White Paper

Electro-Optical Shutters

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Meadowlark Optics manufactures four types of non-mechanical, vibration free, shutters. Three of these require polarized light input, preferably linearly polarized. They are used in conjunction with an exit polarizer. The extinction ratio between the open and closed states depends strongly on the polarization purity of the input beam or input polarizer and on the quality of the exit polarizer.

Twisted Nematic Liquid Crystal Shutters

These devices use liquid crystals of a type and in a configuration often used in displays. Figure 1a shows the arrangement of the nematic molecules when no voltage is applied. Incident linear polarization is rotated by 90^o. Figure 1b shows that the twist is destroyed and the incident polarization is unchanged when 5 or 10 volts is applied to the transparent conductive electrodes on the interior cell walls. The exit linear polarizer is crossed with the input polarization direction so that the transmitted beam is blocked when this voltage is applied. The liquid crystal molecules return to the twisted configuration of 1a when the voltage is removed and the incident beam passes through the exit polarizer in this zero-voltage state. The shutter can act as a variable attenuator by applying intermediate voltages in the range of one to four volts that will only partially destroy the twist.

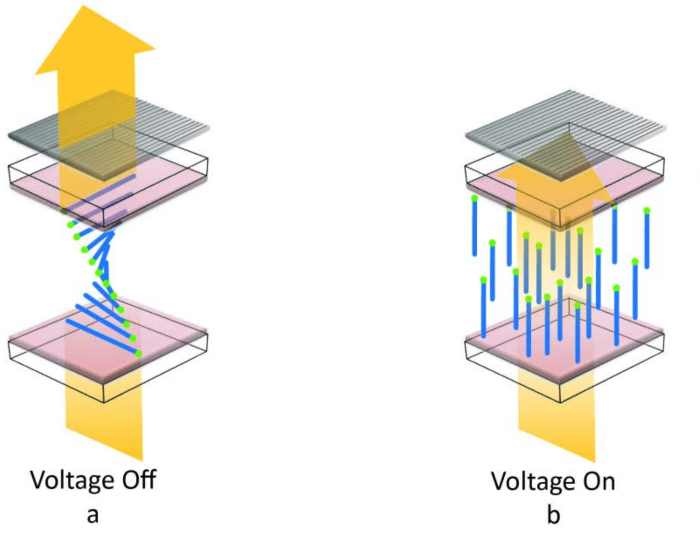

Figure 1 – Shows the open (a) state and the closed (b) state for a twisted nematic shutter.

The polarization form in the zero-voltage state is only preserved for a range of wavelengths selected by appropriate choice of the liquid crystal layer thickness. Figure 2 shows a typical wavelength dependence for the open, zero-voltage state.

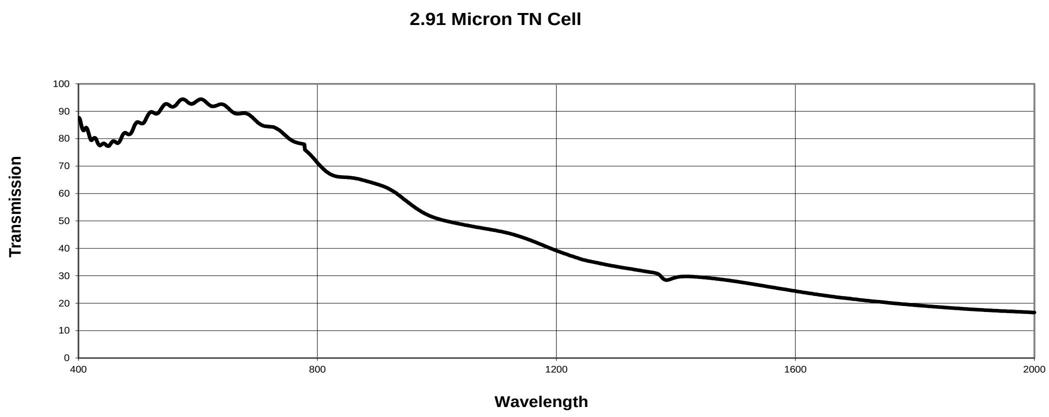

Figure 2 – Shows the measured wavelength dependence of the open state of a twisted nematic shutter using Glan-Thompson polarizers. This cell is optimized for best performance at visible wavelengths.

Response time for these shutters is about 0.35 milliseconds to close and about 4.4 milliseconds to open for shutters optimized for green light. These times increase at longer wavelengths, for example to 0.81 milliseconds to close and 21.2 milliseconds to open for a shutter optimized for 1064 nm wavelength. These times can be reduced by heating the shutter.

