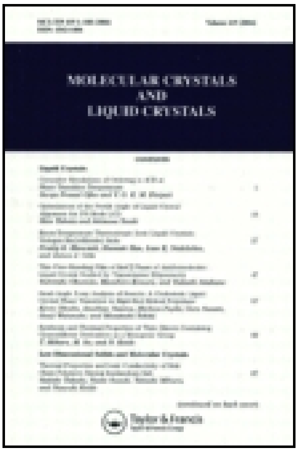

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

# Cholesteric Liquid Crystal Based Beam Steering Device

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Version of record first published: 04 Oct 2006

To cite this article: Sanjay Tripathi, Hemasiri Vithana, J. C. Kralik & S. M. Faris (1997): Cholesteric Liquid Crystal Based Beam Steering Device, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 301:1, 289-294

To link to this article: http://dx.doi.org/10.1080/10587259708041779

*Mol. Cryst. Liq. Cryst.*, 1997, Vol. 301, pp. 289–294
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# CHOLESTERIC LIQUID CRYSTAL BASED BEAM STEERING DEVICE

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Abstract: High speed scanning/deflection of monochromatic laser beams is essential to advanced optical systems and require random and or sequential scanning of laser spot over an image plane. We have developed a beam steering device (BSD) based on a polarization sensitive BSD element which either transmits or reflects a beam of light. This device exploits optical properties of cross linkable cholesteric liquid crystal (CLC) silicones. The CLC, with a half wave retarder, can be used to make a basic building block of a scanner/electro-optical crossbar switch. This device is compact, operates in microsecond second range at ~30 Volts (possibly less).

## I. INTRODUCTION

High-speed steering/deflection of laser beams is essential to advanced optical systems which require random or sequential scanning of a laser spot over an image plane. Such scanning is typically required to draw a pattern on a surface (as in laser projection displays), to sample different regions of a planar surface in order to read or write information (as in optical storage systems), or to sample data arranged in some pattern on a surface (as in a pattern recognition systems). The various methods for accomplishing the spatial scanning are collectively referred to as beam steering.

The myriad applications for high-performance beam steering devices provide a cogent impetus for research and development of this technology. Beam steering is a critical component in optical systems such as $C^3I$ (Command, Control, Communications, and Intelligence), laser weapons, laser radar, range determination, and directed-energy weapons[1-2].

Conventional methods for beam steering have relied upon electro-mechanical or acousto-optic techniques to deflect and scan the light beam. These techniques[3] are inherently slow compared to optical transit times and electronic time scales.

The Beam-Steering Device, discussed below, exploits the unique optical properties of cross-linkable cholesteric liquid-crystal (CLC) silicones. These CLC's are polarization sensitive; they reflect right circularly polarized light and transmit left circularly polarized light or *vice versa*[4]. The CLC, combined with a phase shifter, can be used to make a basic building block of a scanning/steering device[5]. This switch is compact and operates with microsecond switching times.

The beam scanning/steering device can also be used as an optical switch. These high-performance switching elements are cost-effective and have many applications in the fast-growing communications, networking, and parallel computing industries. Owing to their large bandwidths, optical fibers are increasingly utilized in information systems, vehicles, and aircraft; low-cost optical switching will find increasing demand in the interconnection of embedded controllers, sensors, display units, pattern recognition systems, and communication networks[6-7].



## II. BASIC BUILDING BLOCK

### *II. A. Principle of Operation*

The electro-optic scanner contains a matrix of identical BSD elements. The basic BSD elements can change the direction of an incoming laser beam by a fixed angle (for illustration we choose 90° deflection, though other angles may be chosen.). As shown in Figure 1, the deflection is accomplished by the two main components: a thin layer of polarizing reflector, and a phase shifter. The polarizing reflector has the unique property of reflecting light of a particular polarization state P2 and transmitting corresponding orthogonal state P1. The phase shifter is an electrically-controllable half wave retarder which can convert an P1 beam into an P2 beam and *vice-versa*.

