

**6.007 – Applied Electromagnetics**  
Spring 2011

**Lab 3: Liquid Crystal Displays**  
*Tuesday and Wednesday, March 29 and 30, 2011*

---

## Introduction

In this lab, we will construct and characterize a single liquid crystal pixel. The construction consists of several steps, including grooving the substrates to align the liquid crystals, assembling the display cell, and filling the cell with spacers and the liquid crystal material. You will then characterize the switching and optical properties of your liquid crystal cell using the same photoresistor setup as used in Lab 1.

## 1 Theory

Liquid crystals were first identified in 1889 by an Austrian botanist named Friedrich Reinitzer who was studying the melting of a cholesterol ester. Reinitzer observed two melting temperatures, one at which the material turned into a hazy liquid, and then finally a second one at which the material turned clear. Reinitzer's observation was followed up by studies by Lehmann starting in 1890 in which the term liquid crystal was first coined (*Flussige Kristalle* in German). Finally, in 1922, Friedel defined three structural classes of liquid crystals, which he referred to as a “mesophase,” or “intermediate phase.” These phases are *nematic*, *cholesteric*, and *smectic*. A fourth phase, *columnar*, was later discovered.<sup>1</sup>

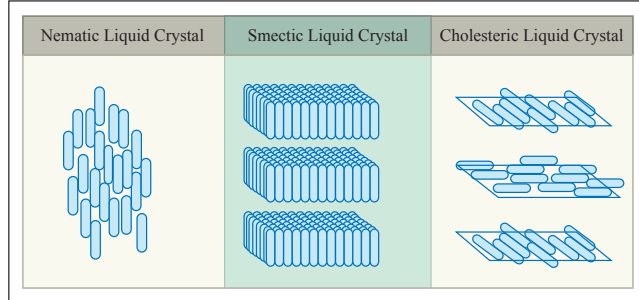


Image by MIT OpenCourseWare.

Figure 1: Types of liquid crystals.(From “Fundamentals of Liquid Crystal Displays,” by Hugo Steemers, SID Seminar Notes 1994.)

Displays making use of liquid crystals' dielectric anisotropy (liquid crystal displays, or LCDs) were first developed in 1967 at Kent State University. These are referred to as TN/LCDs, or twisted-nematic LCDs. The liquid crystals utilized in these displays are nematic phase (not to be confused with the cholesteric, or “twisted nematic,” liquid crystal phase). These displays have recently become the dominant flat panel display technology for computer monitors and televisions.

Due to the dielectric anisotropy of the liquid crystals, when a voltage is applied to the two electrodes, the liquid crystals rotate in order to increase the capacitance of the structure, thereby decreasing the stored energy in the capacitor (when considering a fixed amount of charge on the capacitor,  $Q$ ). The forces that align the liquid crystals act as torsional springs, opposing the rotation induced by the charge on the capacitor. When the charge is removed, the liquid crystals relax back to their aligned position. In the aligned position, the TN/LCD pixel will act as a waveplate, rotating the polarization of the incoming light.

---

<sup>1</sup>From *The Structure of Materials*, by Samuel M. Allen and Edwin L. Thomas.

