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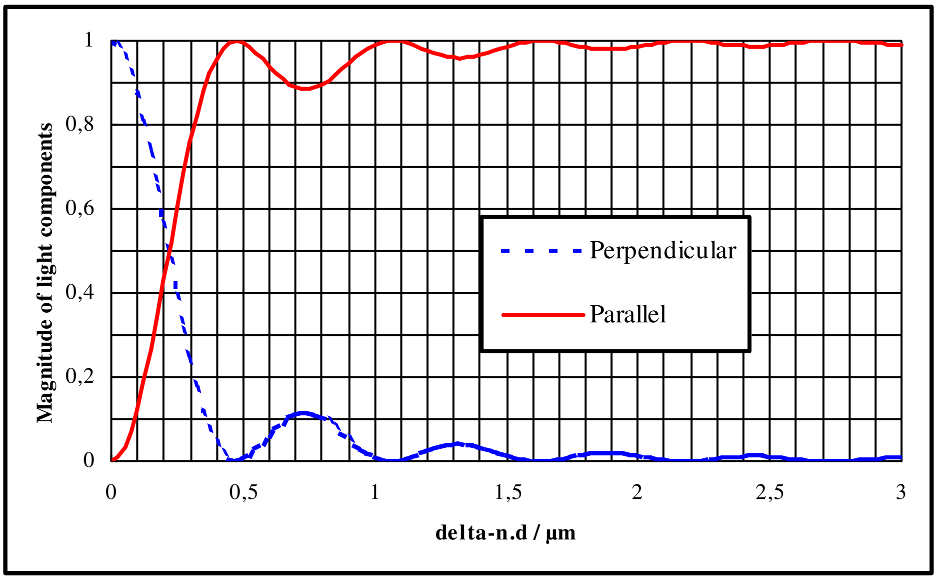
Polarisation Efficiency of TN-optical-shutters

When in the voltage-OFF state, the liquid crystal molecules in a TN-optical-shutter form a helical-structure. However, it is only in the limit of large cell thickness that the helical-structure is capable of rotating the plane of polarisation of light with 100% efficiency and in general the exiting light becomes *elliptically* polarised with components oscillating in directions lying both parallel and perpendicular to the exit liquid crystal molecules.

Furthermore, it is the *optical-path-difference* in the liquid crystal material that controls the overall magnitude of the polarisation efficiency for the optical-shutter. The *optical-path-difference* is given by the $\Delta n.d$ parameter, where Δn is the **anisotropic index of refraction** for the liquid crystal material and d is the **cell-gap** in the optical-shutter.

Figure 1 shows the theoretically calculated magnitude of light components exiting a TN-optical-shutter (90° TN) oriented in directions respectively parallel (**RED** curve) and perpendicular (**BLUE** curve) to the exit liquid crystal molecules as a function of the $\Delta n.d$ parameter. Here, a single wavelength of 550nm (central part of visible spectrum) is used and the incident light is considered as being initially polarised in a direction lying *parallel* to the entrance liquid crystal molecules.

Figure 1: Magnitude of light components at a wavelength of 550nm exiting a TN-optical-shutter (90° TN) in directions lying both parallel (RED curve) and perpendicular (BLUE curve) to the exit liquid crystal molecules as a function of the $\Delta n.d$ parameter.



It is demonstrated that maximum polarisation efficiency is only obtained for specific values of the $\Delta n.d$ parameter and for a single specific wavelength, indicated by points of maxima in the **RED** curve. The values of $\Delta n.d$ that give maximum polarisation efficiency for a single wavelength of 550nm and with a twist angle of 90° within the liquid crystal helical structure can be calculated and are given as follows:

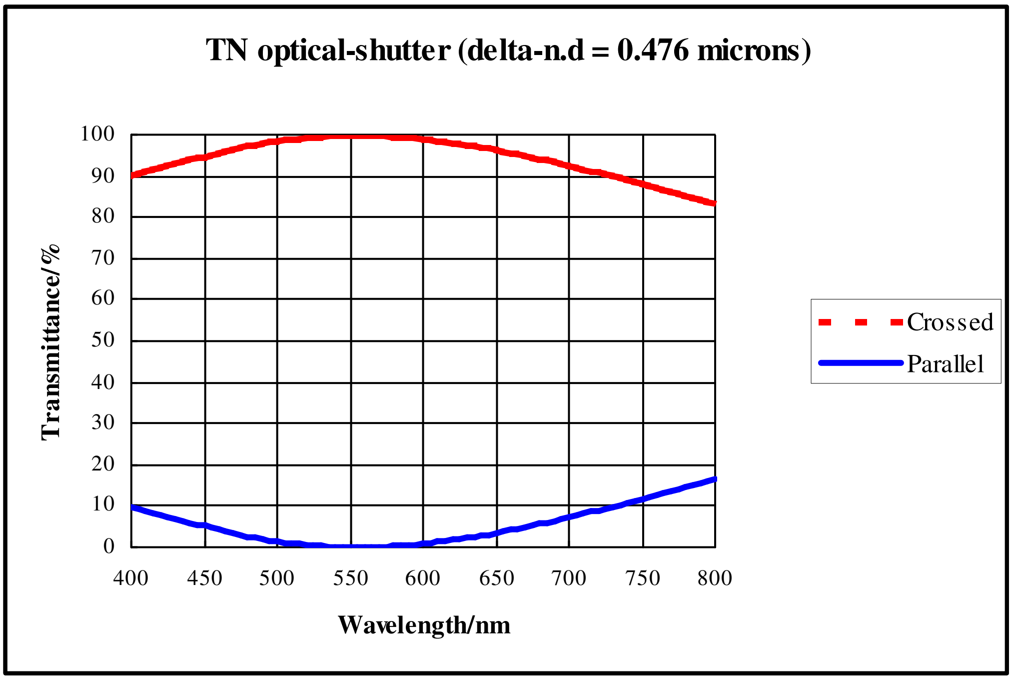
$$\Delta n.d_{maxima} = 0.275\sqrt{3}\ \mu m,\ 0.275\sqrt{15}\ \mu m,\ 0.275\sqrt{35}\ \mu m,\ 0.275\sqrt{63}\ \mu m,\ .....\ etc$$

$$= 0.476\ \mu m,\ 1.065\ \mu m,\ 1.627\ \mu m,\ 2.183\ \mu m,\ 2.736\ \mu m,\ 3.289 \mu m,\ .....\ etc$$

Furthermore, due to the fact that the switching speed for a TN-optical-shutter is inversely proportional to the square of the cell-gap (d^2 parameter), TN-optical-shutters are often manufactured with a $\Delta n.d$ parameter corresponding to the *first-maximum-position* (0.476 micrometers). This provides for both good polarisation efficiency together with fast switching speeds (i.e the cell-gap is minimised).

Figure two shows the theoretically calculated transmittance of a TN-optical-shutter (90° TN) possessing a $\Delta n.d$ parameter of 0.476 micrometers. Here, the transmittance of the optical-shutter when placed between both crossed (**RED** curve) and parallel (**BLUE** curve) polarisers respectively are shown.

Figure 2: Calculated transmission of TN-optical-shutter (90° TN) possessing a $\Delta n.d$ parameter of 0.476 micrometers *(first-maximum-mode)* and placed between both crossed (RED curve) and parallel (BLUE curve) polarisers respectively.



It is demonstrated that although maximum polarisation efficiency is obtained for a single wavelength of 550nm (i.e transmittance through the liquid crystal material = 100% at wavelength 550nm), there is significant *light-leakage* in both the *blue* and *red* wavelength regions. It is hence in these wavelength regions that the polarisation efficiency is seen to decrease.