Our standard twisted nematic shutter (High Contrast Optical Shutter) is normally supplied with sheet polarizers and has an extinction ratio between the open and closed states above 5000:1. This ratio increases to nearly 20,000:1 if the input linear polarizer and the exit polarizer are high quality Glan-Thompson polarizers. (See the white paper on our website "Twisted Nematic Liquid Crystal Devices" for more details.) The drive voltage for these liquid crystal devices is a DC balanced 2kHz square wave.

Ferroelectric Liquid Crystal Shutters

These devices are also low voltage liquid crystal devices but the switching times are much faster, about 100 microseconds. They operate as a half wave retarder whose fast axis direction rotates in the plane of the liquid crystal layer by 45^o when the sign of the applied voltage is reversed. The devices are binary and must be switched in voltage in a DC balanced manner. Voltages are again on the order of 10 volts. The open state transmission is wavelength dependent as shown in Figure 4. The wavelength of maximum transmission is set by the thickness of the liquid crystal layer but there are problems with making the liquid crystal layer thick enough for optimum transmission at wavelengths above about 1064 nm. Meadowlark Optics offers electronic drivers for both ferroelectric and twisted nematic shutters. They can be manually controlled or computer controlled. All liquid crystal devices must be driven in a DC balanced manner.

Figure 3 – Shows ferroelectric liquid crystal shutters with polarizers removed.

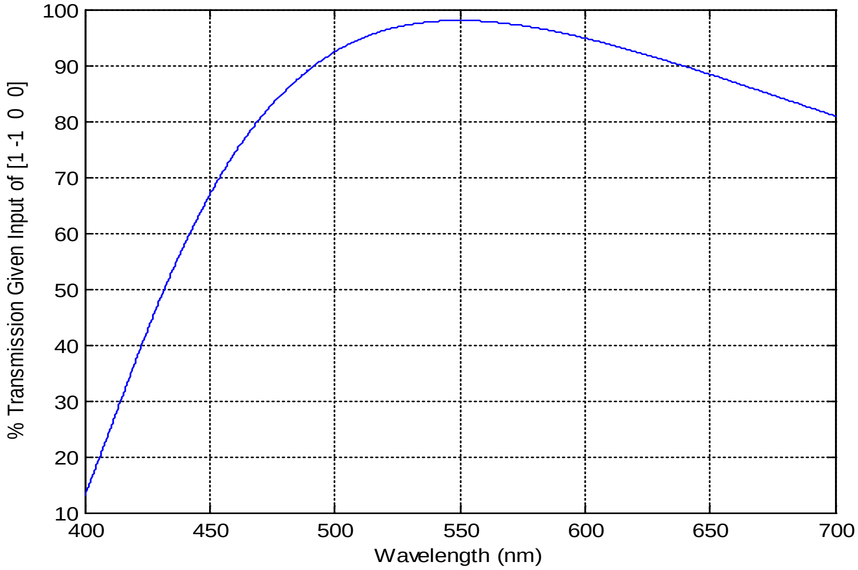

Figure 4 – Shows the wavelength dependence of transmission of a ferroelectric liquid crystal shutter in the open state, optimized for 550 nm wavelength.

(More achromatic performance is now available on a custom basis.)

Pockels Cell Shutters

Figure 5 – Pockels cell with the polarizers removed that are needed for a shutter.

Most Pockels cells are only appropriate for use with lasers because they require highly collimated light. Meadowlark Optics makes a type that works well in noncollimated light for f ratios slower than about f/20, which is still much slower than for the liquid crystal devices already described above. The response time is much faster than for liquid crystals. The structure is similar to that of the liquid crystal devices described above in that there is an electro optic material between transparent conductive electrodes and the device modifies the polarization of light in a manner that depends on the applied voltage. The electro optic material in our devices is KD*P, potassium dideuterium phosphate crystal. Other crystals such as lithium niobate can be used as well.

A major drawback for these shutters is that the applied voltage is several kilovolts, not several volts. The major advantage is that they can switch in 10 nanoseconds or less, about 10,000 times faster than our fastest liquid crystal shutter. The speed is limited by the current available from the driver, which must charge the “capacitor” to create the needed electric field. The device capacitance is on the order of 100 picofarads for a 25 mm diameter clear aperture cell. Apertures up to 40 mm diameter are available.

These should be driven in a DC balanced manner. Pockels cells are variable retarders. At zero volts they are zero wave retarders and at about 4,000 volts they are half wave retarders for a wavelength of 633 nm. The retardation changes linearly with voltage and changes sign when the sign of the applied voltage changes, as shown in Figure 6.

