ECE185

LIQUID CRYSTAL DISPLAYS

Objective:

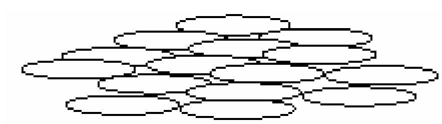
To study characteristics of liquid crystal modulators and to construct a simple liquid crystal modulator in lab and measure its characteristics.

References:

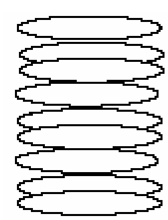
B. Saleh and M. Teich, Fundamentals of Photonics, Ch. 6, pp. 227-230; Ch.18, pp. 721-729.

Background:

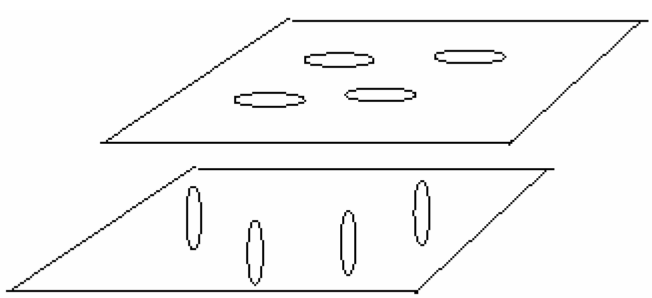
Organic materials with elongated (cigar-like) molecules or flat (disc-like) molecules can give rise to optical anisotropy. For instance, an organic molecule, p-methoxybenzylidene-p'-nbutylanilane (MBBA) has three liquid phases, the nematic phase which exists at temperature 21– 47°C, and the smectic phase, and the cholesteric phase. In the nematic phase, there is a long range orientational order of the axes of the molecules, while the centers of the molecules are randomly distributed:



In the smectic phase, the crystal exhibits one-dimensional translational order as well as orientational order:



In the cholesteric phase, the orientational order also exists; the molecules are in rows with each row has a well-defined angle for the molecular direction:



The smectic phase is closest to the solid phase, while the nematic and cholesteric phases have the greatest E-O uses. As we raise the temperature, solid phase (low temperature) -> smectic liquid phase -> nematic liquid phase -> isotropic liquid.

Due to the orientational ordering of these anisometric structures, the smectic and nematic liquid crystals are uniaxially symmetric, with the optic axis parallel to the axes of the molecules, while that of the cholesteric liquid crystal is defined only locally.

The refractive index difference between the ordinary and extra-ordinary indices is denoted by $\Delta n = n_e - n_o$. In the nematic liquid crystal, the optic axis may be reoriented by the application of an electric field. Usually they tend to rotate in such a way that the direction of maximum dielectric constant coincides with the direction of the electric field. In all known nematic and smectic liquid crystals, $\Delta n > 0$. The dielectric anisotropy, $\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{|}$, can be > 0 or < 0, $\varepsilon_{||}$ and $\varepsilon_{|}$ are the dielectric permittivity for an electric field parallel and perpendicular to the optic axis.

Consider the case where $\Delta\varepsilon > 0$, which is characteristic of molecules having a longitudinal dipole moment. Let's assume the initial orientation of the optic axis is along the x-axis, and the electric field (say, along the z-axis) is perpendicular to the x-axis. In this case the optic axis will align at an angle θ with respect to the x-axis. The extraordinary refractive index seen by light propagating parallel to electric field (z-axis) is given by

$$\frac{1}{n^2(\theta)} = \frac{\cos^2\theta}{n_e^2} + \frac{\sin^2\theta}{n_o^2}$$

The angle θ depends on the field strength. In a strong field θ is 90° and the birefringence (defined as $n_e(\theta) - n_o$) vanishes. When the field is small or zero, θ return to 90° and birefringence reappears.

Because of these electrically induced reorientation of the optic axis, the phase retardation Γ of a thin layer of properly oriented liquid crystal can be switched from $\Gamma = 2\pi(n_e - n_o)d/\lambda$ to zero and back with an applied electric field.

The liquid crystal cell can be used as a voltage-controlled wave retarder. When placed between two crossed polarizers, a half-wave retarder ($\Gamma = \pi$) becomes a voltage-controlled intensity modulator. The liquid-crystal cell is sealed between optically flat glass windows with antireflection coatings. A typical thickness of the liquid crystal layer is d = 10μm and typical values Δn = 0.1 to 0.3.

A critical voltage at which the molecules tilting process begins is typically a few volts. When the applied electric field is sufficiently large, most of the molecules tilt, except those adjacent to the glass surfaces. The tilt angle θ for most molecules is a monotonically increasing function of voltage. When the electric field is removed, all of the molecules tilt back to their original orientation. The applied voltage usually has a square waveform with a frequency in the range between tens of Hz and a few kHz.

Liquid crystals are slow. Their response time depends on the thickness of the liquid crystal layer, the viscosity of the material, temperature, and the nature of the applied drive voltage. The rise time is of the order of milliseconds. The decay time is insensitive to the operating voltage but can be reduced by using cells of smaller thickness.

Experiments:

PART I SLIDE PREPARATION FOR LIQUID CRYSTAL MODULATOR

Objective To prepare the slides that will be used to construct the modulator.

