White Paper

Twisted Nematic Liquid Crystal Devices

Tom Baur, Founder & Chief Technical Officer

Meadowlark Optics first introduced nematic liquid crystal (LC) devices for precision optical applications more than 25 years ago. These devices are variable retarders, sometimes called LCVRs. They provide electrical control of retardance at low voltages, usually 20 volts (2 kHz square wave AC) or less. Figure 1 shows an example of the relationship of retardation to voltage for one of these devices. In many applications they have supplanted their much higher voltage cousin, the Pockels cell. Pockels cells respond more quickly (a few nanoseconds vs. a few milliseconds) but require drive voltages of a few kilovolts in most cases.

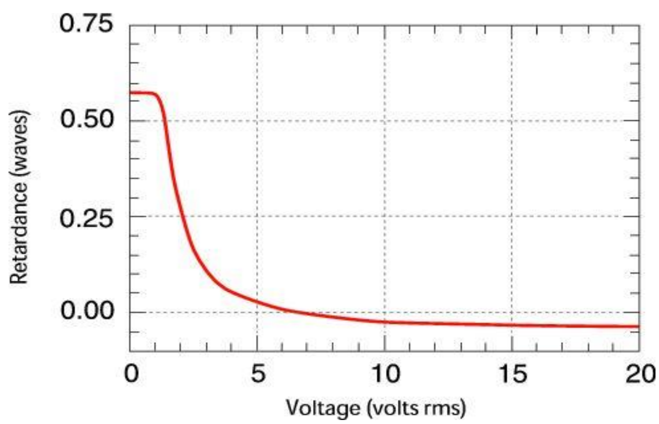

Figure 1 – Shows the change in retardance with voltage for a typical LCVR.

Nematic LC birefringences are usually in the range of 0.1 to 0.3 so the LC layer is usually less than 10 microns thick for retardances of at least half wave. The LC molecules are arranged to behave optically as would be the case for a solid uniaxial crystal with its fast and slow axes in the plane of the LC layer. The LCVR cell structure is shown in Figure 2.

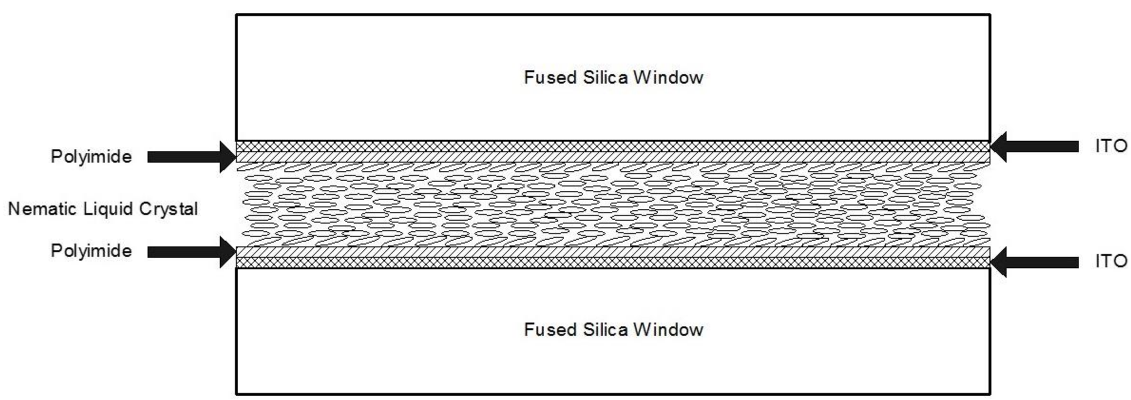

Figure 2 – shows schematically the structure of a nematic LCVR.

The rod shaped LC molecules tip up when a voltage is applied to the transparent ITO (indium tin oxide) electrodes because the electric field induces a dipole in the molecules along the long axis of the molecules. The dipole interacts with the electric field to produce a torque on the molecules. This tip effectively changes the birefringence of the LC layer driving it to near zero at 20 volts.

The twisted nematic (TN) LC device is less commonly used in precision optics but has important advantages for making non-mechanical shutters or variable attenuators. The primary advantages over LCVR's are:

1. Less wavelength dependence of performance,
2. Much higher extinction ratio between the "open" and the "closed" state and
3. Less dependence of performance on angle of incidence.

