Simultaneous Red-Green-Blue Organic Laser Devices

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***Abstract*—This paper describes recent developments in organic laser devices based upon liquid crystalline media. The key features of a typical laser device are discussed along with a method for controlling the band gap (>100 nm) using electric fields. Finally, simultaneous red-green-blue laser arrays are demonstrated from a single device when optically pumped.**

Keywords; laser, photonic band gap, liquid crystals

I. INTRODUCTION

Liquid crystals are best known for their role in flat panel displays but recent research has shown that these materials can, in fact, be used to form low threshold organic laser devices. This technology is of significant interest for a number of applications including laser projection displays, telecommunication devices and medical diagnostic techniques. The liquid crystal laser exhibits many characteristics which make it an attractive alternative to semiconductor lasers. First and foremost, the periodic structure self-organizes without the need for any complex fabrication procedure. Secondly, any wavelength can be chosen ranging from the deep ultraviolet to the infra-red by adjusting the periodicity of the structure through chemical, mechanical, or electrical stimulus. Finally, due to the sensitivity of liquid crystals to external electric fields, the 'molecular' ordering and thus the optical properties can be altered in-situ. This can lead to a number of significant effects not least of all tuning of the emission wavelength. Laser emission from these materials is a manifestation of the large gain that exists at the edge of a photonic band-gap due to the large density of photon states. Combined with spontaneous emission from a gain medium, such as a laser dye, this can lead to laser action [1 – 5].

In recent years, we have studied these organic laser devices in detail to show low excitation thresholds, high slope efficiencies, and wavelength tuneability [2 - 8]. Our research has focused on understanding the correlations between the macroscopic properties of the liquid crystal such as birefringence, dielectric anisotropy, elasticity etc and the performance properties of the corresponding liquid crystal laser device [2 – 4]. Results have shown that high birefringence and a high order parameter are of paramount importance to the performance characteristics. Furthermore, optimization of the device thickness also has a significant effect on the emission properties [3]. The cell thickness ranges from 5 microns to 25 microns.

To demonstrate the versatility of this laser technology we have recently shown simultaneous multi-wavelength laser emission from a single liquid crystal sample by creating a two-dimensional laser array fabricated from a dye-doped chiral nematic liquid crystal [5, 6]. By forming a pitch gradient across the cell, thus varying the periodicity, and optically pumping the sample using a micro-lens array, a polychromatic laser array can be observed consisting simultaneously of Red-Green-Blue colors [6]. As an example, the two-dimensional polychromatic array could be used as a means for producing a laser-based display whereby no complex fabrication procedure is required to generate the individual 'pixels'.

II. FABRICATING A LIQUID CRYSTAL LASER

A. *The liquid crystal host*

There are several different liquid crystal phases that are suitable for generating band-edge laser emission. Specifically, these are phases which exhibit a macroscopic periodic structure such as a chiral nematic or chiral smectic whereby the 'local' director (the average pointing direction of the molecules) rotates about a common axis to form a helix. This helix results in a periodic refractive index which leads to a gap in the photonic bands. Examples of liquid crystal phases which exhibit a helical/periodic structure include the chiral nematic phase, the chiral smectic phase, and the blue phases. The latter exhibit a 3-d band-gap whilst the former only exhibit a band-gap that is 1-d.The majority of the research on these lasers has been carried out on the chiral nematic phase as this typically exists over wide temperature ranges, forms uniform high-quality macroscopic helices, and is miscible with commercial laser dyes.

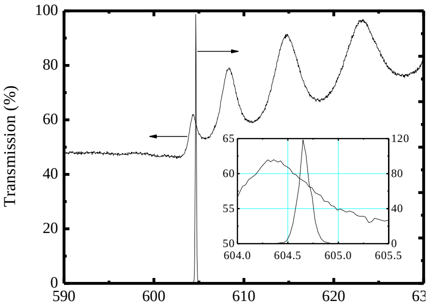

Figure 1. The transmission spectrum of the photonic band gap (left-hand axis) and the laser emission spectrum (right hand axis).