In transmission mode a pre-specified threshold voltage, $V_{th}$, is applied to the phase shifter, which results in the input beam maintaining its polarization. The beam is then transmitted through the polarizing reflector. In reflection mode, no voltage is applied to the phase shifter; Therefore, the polarization state of the input beam is changed from P1 to P2 as it travels through the cell. The beam is then reflected by the polarizing reflector.

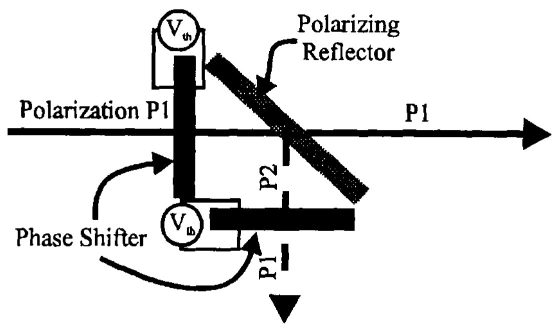


Figure 1: Basic building block



## III. POLARIZING REFLECTORS

*III.A. Optical Properties of CLC's.*

The CLC layer exhibits the property of selective reflection. A monochromatic beam of wavelength $\lambda \equiv \lambda_o = n_a P$, and propagating along the helix axis is reflected completely, where $n_a$ is the average index of refraction of the CLC material and $P$ is the helical pitch of the CLC[2]. Typical spectrograph of CLC film is shown in Figure 2

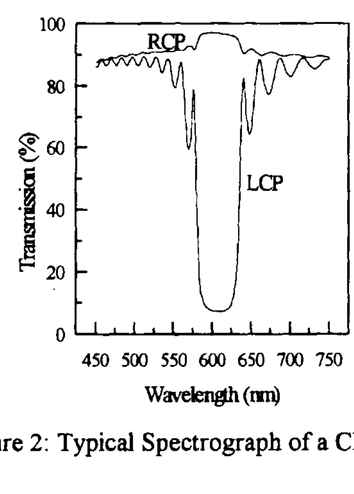


Figure 2: Typical Spectrograph of a CLC film

Since the polarizing reflector reflects only one particular wavelength ($\lambda_o$), all other wavelengths ($\neq\lambda_o$) are transmitted without attenuation or distortion[4]. Therefore, the scanner/switch is *both wavelength and polarization sensitive*.

The reflection wavelength can be changed by changing the pitch, P, in nematic-cholesteric liquid crystal mixtures or by varying the relative concentration chiral components, of different pitches, in a CLC mixtures (Figure 3). The polymerization temperature also dictates the pitch of CLC sample (Figure 4).

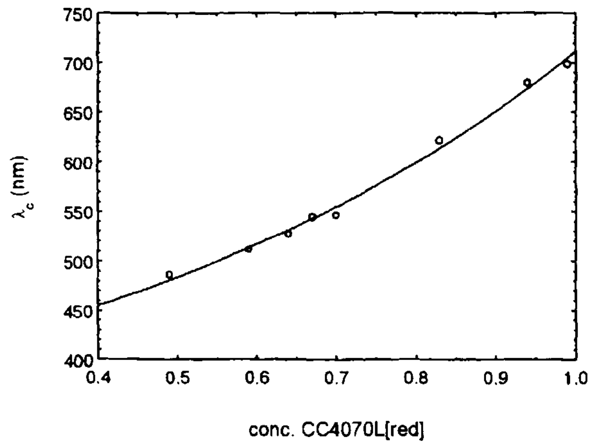


Figure 3: Center wavelength *Vs.* concentration of CC4070L(red) in CC4039L(UV)

