3. Theory

Liquid crystal is a state of matter between liquid and crystal. In general, the arrangement of molecules in a liquid is disordered, and liquid crystal has both liquid fluidity and its molecules are arranged in an orderly manner so that it exhibits crystal anisotropy. When light passes through the liquid crystal, it will produce polarization rotation, birefringence and other effects. The shape of the liquid crystal molecules is like sticks of length about 10 angstroms and diameter 4 - 6 angstroms. The thickness of the liquid crystal layer is generally 5 - 8 microns.

Twisted nematic liquid crystals have an important effect on incident light, i.e. it will rotate the polarization direction of incident linearly polarized light along the twisting direction of the molecule, similar to the optical acitvity effect of matter. The angle of rotation (twist angle) under general conditions is equal to the orientation angle between the two substrates.

Due to the structural characteristics of liquid crystal molecules, their polarizability and electrical conductivity are all anisotropic. When a large number of liquid crystal molecules are regularly arranged, their overall electrical and optical characteristics, such as dielectric constant and refractive index, will also demonstrate anisotropic characteristics. If we apply an electric field to a liquid crystal substance, it may change the state of molecular arrangement. As a result, the optical properties of liquid crystal materials change, which is the electro-optic effect of liquid crystal.

In order to apply an electric field to the liquid crystal, a layer of transparent electrode is coated on the inside surface of each of the two glass substrates. The structure composed of substrate electrodes, alignment film, liquid crystal and sealing material is called as a liquid crystal cell.

According to the structural characteristics, the liquid crystal molecules have no fixed electrodes. However, they can be polarized by an external electric field to form an induced electrode moment. This induced electrode moment will also have its own direction. When the direction of the electric field is different from this direction, the external electric field will cause the liquid crystal molecules to rotate until the various interaction forces reach equilibrium. The change of liquid crystal molecules under the action of an external electric field will also cause the total arrangement of liquid crystal molecules in the liquid crystal volume to change. When the external electric field is strong enough, the liquid crystal molecules between the two electrodes will be arranged along the electric field.

If the liquid crystal cell is placed between two parallel polarizer plates, the polarization direction is the same as the orientation of the liquid crystal molecules on the upper surface. When no voltage is applied, the linearly polarized light formed by the incident light through the polarizer, the polarization direction rotates 90^{o} with the liquid crystal molecular axis after passing through the liquid crystal cell. It cannot pass through the analyzer. After the voltage is applied, the transmitted light intensity is related to the amplitude of the applied voltage, their relationship is shown in Figure 3.

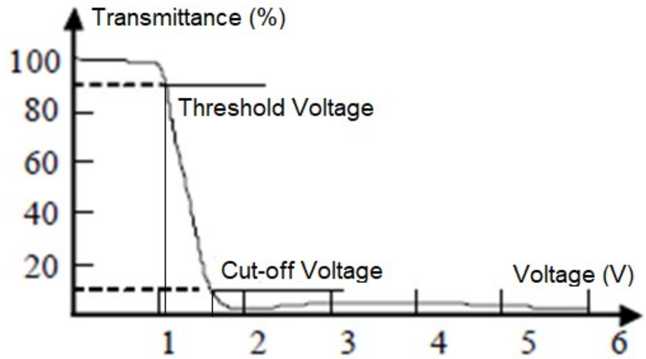

Figure 3 Relationship between transmittance and voltage

The value of the applied voltage corresponding to 90% of the maximum light transmittance is called the threshold voltage (U_{th}), which marks the beginning of the observable reaction of the electro-optic effect of the liquid crystal. The applied voltage value corresponding to 10% of the maximum light transmission intensity is called the cutoff voltage (U_r), which indicates the value of the applied voltage required to obtain the maximum contrast. Small U_r means it is easy to obtain a good display effect with fewer display power consumption.

Contrast is defined as $D_r = I_{max}/I_{min}$, where I_{max} is the maximum observation (reception) brightness (illuminance), and I_{min} is the minimum brightness. Steepness is defined as $\beta = U_r/U_{th}$ i.e. the ratio of cutoff voltage to threshold voltage.

Figure 4 shows a schematic of the principle of a LC optical switch.

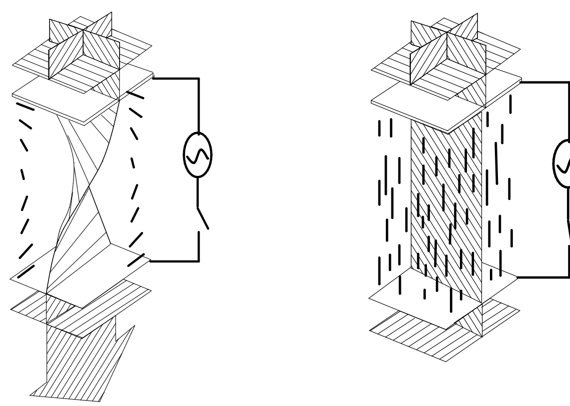

Figure 4 Working principle of a LC optical switch

The above analysis is only a preliminary analysis of the liquid crystal cell in the "switch" two extreme states. And for the intermediate state between these two states, we do not yet have a clear understanding. In fact, in this intermediate state, there are many optical phenomena. We will observe and analyze them in the experiment.

The response speed of the liquid crystal to the changing external electric field is a very important parameter of the liquid crystal product. Generally speaking, the response speed of liquid crystal is relatively low. We use the rising edge time t_r and falling edge time t_d to represent the response speed of the liquid crystal to the external driving signal. The definition is shown in Figure 5.

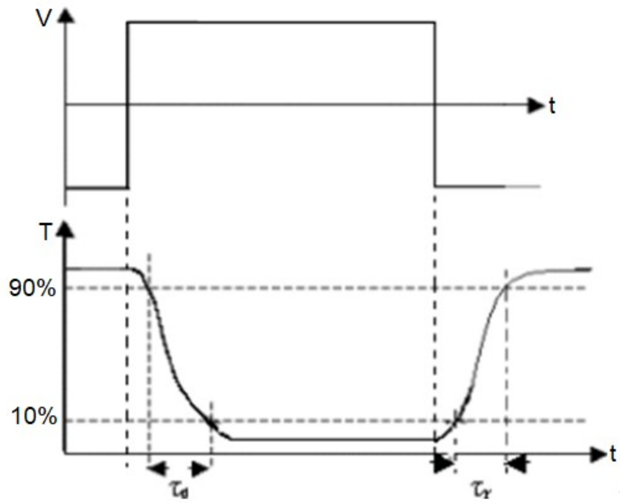

Figure 5 LC screen response time

This experiment is purposed to have a basic understanding of the optical properties and physical structure of liquid crystal materials through some basic observations and research, and use the existing physical knowledge to perform the preliminary analysis and interpretation.