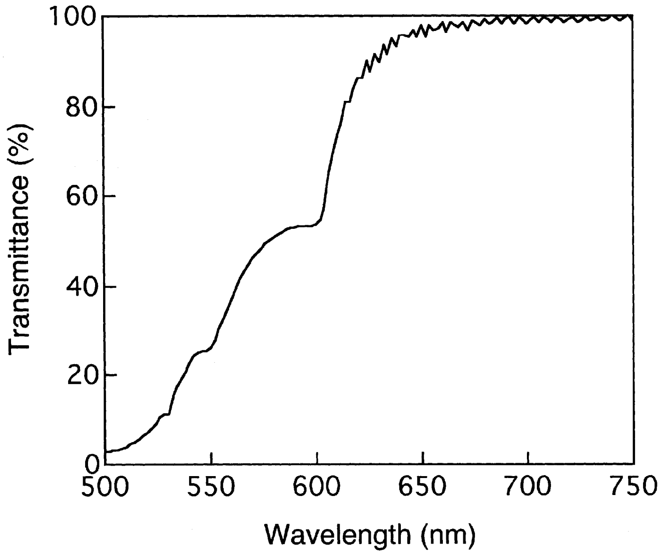


FIGURE 3 Transmission spectrum of the dye-doped PCLC.

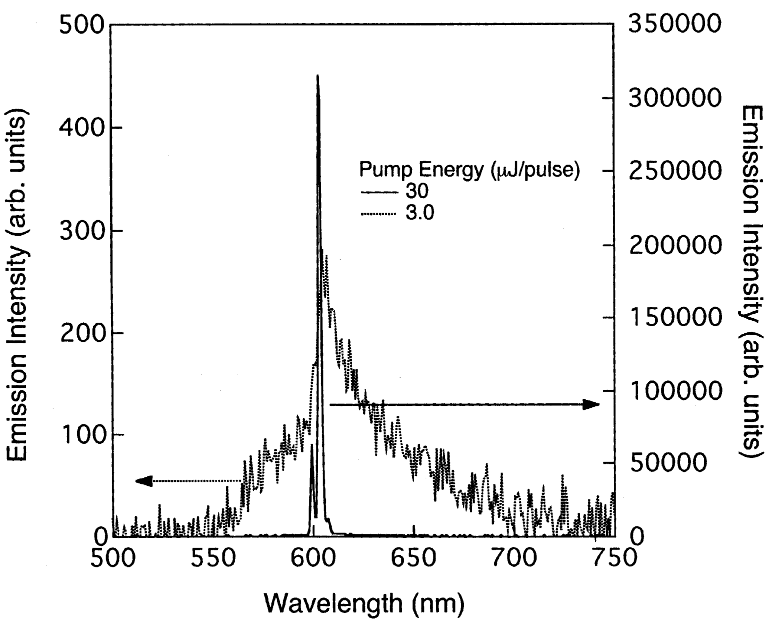


FIGURE 4 Emission spectra of the dye-doped PCLC film at below (3.0 μJ/pulse, dotted line) and above (30 μJ/pulse, solid line) the threshold pump pulse intensity.

3. RESULTS AND DISCUSSIONS

Figure 3 shows the transmission spectrum of the dye-doped PCLC. The drop of the transmittance due to the selective reflection is observed around 600 nm.

Figure 4 shows the emission spectra of the dye-doped PCLC film for various values of the excitation pulse energy. At high excitation energy (30 μJ/pulse), laser action is observed at the edge of the dip as shown in solid line. The full width at half maximum (FWHM) of the emission peak is about 2 nm, which is limited by the spectral resolution of our experimental setup.