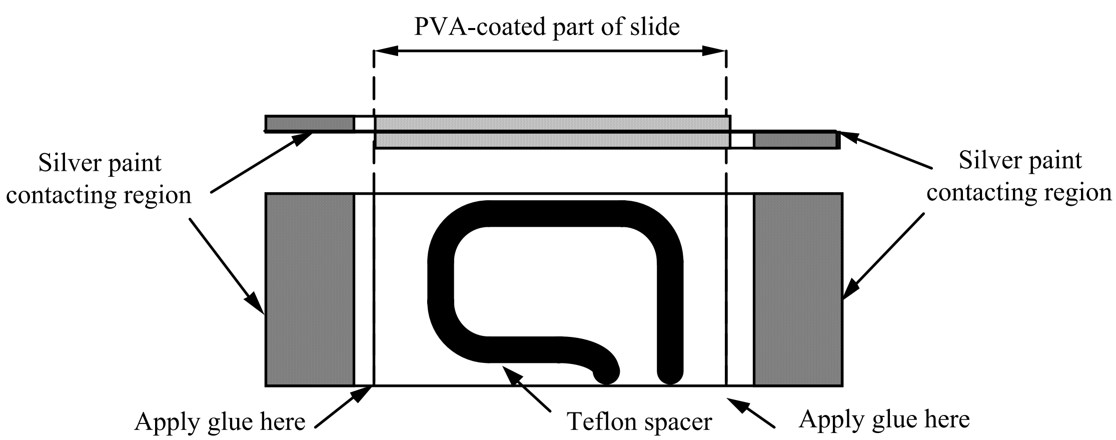
Discussion To build a liquid crystal modulator, a transparent conductive material Indium Tin Oxide (ITO) is applied to a glass plate. The process requires several steps and waiting between each step.

Procedure

1. Clean two ITO-coated microscope slides with methanol.
2. Using ohmmeter, determine which side of the plates has the ITO. Remember it is conductive.
3. Using a Q-Tip as a brush, apply a thin layer of silver paint 1/4" from the end of each slide **on the same side as the ITO**.

LATER AFTER PAINT DRIES (You can start Part II while the paint dries)

4. Dip the slides in a 10% solution of PVA. The TA will show this to you. This is a polymer that we will then brush to help align the liquid crystals. Be sure to dip the side of the slide where there is no silver paint.



LATER AFTER THE PVA DRIES

5. Once the slides are dry, use a soft towel (lens tissue) to brush alignment grooves into the PVA. Be sure to brush on the ITO side of the slide. Brush lightly in a **single** direction along the length of the plates. These grooves will help align the liquid crystal in a single direction.

6. Assemble the display using a Teflon spacer ring as shown below. Be sure to leave a 1/4" in the Teflon spacer ring to inject the liquid crystal.

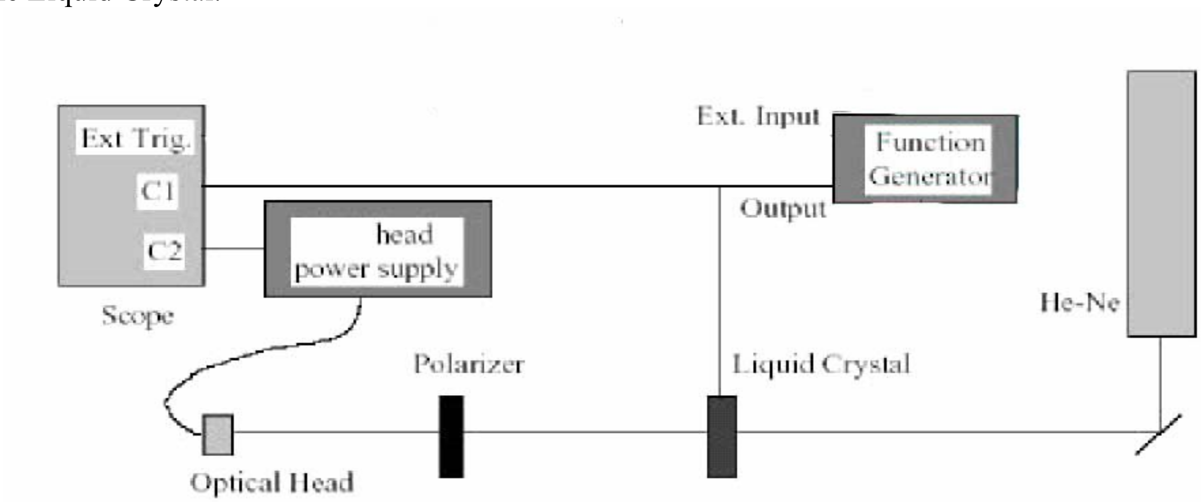
7. Clip the plates together using paper holders. Using a capillary tube, insert the liquid crystal into the display. **Lightly** glue the edges of the plates around the edges of the Teflon spacer. Capillary action will draw the glue between the plates. Let the glue dry.

PART II COMMERCIAL LIQUID CRYSTAL DISPLAY

Objective To examine the operating characteristics of commercial liquid crystal shutter. We will repeat all of these experiments on the device that you are building.

Experiment

1. The experiment is shown below. Set the polarizer to be crossed to the output of the laser and place **after** the Liquid Crystal.



2. **Before** connecting the function generator to the Liquid Crystal, set the function generator to produce 20*Hz* square wave with no DC offset. Vary applied voltage and observe the response of LC. Plot P_{out} (mW) vs. Voltage (V) and find boundary voltages when LC starts and stops to response.

3. Modulate applied voltage with the same frequency square-wave between boundary voltages (it does not have to be exact). You should see something like this on the scope.

4. Turn on Channel 2 on the scope and adjust the two voltage levels on the liquid crystal to generate the faster rise and fall times. You should see something like this

5. Measure the contrast ratio. Measure the rise and fall times.

PART III TESTING THE CUSTOM LIQUID CRYSTAL DISPLAY

Experiment Using the same procedure as in Part II, repeat the testing for the custom made liquid crystal display.