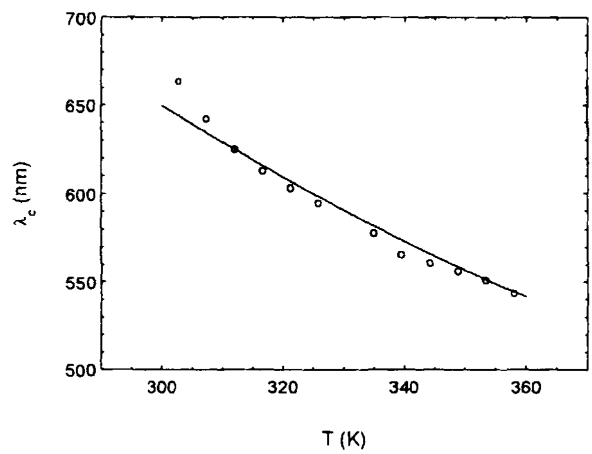


Figure 4: Center wavelength Vs. Polymerization temperature

## IV. PHASE SHIFTER

The phase shifter used in the implementation of the scanner/switch is an electrically-controllable half-wave retardation plate. The phase shifter acts as a half wave retarder in the absence of an electric field, and converts right-handed circularly polarized light (RCP) into left-handed circularly polarized light (LCP) and vice versa. When a sufficiently strong electric field is applied to the walls of the cell, the retardation property of the cell disappears, leaving the polarization state of the beam unaltered.

### *IV. A. Ferroelectric Liquid Crystals (FLC's)*

Ferroelectric liquid crystal[8] phase shifters are commercially available, and can achieve switching times of microseconds. The FLC layer has two preferred orientations differing by 45°, and by changing the polarity of the applied voltage the optic axis can be switched between these two bistable states. If the FLC thickness, d, and birefringence, $\Delta n$, are chosen such that $\Delta nd=\lambda/2$, then the FLC acts as a half-wave retarder. An FLC combined with a quarter-wave plate (QWP) can be used to modulate between RCP and LCP.

## V. MANUFACTURING ISSUES

A 1 x N optical scanner device (Faris, US Patent 5,459,591) is made by arranging N switching elements in a row. (Figure 5) The 1-D switch array operates as follows: if all of the individual switching elements are in their transmission mode of operation, the input beam will emerge from the end of the row of switches. If a voltage is applied to one of the switches, then the input beam will be reflected by the polarizer inside that element, and will emerge from the device at the location corresponding to that element. In this way one input optical channel can feed into N separate output channels.

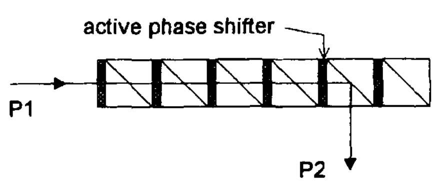


Figure 5: One dimensional Scanner

A two-dimensional electro-optic scanner can be fabricated by stacking N one dimensional (1×M) arrays as shown in Figure 4. The input beam (incident along **x** axis) is steered along the **y** axis by one of the M elements in X array. The output from the X-array becomes the input beam to the second 1-D array (Y-array) which causes the beam to emerge to any desired position in XY plane. The Y-array consists of a linear array of BSD *slices*. Each slice is a single rectangular prismatic BSD element. The selective reflection element in each slice of Y-array is angled such that the reflected beam emerges normal to the plane of the device (i.e. towards the observer).

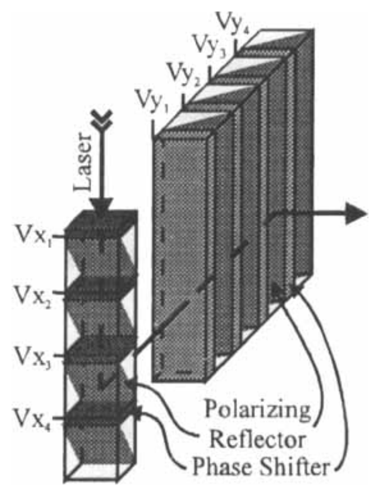


Figure 6: Two dimensional Beam Steering Device

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