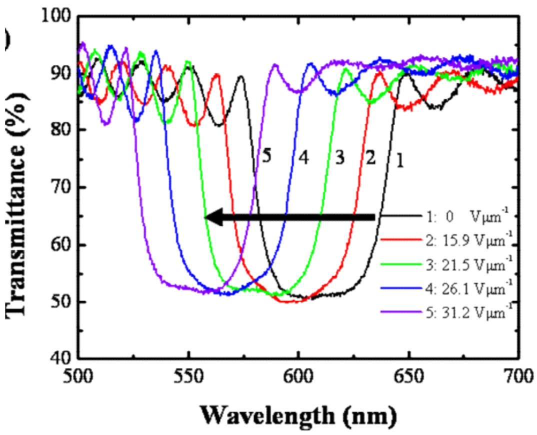

Figure 2.Wavelength tuning of the photonic band gap for an increase in the electric field strength. The frequency of the applied a.c. electric field is 1 kHz.

The position and width of the photonic band gap in terms of wavelength is governed by the first order approximation $\Delta np = \Delta\lambda$ whereby Δn is the birefringence and p is the pitch of the helix. Both of these properties can be controlled at the molecular level by adjusting the chemical structure and thus enabling the band-gap to be positioned at any desired wavelength from the ultra-violet to the infrared.

B. The gain medium

For the gain medium a laser dye is typically used although a rare-earth or transition metal may also be suitable. In order to ensure that laser emission occurs, one edge of the photonic band gap must be matched, spectrally, to the fluorescence curve of the laser dye. Moreover, so as to maximize the emission efficiency this band-edge must be matched to the gain maximum which usually occurs at, or close to, the fluorescence maximum. High quantum efficiency dyes are required for low thresholds and high slope efficiencies [7].

III. EMISSION CHARACTERISTICS

The emission from these laser devices, when optically pumped with a solid state laser such as an Nd:YAG operating with nanosecond pulse widths, have been found to be single mode with a narrow linewidth (~ 0.06 nm – limited by resolution of the apparatus, see Figure 1) although this does depend upon the uniformity and alignment of the liquid crystalline structure. If defects are present or the alignment consists of polydomains then broader linewidths and multimode emission are observed. Nevertheless, for low molar mass liquid crystalline compounds, large-area monodomains are readily achievable resulting in high quality factor structures and narrow linewidth emission. The emission profile is near-Gaussian. As for the slope efficiencies these can be as high as 70% for multi-pass device architectures.

IV. TUNING THE PHOTONIC BAND GAP

It is possible to tune the wavelength of the photonic band gap using electric fields. However, for the majority of cases this often leads to deterioration of the quality of the macroscopic periodic structure and thus a decrease in the transmission quality of the photonic band gap. Using ferroelectric electric dopants in a chiral nematic liquid crystal host we have observed broadband wasvelength tuning covering over a 100 nm without any change to the finesse of the structure (see Figure 2). This is the result of a contraction of the pitch as the electric field strength is increased.

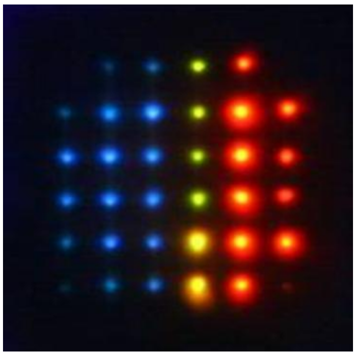

Figure 3.Simultaneous red-green-blue laser emission from a single liquid crystal device when optically pumped at 430 nm.

V. SIMULTANEOUS RED-GREEN-BLUE ARRAYS

Using a combination of dyes in a single liquid crystal cell, which exhibited a gradient in the pitch, the result was laser emission at multiple wavelengths when optically pumped at 430 nm. Figure 3 shows a 2-d array of simultaneous red-green-blue laser emission from a single liquid crystal cell.

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