The LC structure for these devices is similar to that in the LCVR except that the long axis direction of the molecules, called the director, twists such that it is in the plane of the Figure 2 diagram at the top of the LC layer and perpendicular to the plane at the bottom of the layer. A linearly polarized incident light beam will "adiabatically follow" the director as it moves through the LC layer and will emerge from it with a linear polarization direction perpendicular to that of the incident beam. This effect only works well for certain thicknesses of the LC layer but they are usually less than 10 microns thick.

Usually the TN LC is placed between crossed linear polarizers for use as either a shutter or an attenuator that gives a voltage dependent transmission. At zero voltage the TN LC rotates the plane of the incoming beam polarization $90^o$and produces the open state of this non-mechanical shutter or attenuator. The polarization twist effect is destroyed when 10 volts or so is applied to the LC and this produces the closed state of the shutter. Intermediate voltages produce intermediate transmission states. The efficiency of the polarization twist at zero volts varies with wavelength and can be optimized for any specific wavelength by selecting the appropriate combination of cell thickness and LC birefringence. Figure 3 shows the measured wavelength dependence of zero voltage transmission of a shutter for an LC thickness of 2.91 microns and an LC birefringence of about 0.2.

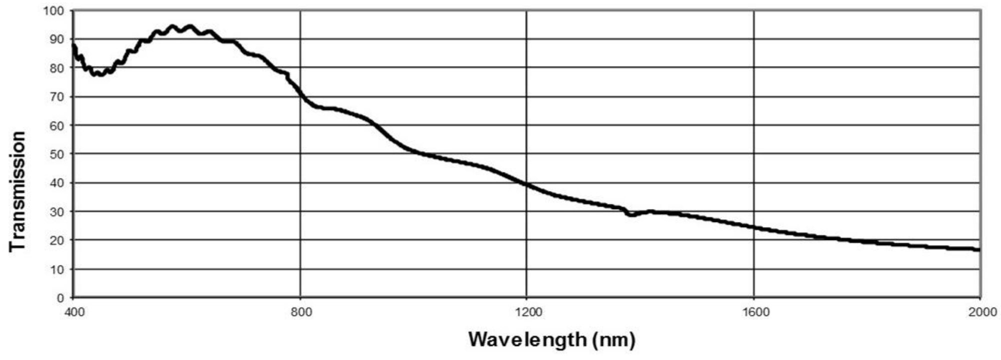

Figure 3 – Shows the measured open state transmission of a TN LC cell that has not been antireflection coated.

Thicker LC layer or higher birefringence LC is required for the best open state transmission at longer wavelengths than that shown in Figure 3. Table 1 below shows optimum cell thickness and 10% to 90% transmission response times for TN shutters using the same LC as in Figure 3. Response time is different for opening and closing the shutter and increases with the LC layer thickness.

Table 1.

Wavelength	LC Thickness	Open Time	Close Time
670 nm	2.91 µm	4.52 ms	.38 ms
1064 nm	4.24 µm	21.2 ms	.81 ms
1550 nm	7.0 µm	40 ms (est.)	1.2 ms (est.)

Contrast ratio between the open and closed state of a TN shutter depends mostly on the quality of the polarizers used and how carefully they are aligned. Table 2 shows the measure contrast ratio using carefully crossed Glan-Thompson polarizers.

Table 2

Wavelength	Measured Contrast Ratio
532 nm	18,000:1
670 nm	46,000:1
1064 nm	71,000:1
1580 nm	500,000:1

Modified TN configurations also work well on reflective spatial light modulators and can show contrast ratios of several thousand to one. Some transmissive devices show better angular field of view with twist angles greater than 90^{o}. Supertwist nematic devices use a twist angle of 270^{o}. Detailed discussion of reflective and supertwist LC devices is beyond the scope of this paper.

For more information on our Twisted Nematic Liquid Crystal products, please do not hesitate to contact one of our sales engineers at:

meadowlark optics
polarization solutions

Meadowlark Optics
5964 Iris Parkway
Frederick, CO 80530

sales@meadowlark.com
Tel: 303.83.4333
Fax: 303.833.4335