The peak intensity and linewidth of the emission spectrum are shown in Figure 5 as a function of the pump pulse energy. This indicates the presence of a lasing threshold. At lower excitation energies, the emission intensity increases in proportion to the pump energy. Above the threshold at a pump pulse energy of about 3 μJ, the emission intensity increases

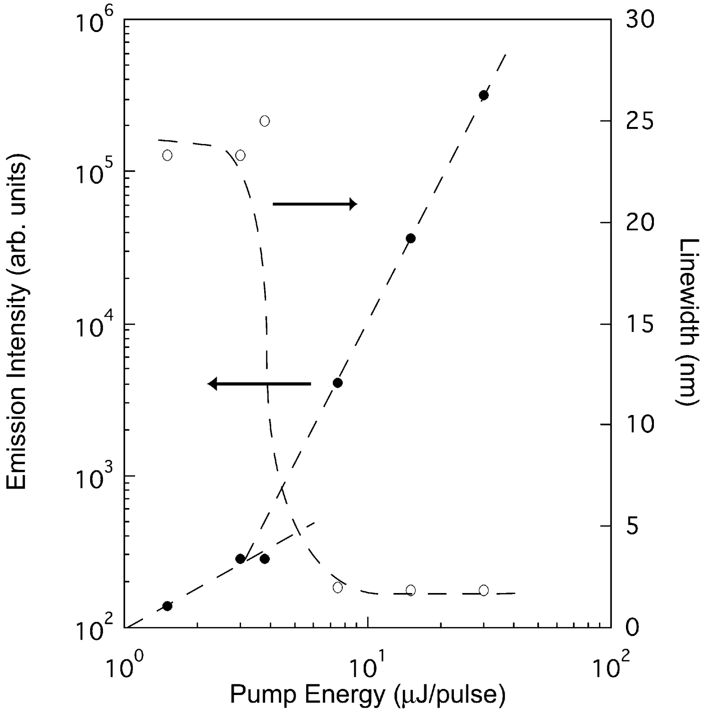
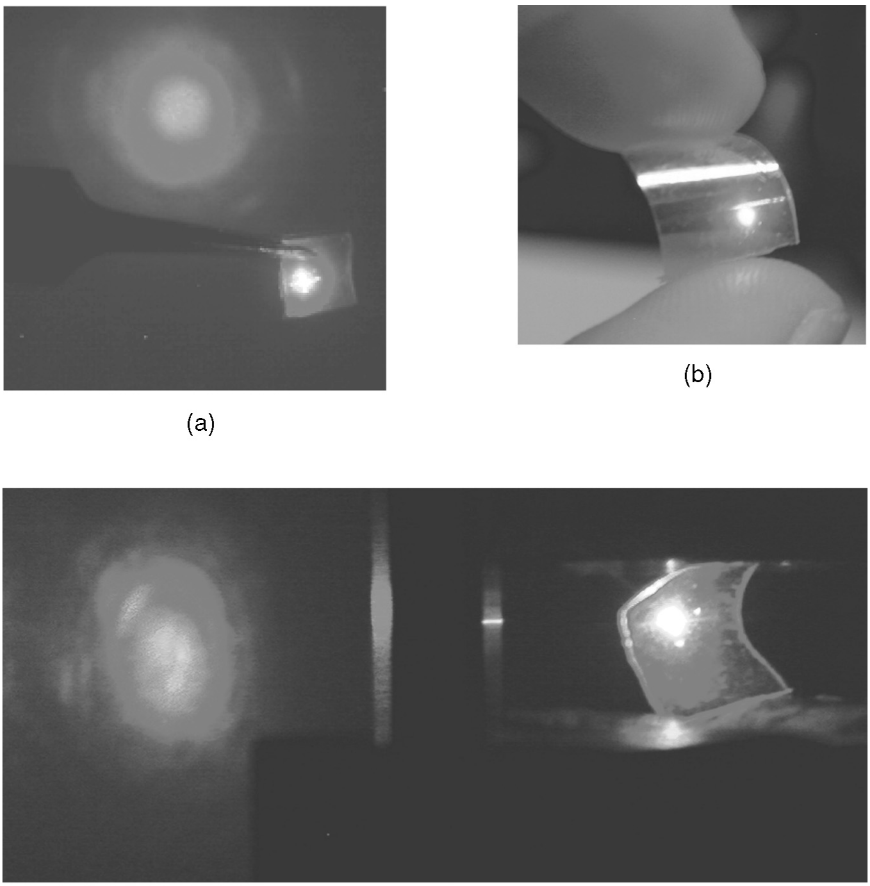


FIGURE 5 Pump energy dependence of the peak intensity (closed circle) and linewidth (FWHM) (open circle) of the emission spectrum of the dye-doped PCLC.

nonlinearly. The linewidth of the emission spectrum also drastically decreases above the threshold. These results confirm that lasing occurs above the threshold of the pump energy at the edge of the photonic stop band in the spontaneous emission. The emitted laser light was right-handed circularly polarized.