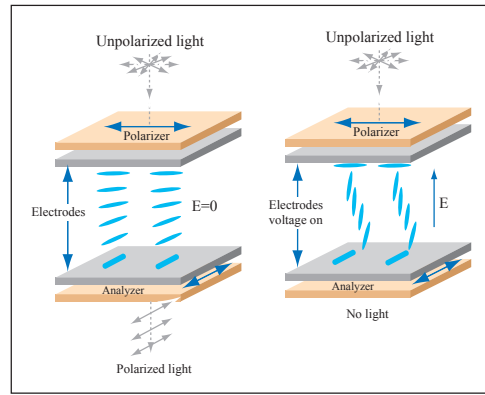
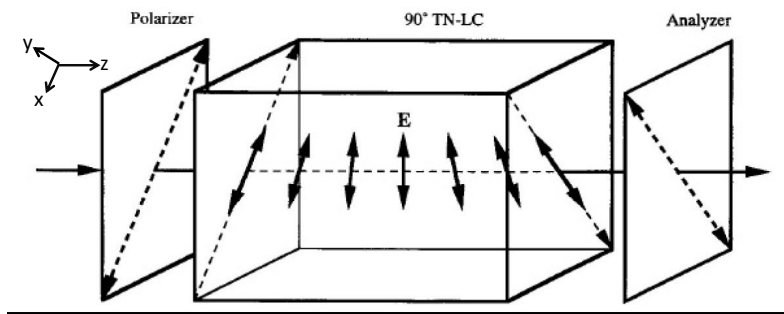
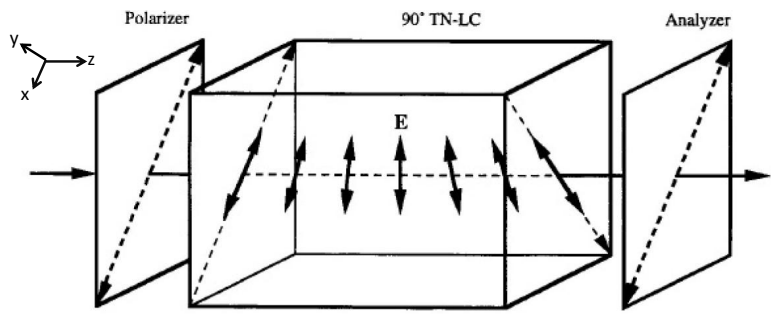


Image by MIT OpenCourseWare.

Figure 2: Schematic of operation of LCD pixel.

Whether a TN/LCD pixel is by default blocking light or passing light will depend on the orientation of the polarizers on the two sides of the cell. If the polarizers are passing light by default, the two polarizers must be off angle from one another (such that the TN/LCD rotates the light from one polarizer to the other). If the polarizers are blocking light by default, then the polarizers must be parallel (such that the rotation of light by the TN/LCD results in filtering of the light by one of the polarizers in the stack).

Figure 3: Schematic of basic LCD pixel that is transparent by default.(From *Optics of Liquid Crystal Displays* by Pouchi Yeh and Claire Gu.)Figure 4: Schematic of basic LCD pixel that is dark by default.(From *Optics of Liquid Crystal Displays* by Pouchi Yeh and Claire Gu.)

Source: Yeh, Pochi, and Claire Gu. *Optics of Liquid Crystal Displays*. New York, NY: Wiley, 1999. Courtesy of John Wiley & Sons. Used with permission.

In this lab, we'll be constructing a rudimentary TN/LCD pixel utilizing the nematic liquid crystal 5CB (4'-Pentyl-4-biphenylcarbonitrile), shown below in Figure 5. Additionally, you'll be using the oscilloscope, signal generator, and photodiode setup to determine the switching speed and on/off contrast of your TN/LCD pixel.

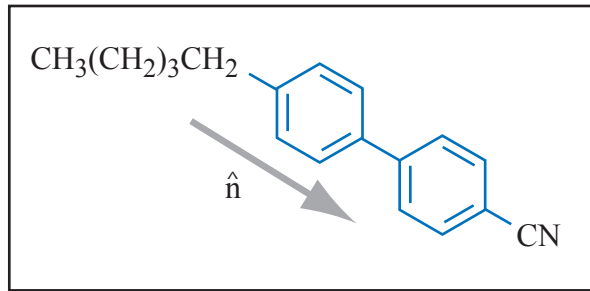


Image by MIT OpenCourseWare.

Figure 5: Molecular schematic of 5CB (4'-Pentyl-4-biphenylcarbonitrile).

## 2 Procedure

This lab will be conducted in groups of three so that you can assist each other in building your TN/LCD pixel and testing the TN/LCD pixels. Each group member will build their own TN/LCD pixel.

