the City College of New York
OF THE CITY UNIVERSITY OF NEW YORK

ENGR 101 Laboratory Manual Supplement

Nanotechnology Module

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Table of Contents

1. Introduction to MEMS and Nanotechnology

2. Introduction to How LCD's Work

3. Disassembly of a Liquid Crystal Watch

1. Introduction to MEMS and Nanotechnology

This material has been adopted from:
- http://www.mems-exchange.org/MEMS/what-is.html
- http://en.wikipedia.org/wiki/MEMS

What is MEMS and Nanotechnology?

In the 1960s, scientists learned that by arraying large numbers of microtransistors on a single chip, microelectronic circuits could be built that dramatically improved performance, functionality, and reliability, all while reducing cost and increasing volume. The result was the information revolution.

More recently, scientists have learned that not only electrical devices, but also mechanical devices, may be miniaturized and batch-fabricated, promising the same benefits to the mechanical world as integrated circuit technology has given to the electrical world. While electronics now provide the ‘brains’ for today’s advanced systems and products, micromechanical devices can provide the sensors and actuators — the eyes and ears, hands and feet — which interface to the outside world.

The term MEMS, for Micro-Electro-Mechanical-Systems, describes new, sophisticated mechanical systems on a chip, such as micro electric motors, resonators, gears, etc. Today, the term MEMS in practice is used to refer to any microdevice with a mechanical function, which can be fabricated in a batch process.

MEMS generally range in size from a micrometer (a millionth of a meter) to a millimeter (thousandth of a meter) and is often viewed as a stepping stone between conventional macro scale machinery and futuristic nano machinery. MEMS technology has generated a tremendous amount of excitement, due to the vast range of important applications where MEMS can offer previously unattainable performance and reliability standards. Nanotechnology refers to applications on the order of nanometer (one billionth of a meter), usually in the range of 1 to 100nm.

Applications of MEMS

There are numerous possible applications for MEMS and Nanotechnology. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new MEMS and Nanotechnology applications will emerge, expanding beyond that which is currently identified or known.

A few common applications include:
- Inkjet printers - use piezoelectric or bubble ejection to deposit ink on papers
- Accelerometers-used in modern cars for a large number of purposes including airbag deployment in collisions

- MEMS gyroscopes -used in modern cars and aerospace vehicles to detect yaw; e.g. to deploy a rollover bar or trigger dynamic stability control
- Pressure sensors -e.g. car tire pressure sensors, and disposable blood pressure sensors.
- Displays -e.g. the DMD (Digital Micro mirror Device) chip in a projector based on DLP (Digital Light Processing) technology has on its surface several hundred thousand micro mirrors.
- Optical switching technology -which is used for switching technology and alignment for data communications, and is part of the emerging technology of smartdust (a hypothetical network of tiny MEMS sensors, robots, or devices, installed with wireless communications, that can detect anything from light and temperature, to vibrations, etc).

MEMS Materials

MEMS technology can be implemented using a number of different materials and manufacturing techniques; the choice of which will depend on the device being created and the market sector in which it has to operate. Some of the commonly used materials in MEMS technology are as follows:

- **Silicon**-The ability to incorporate electronic functionality and availability of cheap high-quality materials makes silicon attractive for a wide variety of MEMS applications. Silicon has significant advantages engendered through its material properties. In single crystal form, silicon is an almost perfect Hookean material, meaning that when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. Silicon is also very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking. The basic techniques for producing all silicon based MEMS devices are deposition of material layers, patterning of these layers by lithography and then etching to produce the required shapes.

- **Polymers**- Polymers can be produced in huge volumes, with a great variety of material characteristics. MEMS devices can be made from polymers by processes such as injection molding, embossing or stereo lithography and are especially well suited to micro fluidic applications such as disposable blood testing cartridges.

- **Metals**- While metals do not have some of the advantages displayed by silicon in terms of mechanical properties, when used within their limitations, metals can exhibit very high degrees of reliability. Metals can be deposited by electroplating, evaporation, and sputtering processes. Commonly used metals include gold, nickel, aluminum, chromium, titanium, tungsten, platinum and silver.