Figure 6 shows a photograph of the laser emission from the free-standing dye-doped PCLC film at above the threshold pump energy. It should be noted that mirrorless laser action is achieved without any substrates, and the operation of this laser needs no optical setup for such as fixation, alignment, temperature control and so on. It should also be noted



(a) (b)

(c)

FIGURE 6 The photographs of laser action from the free-standing film of PCLC at above threshold pump pulse energy.

that the laser emission is observed even when PCLC film is bent as shown in Figures 6(b) and (c). This suggests that 1-D helical structure necessary for the laser action is maintained even in the deformed film. This flexibility may enable us to fabricate optical devices with novel functionalities. Using such a flexible characteristic of PCLC film, the focusing effect of laser emission in a circularly deformed PCLC film was demonstrated. The detailed results was presented elsewhere [7].

From the practical point of view, the thermal stability is important for the laser action. Figure 7 shows the temperature dependence of the emission peak wavelength of PCLC (closed symbols) and unpolymerized CLC mixture (open symbols). The unpolymerized CLC mixture sample was composed by nematic liquid crystal mixture E44 (Merck) as a liquid crystal host, S811 (Merck) as a chiral dopant and DCM as a laser dye. It should be noted that the shift of the emission peak wavelength is negligible over the temperature range of about 40°C in the case of PCLC film. On the other hand, in the unpolymerized CLC sample, the emission peak wavelength shifted to shorter wavelength, and laser action was not observed at higher than 28°C, which can be attributed to the shrinkage of helical pitch. This thermal stability of the lasing wavelength in the PCLC originates from fixing of the helical structure by closslinking liquid crystal molecules each other, which is favorable from the view point of the laser device application.

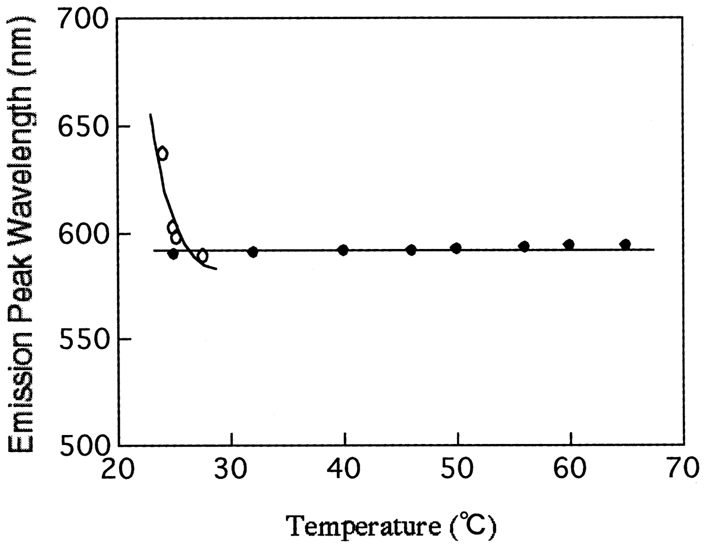


FIGURE 7 Temperature dependence of the lasing emission peak wavelength of the PCLC film (closed symbols) and unpolymerized CLC mixture (open symbols).

4. CONCLUSIONS

In conclusion, optically pumped mirrorless laser action was observed at the edge of the stop band of the dye-doped PCLC. At high excitation energy above the threshold, the laser action is observed at an edge of the one-dimensional photonic band of the PCLC helical structure. This PCLC film possesses a mechanical flexibility, and laser action is observed even in a bent film, and focusing effect of the laser emission was also observed. The helical pitch of the PCLC has no temperature dependence, which is favorable for the laser device application.

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