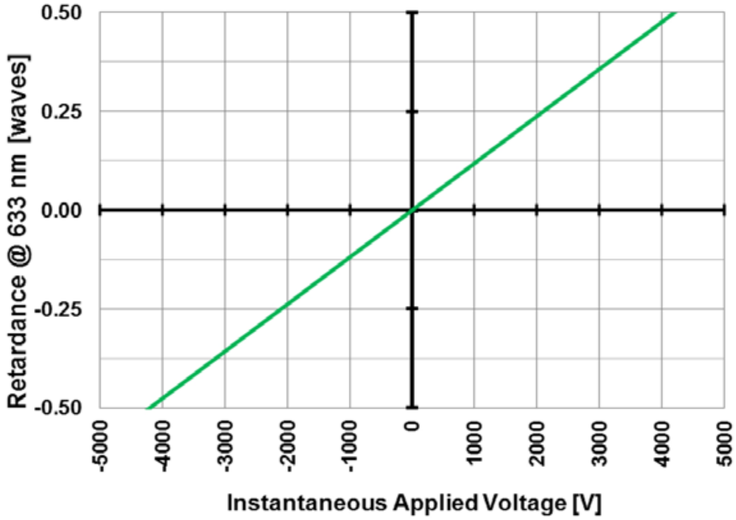

Figure 6 – Shows the linear response of the Pockels cell to applied voltage.

The Pockels cell is used as a fast shutter by placing it between crossed linear polarizers with the optic axis of the cell at 45^o to the polarization directions. The shutter is closed with no voltage applied and open when half wave voltage is applied. The wavelength dependence of transmission in the open state is nearly identical to that of the ferroelectric shutter as shown in Figure 4. However, the center wavelength of the open state transmission is easily changed by changing the applied voltage. Extinction ratio exceeds 1000:1 for an f/20 beam.

Polarizers and Power Levels

The three shutter types described above all require polarizers. Acceptable power levels for these shutters depends on the polarizer type. Polarizers that reject light by absorption, for example most sheet polarizers, are more easily damaged than ones that reject light by reflection or refraction such as wire grid polarizers or birefringent crystal polarizers. Common crystal polarizers are Glan-Thompson, Rochon and Wollaston. These are usually made using calcite crystals. Twisted nematic and ferroelectric shutters are usually supplied with dichroic sheet polarizers that are easily damaged by light fluxes above one watt/cm^2. This increases to about 30 watts/cm^2 for calcite crystal polarizers and to 500 watts/cm^2 for Macneille cube type polarizers, which is about the same safe flux level as for liquid crystal devices. These safe levels are approximate and depend on wavelength as well. Liquid crystals are more easily damaged by blue or UV light than by light at longer wavelengths.

Polymer Dispersed Liquid Crystal Shutter

This shutter is non-mechanical and uses liquid crystals but does not require polarizers. It is a variable scattering device and can have up to 70% transmission in the open state for unpolarized light. All of the shutters described above cannot exceed 50% transmission for unpolarized light and 40% or less transmission is more typical. The shutter is open when 70 volts AC is applied and it becomes a diffuse scatterer when voltage is zero. The applied electric field controls the index of refraction of liquid crystal droplets imbedded in a polymer sheet. The sheet is transparent when the indices of the polymer and the liquid crystal match and the sheet is translucent when they do not. Contrast ratio is usually above 100:1 but depends on wavelength and the geometry of the optical system.

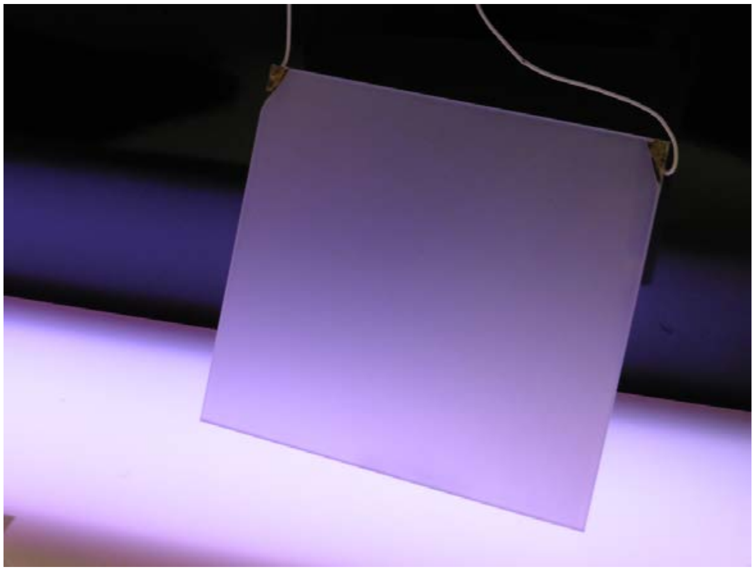

Figure 7 – Shows a polymer dispersed liquid crystal shutter in the closed, zero voltage state.

For more information on our shutter products, please do not hesitate to contact one of our sales engineers at:

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