When you arrive for the lab, the groups will be divided into two sections, **1** and **2**. Those groups in section 1 will build their TN/LCD pixels first. Those groups in section 2 will be making their photoresistor detector setup first and then build their TN/LCD pixels once section 1 has finished.

### 2.1 Lab Kit Contents

- Two pieces of ITO-coated glass, 1.5 in  $\times$  1 in , coated with poly(vinyl alcohol) (PVA).
- Microfiber dust cloth.
- Copper tape.
- Two 1 in  $\times$  1 in polarizers.
- Binder clip.
- Photoresistor.
- 10 k $\Omega$  resistor.
- 9V battery.

### 2.2 Constructing the Phototransistor

You will start working in groups of two. While some groups start with making the LCD, you can start by constructing the phototransistor to fit with the LCD pixel.

- (1) The phototransistor has the same theory and geometry as what is used in lab 1. The photoCell (in this case the photoresistor) has a voltage which is high in the dark and lower in the light. As a reminder, the circuit diagram is shown in Figure 6.
- (2) The construction of the phototransistor is fairly simple: attach the photoresistor in series with the 10 k $\Omega$  resistor, and bias with a 9 V battery (connected with alligator clips). Now tape the circuit face-down onto one of the polarizer sheets with clear scotch tape. See Figure 7.

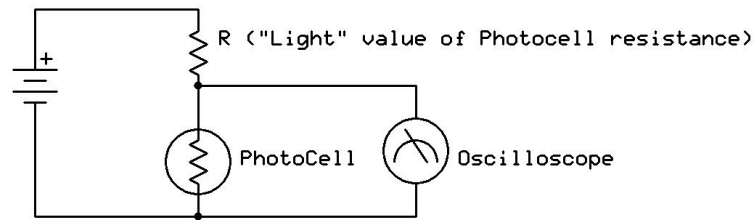


Figure 6: Phototransistor circuit diagram

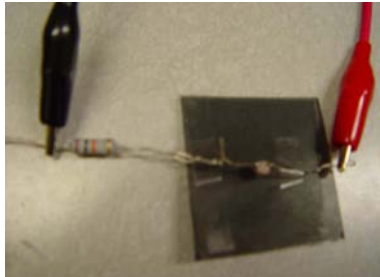


Figure 7: Completed phototransistor

### 2.3 Constructing LCD crystal

**Important:** Wear nitrile gloves when handling your optical components to avoid getting skin grease on your polarizers, glass, etc. Additionally, avoid skin and especially eye contact with the liquid crystal material (5CB) since it is classified as harmful (similar to epoxies, paint, etc.).

There are plenty of gloves, so if you have to scratch your eye or for other reason take your gloves off, make sure to get a new pair.

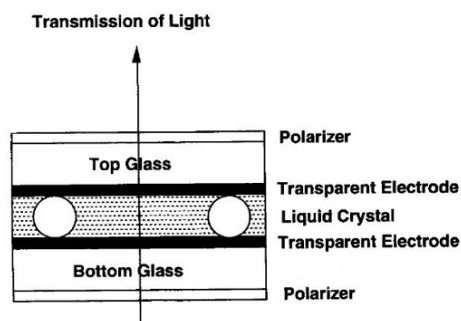


Figure 8: Schematic of basic LCD pixel that we will be making in this lab.

Source: Yeh, Pochi, and Claire Gu. *Optics of Liquid Crystal Displays*. New York, NY: Wiley, 1999. Courtesy of John Wiley & Sons. Used with permission.

Figure 8 shows a completed schematic of the LCD pixel that we will be constructing. In your lab kit, you'll find two 1.5 in  $\times$  1 in pieces of glass which are coated with a **transparent** electrode material, indium tin oxide (ITO), and a poly(vinyl alcohol) (PVA) layer to be used for alignment of the liquid crystals.