Manufacturing processes of MEMS

MEMS technology is based on a number of tools and methodologies, which are used to form small structures with dimensions in the micrometer scale. Significant parts of the technology have been adopted from integrated circuit (IC) technology. For instance, almost all devices are built on wafers of silicon. The structures are realized in thin films of materials and they are patterned using photolithographic methods, like ICs. There are however several processes that are not derived from IC technology, and as the technology continues to grow the gap with IC technology will also grow.

There are three basic building blocks in MEMS technology which are, the ability to deposit thin films of material on a substrate, to apply a patterned mask on top of the films by photolithographic imaging, and to etch the films selectively to the mask. A MEMS process is usually a structured sequence of these operations to form actual devices.

Deposition process-One of the basic building blocks in MEMS processing is the ability to deposit thin films of material. Here we assume a thin film to have a thickness anywhere between a few nanometers to about 100 micrometer.

MEMS deposition technology can be classified in two groups:

1. Depositions that happen because of a chemical reaction:
    - **Chemical Vapor Deposition (CVD)-**substrate is placed inside a reactor to which a number of gases are supplied. The fundamental principle of the process is that a chemical reaction takes place between the source gases. The product of that reaction is a solid material which condenses on all surfaces inside the reactor.
    - **Electrodeposition** - This process is also known as "electroplating" and is typically restricted to electrically conductive materials.
    - **Epitaxy** - This technology is quite similar to what happens in CVD processes, however, if the substrate is an ordered semiconductor crystal (i.e. silicon, gallium arsenide), it is possible with this process to continue building on the substrate with the same crystallographic orientation with the substrate acting as a seed for the deposition. If an amorphous/polycrystalline substrate surface is used, the film will also be amorphous or polycrystalline.
    - **Thermal oxidation** - This is one of the most basic deposition technologies. It is simply oxidation of the substrate surface in an oxygen rich atmosphere.

These processes exploit the creation of solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material. The solid material is usually not the only product formed by the reaction. Byproducts can include gases, liquids and even other solids.

2. Depositions that happen because of a physical reaction:
    - **Physical Vapor Deposition (PVD)-**This process covers a number of deposition technologies in which material is released from a source and transferred to the substrate. The two most important technologies are **evaporation** and **sputtering**. In evaporation the substrate is placed inside a vacuum chamber, in which a block (source) of the material to be deposited is also located. The source material is then heated to the point where it starts to boil and evaporate. The vacuum is required to allow the molecules to evaporate freely in the chamber, and they subsequently condense on all surfaces. Sputtering relies on a plasma (usually a noble gas, such as Argon) to knock material from a "target" a few atoms at a time. The target can be kept at a relatively low temperature, since the process is not one of evaporation, making this one of the most flexible deposition techniques.
    - **Casting** - In this process the material to be deposited is dissolved in liquid form in a solvent. The material can be applied to the substrate by spraying or spinning. Once the solvent is evaporated, a thin film of the material remains on the substrate. This is particularly useful for polymer materials, which may be easily dissolved in organic solvents, and it is the common method used to apply photoresist to substrates (in photolithography).

Common for all these processes are that the material deposited is physically moved on to the substrate. In other words, there is no chemical reaction which forms the material on the substrate. This is not completely correct for casting processes, though it is more convenient to think of them that way.

Lithography - Lithography in the MEMS context is typically the transfer of a pattern to a photosensitive material by selective exposure to a radiation source such as light. A photosensitive material is a material that experiences a change in its physical properties when exposed to a radiation source.

Etching - In order to form a functional MEMS structure on a substrate, it is necessary to etch the thin films previously deposited and/or the substrate itself. In general, there are two classes of etching processes:

1. Wet etching where the material is dissolved when immersed in a chemical solution
2. Dry etching where the material is sputtered or dissolved using reactive ions or a vapor phase etchant.

Wet Etching - This is the simplest etching technology. All it requires is a container with a liquid solution that will dissolve the material in question. Unfortunately, there are complications since usually a mask is desired to selectively etch the material. One must find a mask that will not dissolve or at least etches much slower than the material to be patterned. Secondly, some single crystal materials, such as silicon, exhibit anisotropic etching in certain chemicals. Anisotropic etching in contrast to isotropic etching means different etch rates in different directions in the material. The classic example of this is the <111> crystal plane sidewalls that appear when etching a hole in a <100> silicon wafer in a chemical such as potassium hydroxide (KOH). The result is a pyramid shaped hole instead of a hole with rounded sidewalls as in an isotropic etchant. The principle of anisotropic and isotropic wet etching is illustrated in the figure below.