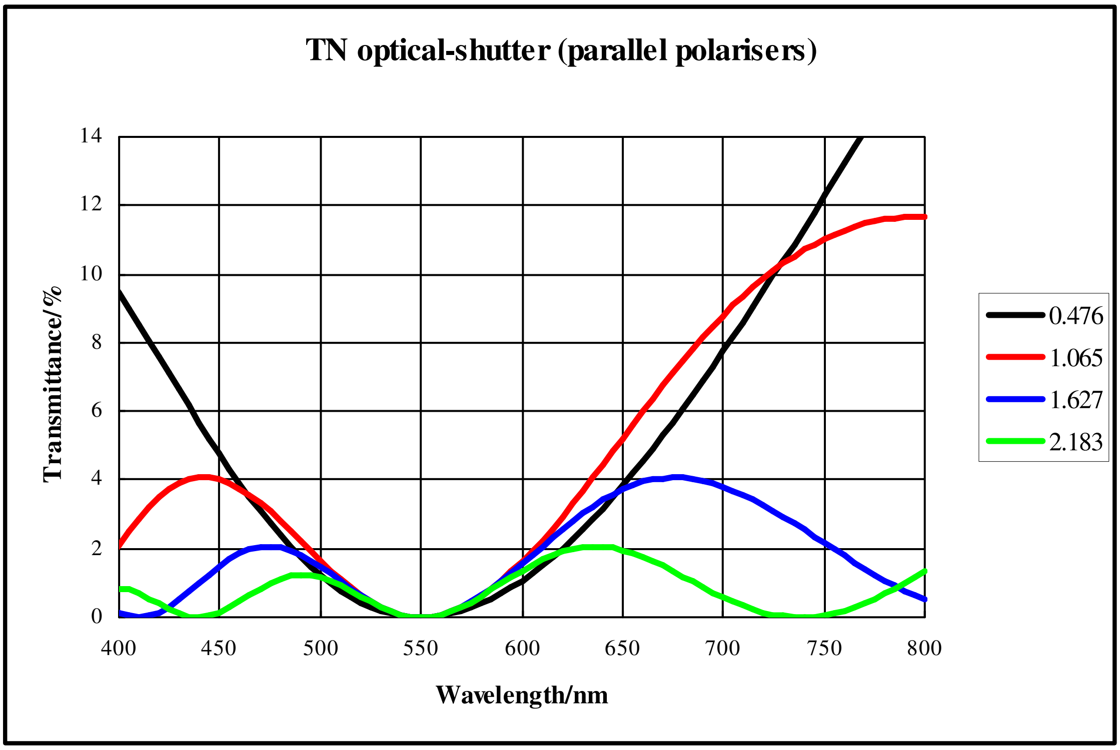
This effect is particularly apparent when the TN-optical-shutter is placed between mutually **parallel** polarisers *(normally-black mode of operation)*. In such case, light-leakage significantly degrades the perceived level of DARKNESS, giving a *magenta* colouration with up to 10% transmission (light leakage) in both the blue & red wavelength regions.

However, due to the logarithmic perception of human vision, this effect is less apparent when the TN-optical-shutter is placed between mutually **crossed** polarisers *(normally-white mode of operation)*. In such case, the optical-shutter is in the high-transparent state when inactivated (voltage-OFF state) and the loss of transmission in both the blue & red wavelength regions is less problematic.

In terms of display devices, the problem of light-leakage (polarisation efficiency) can be mitigated either via avoiding the use of the mutually parallel polariser configuration, or by the addition of dichroic-dye materials to the liquid crystal material that absorb in the red & blue wavelength regions, hence improving the level of DARKNESS when in the voltage-OFF state. Furthermore, in the case of using dichroic-dye materials, it is noted that although the overall optical contrast is improved, the polarisation efficiency remains unaffected.

Figure three shows the theoretically calculated transmittance spectra of TN-optical-shutters (90^o TN) placed between mutually **parallel** polarisers *(normally-black mode of operation)* as a function of the *Δn.d* parameter. Here, the *Δn.d* values for the first four (4) maxima shown in figure one above (**RED** curve) are considered. The four (4) different spectra therefore possess minima at wavelength 550nm, corresponding to 100% polarisation efficiency at this individual specific wavelength interval.

Figure 3: Calculated transmittance of TN-optical-shutters (90^o TN) placed between parallel polarisers as a function of the *Δn.d* parameter. Here, the *Δn.d* values corresponding to the first four (4) maxima in FIGURE ONE above (RED curve) are considered.



It is demonstrated that the level of light-leakage in the blue & red wavelength regions is reduced (polarisation efficiency improves) as the *Δn.d* parameter increases. Specifically, when operating in the *first-maximum-mode* (*Δn.d* = 0.476 micrometers), the transmission at 400nm (blue wavelength region) exceeds 9%, whereas when operating in the *second-maximum-mode* (*Δn.d* = 1.065 micrometers), the transmission of the TN-optical-shutter remains under 4% in this wavelength interval.

The polarisation efficiency of the TN-optical-shutter can therefore be improved by using a *higher-order-maximum-mode* (larger *Δn.d* parameter). However, it is also noted that increasing the cell-gap will reduce the switching speed of the optical-shutter and may also have a negative effect upon the optical angular properties (viewing angle) of the TN-optical-shutter when in the voltage-ON state.