**Step (1)** Using the microfiber cloth in your lab kit, rub both of your transparent ITO-PVA slides along the 1.5 in direction. **(There is a black dot on the glass side of the slide. You need to rub the opposite side which is coated with ITO and PVA).** Figure 9 illustrates the effect of the rubbing direction on the alignment of the liquid crystals.

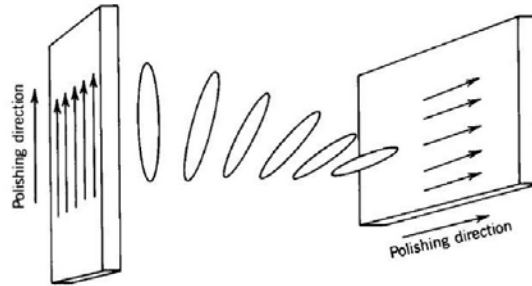


Figure 9: Effect of rubbing direction on LCD alignment. (From *Fundamentals of Photonics* by B.E.A. Saleh and M.C. Teich.)

**Step (2)** With the assistance of the TAs at the gluing station, put **tiny** drops of super glue on the four corners that will define your LCD pixel, as shown in Figure 10. Drop size of 0.5 mm x 0.5 mm will be more than enough. The standard LCD crystal has spacers (which are usually microspheres) to define the space between the two slides. In our case, the glue will also act as the spacer. Press the slides together firmly and let your pixel dry for 5 minutes.

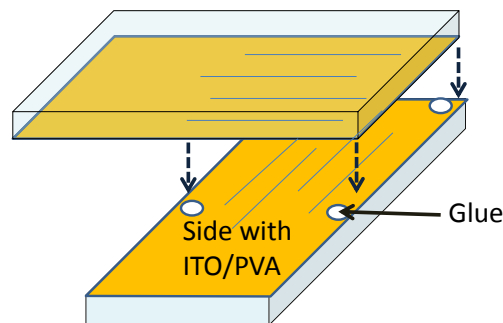


Figure 10: Defining LCD pixel area and fastening of slides together with glue.

**Step (3)** After your super glue has dried, go to the liquid-crystal station and use a 10  $\mu\text{L}$  pipet to capillary fill your pixel with 5CB liquid crystal. The drop should be placed at the edge of the crossed slides, as shown in Figure 11. With the help of gravity (i.e., tilting appropriately if needed), the 5CB molecules drop will be pulled between the slides by capillary forces. The filling may take a few minutes. Wipe up any excess 5CB with a chemical wipe.

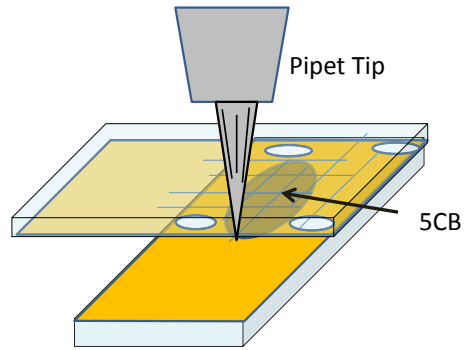


Figure 11: Filling pixel with 5CB liquid crystal with capillary action.

**Step (4)** Place your pixel between two polarizers, one of which should have the photoresistor setup attached. You should align the polarizers such that the pixel is by default in the "OFF" state. Secure the polarizers with a binder clip as shown in Figure 12.

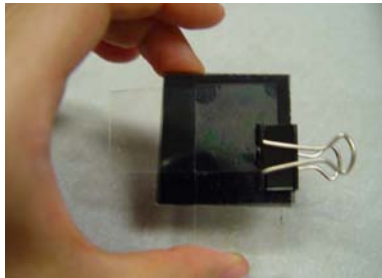


Figure 12: Attaching polarizers.