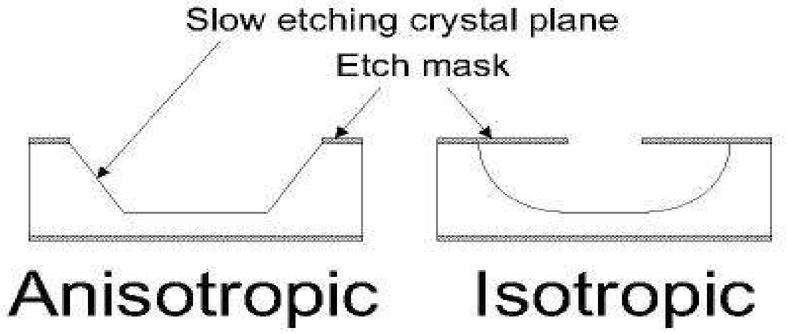


Fig 1.Difference between anisotropic and isotropic wet etching

Dry Etching - The dry etching technology can split in three separate classes called reactive ion etching (RIE), sputter etching, and vapor phase etching.

a) Reactive Ion Etching (RIE) - Here the substrate is placed inside a reactor in which several gases are introduced. Plasma is struck in the gas mixture using an RF power source, breaking the gas molecules into ions. The ions are accelerated towards, and react at the surface of the material being etched, forming another gaseous material. This is known as the chemical part of reactive ion etching. There is also a physical part which is similar in nature to the sputtering deposition process. If the ions have high enough energy, they can knock atoms out of the material to be etched without a chemical reaction. It is a very complex task to develop dry etch processes that balance chemical and physical etching, since there are many parameters to adjust. By changing the balance it is possible to influence the anisotropy of the etching, since the chemical part is isotropic and the physical part highly anisotropic the combination can form sidewalls that have shapes from rounded to vertical.

b) Sputter etching - This is essentially RIE without reactive ions. The systems used are very similar in principle to sputtering deposition systems. The big difference is that substrate is now subjected to the ion bombardment instead of the material target used in sputter deposition.

c) Vapor phase etching - In this process the wafer to be etched is placed inside a chamber, in which one or more gases are introduced. The material to be etched is dissolved at the surface in a chemical reaction with the gas molecules. The two most common vapor phase etching technologies are silicon dioxide etching using hydrogen fluoride (HF) and silicon etching using xenon diflouride (XeF2), both of which are isotropic in nature. Usually, care must be taken in the design of a vapor phase process to not have bi-products form in the chemical reaction that condense on the surface and interfere with the etching process.

2. Introduction to How LCD's work

This material has been adopted from:

- http://electronics.howstuffworks.com/lcd.htm
- http://en.wikipedia.org/wiki/LCD

What is a liquid crystal?
Solids act the way they do because their molecules always maintain their orientation and stay in the same position with respect to one another. The molecules in liquids are just the opposite: They can change their orientation and move anywhere in the liquid. But there are some substances that can exist in an odd state that is sort of like a liquid and sort of like a solid. When they are in this state, their molecules tend to maintain their orientation, like the molecules in a solid, but also move around to different positions, like the molecules in a liquid. Liquid crystals exist in this odd state; they are neither solid nor liquid and are considered as a fourth state of matter.

Some characteristics of liquid crystals
Liquid crystals are closer to a liquid state than a solid. It takes a fair amount of heat to change a suitable substance from a solid into a liquid crystal, and it only takes a little more heat to turn that same liquid crystal into a real liquid. This explains why liquid crystals are very sensitive to temperature and why they are used to make thermometers and mood rings. It also explains why a laptop computer display may act funny in cold weather or during a hot day at the beach.

Liquids crystals have become very common in the last 20 years as displays for electronic devices. This is the result of the unusual optical and electrical properties they possess. The long thin liquid crystal molecules cause light to travel at different speeds along the molecular axis and perpendicular to that axis. This leads to their ability to rotate the plane of polarized light. These long thin molecules also have a tendency to align parallel to an applied electrical field. This response and the optical properties of liquid crystals lead to their application in various electronic devices ranging from watches and calculators to computers and televisions.

