Color-tunable liquid-crystal laser

Masanori Ozaki, Yuko Matsuhisa, Yo Inoue, and Hiroyuki Yoshida

An in-plane configuration of the liquid-crystal helix axes enables electric-field-controlled laser tuning.

Cholesteric liquid crystals (CLCs) composed of chiral molecules spontaneously form helical structures in which the refractive index changes periodically along the helix axis, and which is essentially a 1D photonic crystal. In this type of spiral periodic structure, laser action—caused by suppression of the photon-group velocity at the photonic band edge—is expected. CLCs have attracted significant interest for applications in mirrorless lasers because of these spontaneously formed periodic structures.^{1,2} In particular, electrical laser-color tuning can be achieved with CLC lasers because the helix pitch can be controlled by varying the electric field.^{3–5}

The types of CLC lasers thus far proposed have been based on a planar-aligned cell configuration with the helix axis oriented perpendicularly to the cell substrates: see Figure 1(a). Laser light is emitted perpendicularly to the cell plates. In this setup, the helix pitch does not change smoothly when the electric field is applied normal to the helix axis, because the CLC molecules on the surfaces of both substrates are strongly anchored in an initially aligned direction while the free molecular motion required for helix-pitch elongation is blocked.⁶ Despite a number of attempts to use planar aligned cells,⁷ continuous color tuning of CLC laser action has never been accomplished over a wide wavelength range.

To achieve continuous tuning of the lasing wavelength by a varying electric field, the molecules must be released from their strong anchoring to the substrate surfaces. We propose a waveguide-cell configuration in which the helix axis is confined to a plane as shown in Figure 1(b). For in-plane helix alignment, surface anchoring does not affect the pitch change and a smooth shift of the stop band is expected. This can be used to construct a CLC laser with continuous color tunability.

Figure 2 shows the resulting lasing spectra as a function of the electric field applied perpendicularly to both the helix axis and the substrates of the in-plane cell. The CLC-waveguide laser device was sandwiched between two In₂O₃:Sn (tin-doped

Figure 1. Device configurations of cholesteric liquid-crystal (CLC) lasers. (a) Conventional planar configuration with the helix axis perpendicular to the substrates. (b) Proposed in-plane configuration with the helix axis parallel to the substrates.

indium oxide, or ITO)-coated glass substrates. The laser's dye-doped cell thickness was 6 μm and the CLC film was photo-pumped at 532nm using 20ns pulses from a frequency-doubled quality-switched neodymium-doped yttrium-aluminum-garnet laser, with a threshold lasing pump energy of 0.4mJ/cm². The lasing emitted along the helix axis was collected from the cell edge.

The lasing peak wavelength shifts to the red with increases of the electric field (see Figure 2, inset). Although the lasing wavelength remains almost constant for smaller fields, above 1.0V/ μm it can be tuned by changing the electric-field strength. This corresponds to CLC helix elongation by the electric field applied perpendicularly to the helical axis, as supported by theoretical calculations for in-plane helical alignment under the influence of a variable electric field (see Figure 2). As the electric field was applied, the helix deformed, with its pitch increasing because the dielectric coupling of the CLC molecules to the electric field tends to rotate the molecules so that they align themselves along the electric field.

Note that the lasing wavelength is controlled continuously in our proposed configuration. Although in the planar-cell CLC-laser configuration—Figure 1(a)—the lasing wavelength shifted discontinuously because of the strong molecular anchoring to the surfaces, for in-plane helix alignment the plate surfaces do not affect the field-induced molecular rotation. The helix pitch is

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Figure 2. Emission spectra of the in-plane CLC laser with a pump energy of 1.7 mJ/cm^2 as a function of the electric field applied. (Inset) Field dependence of the lasing peak wavelength.

therefore elongated smoothly, resulting in continuous electrical tuning of the lasing wavelength.

In summary, we developed an in-plane CLC laser in which the helix axis is parallel to the substrates and the emission wavelength can be tuned continuously by varying the electric field. Our next step will be to reduce the lasing threshold and improve the efficiency for continuous-wave color-tunable lasers.

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Author Information

Masanori Ozaki, Yuko Matsuhisa, Yo Inoue, and Hiroyuki Yoshida

Department of Electrical, Electronic, and Information Engineering
Osaka University
Suita, Japan

Masanori Ozaki is a professor of electrical, electronic, and information engineering. He has published over 360 scientific papers. His interests focus on nanostructured materials and devices based on liquid crystals, and electronic and photonic devices based on organic materials, photonic crystals, and plasmonics.

Yuko Matsuhisa received her PhD in electronic engineering from Osaka University and joined Panasonic Electric Works in 2008.

Yo Inoue is a graduate student. His research interests focus on liquid-crystal lasers.

Hiroyuki Yoshida is a PhD candidate about to receive his degree. His research interests focus on photonic phenomena in nanostructured liquid crystals and their applications.

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