**Step (5)** Wrap copper tape around the two ITO electrodes. ( You may want to scratch the PVA layer to expose the ITO underneath.) Complete your LCD pixel by contacting the two ITO electrodes with alligator clips to the waveform generator (see Figure 13).

Your LCD pixel is complete.

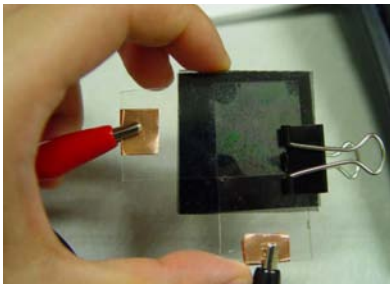


Figure 13: Attaching copper tape to electrodes.

## 2.4 Measure voltage response and frequency response

Using room light, you should have enough signal on the photodiode to measure the contrast between the transparent and dark states of your liquid crystal. Measure the voltage across the photoresistor with the oscilloscope and make sure the voltage changes when you cover up the photoresistor with your hand.

Attach the signal generator output leads to your liquid crystal. Set the oscilloscope on the AC setting. Orient the photoresistor underneath the LCD pixel and facing one of the overhead lights. The photoresistors have a polarization as well, so you may need to rotate the orientation of the photoresistor with respect to your LCD pixel to get the maximum signal.

### Measure the voltage response of the LCD pixel

- On the signal generator, select a square wave, set the frequency at 20 Hz and voltage at 5 V.
- If there is zero voltage difference between the LCD pixel leads, the liquid crystals will relax to their default state. Therefore, when driving the pixel with the signal generator, you want the voltage to vary between 0 V and your chosen driving voltage. This means that you'll need to set the peak-to-peak voltage on the signal generator to the driving voltage and the DC offset to a voltage one-half that of the driving voltage. (Depending on your signal generator you could also use the low voltage and high voltage settings)
- Vary the input voltage from 5 V to 1 V and measure the peak-to-peak voltage across the photoresistor. Make sure you get enough data points to plot a good curve.

### Measure the frequency response of the LCD pixel

- On the signal generator set the input voltage to 5 V and frequency at 5 Hz.
- Increase the frequency in 5 Hz increments and measure the peak-to-peak voltage across the photoresistor. When the voltage swing has decreased by 50%, you have found the LCD pixel's response time at your current driving voltage.
- Rotate the pixel so that it is  $45^\circ$  with respect to the polarizers. Do you see a difference in the voltage swing?

## 3 Pre-Lab Exercise

- (a) Read through the entire lab prior to coming on Tuesday/Wednesday evening.
- (b) Referencing Figures 3 and 4, Write an expression for the E field immediately after the first polarizer and after the LCD crystal in the case of the "ON" state (voltage applied) and the "OFF" state (no voltage applied). Assume the liquid crystal has length of  $z$  and the first polarizer outputs light with only an x component. You can call the propagation constants  $k_r$  and  $k_l$  for the two circular polarizations. What is the  $z$  needed to achieve a  $90^\circ$  polarization rotation?
- (c) A polarizer works by taking a particular component of the input electric field. Here, we are working with two crossed polarizers. What happens to the contrast ratio (the ratio between the intensities in "ON" and "OFF" states) if the second polarizer is rotated so it's only  $45^\circ$  with respect to the first polarizer?

#### 4 Post-Lab Exercises: Analyze Switching Data

- (a) Using MATLAB plot the frequency response and voltage response data. Don't forget to label your graphs.
- (b) Would you use 5CB to make a computer display with 5 V driving voltage and running at 60 Hz refresh rate?
- (c) Without changing the liquid crystal material, what does your data indicate about how manufacturers of LCDs might decrease the response time of an LCD pixel?
- (d) Would the LCD pixel change its voltage swing or frequency response if you oriented the polarizer pair differently? Why is it different or not different?



MIT OpenCourseWare  
<http://ocw.mit.edu>

6.007 Electromagnetic Energy: From Motors to Lasers  
Spring 2011

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.