Nematic Phase Liquid Crystals
Just as there are many varieties of solids and liquids, there is also a variety of liquid crystal substances. Depending on the temperature and particular nature of a substance, liquid crystals can be in one of several distinct phases. In this class, we will deal with liquid crystals in the **nematic phase**, the liquid crystals that make LCD's possible.

One feature of liquid crystals is that they're affected by an electric current. A particular sort of nematic liquid crystal, called twisted nematics (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the current's voltage. LCD's use these liquid crystals because they react predictably to electric current in such a way as to control light passage.

Liquid Crystal Types

Most liquid crystal molecules are rod-shaped and are broadly categorized as either:

1) Lyotropic- The reaction of lyotropic liquid crystals, which are used in the manufacture of soaps and detergents, depends on the type of solvent they are mixed with.

2) Thermotropic - These liquid crystals will react to changes in temperature or, in some cases, pressure. Thermotropic liquid crystals are either **isotropic** or **nematic**. The key difference is that the molecules in isotropic liquid crystal substances are random in their arrangement, while nematics have a definite order or pattern.

The orientation of the molecules in the nematic phase is based on the **director**. The director can be anything from a magnetic field to a surface that has microscopic grooves in it. In the nematic phase, liquid crystals can be further classified by the way molecules orient themselves in respect to one another. **Smectic**, the most common arrangement, creates layers of molecules. There are many variations of the smectic phase, such as smectic C, in which the molecules in each layer tilt at an angle from the previous layer. Another common phase is **cholesteric**, also known as **chiral nematic**. In this phase, the molecules twist slightly from one layer to the next, resulting in a spiral formation.

Creating an LCD

The combination of four facts makes LCD's possible:

- Light can be polarized
- Liquid crystals can transmit and change polarized light.
- The structure of liquid crystals can be changed by electric current.
- There are transparent substances that can conduct electricity.

An LCD is a device that uses these four facts in a surprising way.

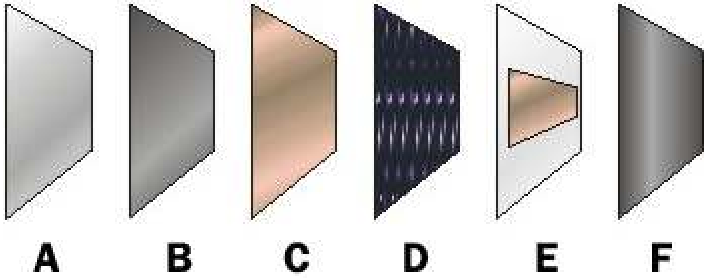
To create an LCD, you take two pieces of polarized glass. A special polymer that creates microscopic grooves in the surface is rubbed on the side of the glass that does not have the polarizing film on it. The grooves must be in the same direction as the polarizing film. You then add a coating of nematic liquid crystals to one of the filters. The grooves will cause the first layer of molecules to align with the filter's orientation. Then add the second piece of glass with the polarizing film at a right angle to the first piece. Each successive layer of TN molecules will gradually twist until the uppermost layer is at a 90-degree angle to the bottom, matching the polarized glass filters.

As light strikes the first filter, it is polarized. The molecules in each layer then guide the light they receive to the next layer. As the light passes through the liquid crystal layers, the molecules also change the light's plane of vibration to match their own angle. When the light reaches the far side of the liquid crystal substance, it vibrates at the same angle as the final layer of molecules. If the final layer is matched up with the second polarized glass filter, then the light will pass through.

If we apply an electric charge to liquid crystal molecules, they untwist. When they straighten out, they change the angle of the light passing through them so that it no longer matches the angle of the top polarizing filter. Consequently, no light can pass through that area of the LCD, which makes that area darker than the surrounding areas.

Building a simple LCD

Start with the sandwich of glass and liquid crystals described above and add two transparent electrodes to it. For example, imagine that you want to create the simplest possible LCD with just a single rectangular electrode on it. The layers would look like this:



The LCD needed to do this job is very basic. It has a mirror (A) in back, which makes it reflective. Then, we add a piece of glass (B) with a polarizing film on the bottom side, and a common electrode plane (C) made of indium-tin oxide on top. A common electrode plane covers the entire area of the LCD. Above that is the layer of liquid crystal substance (D). Next comes another piece of glass (E) with an electrode in the shape of the rectangle on the bottom and, on top, another polarizing film (F), at a right angle to the first one.

The electrode is hooked up to a power source like a battery. When there is no current, light entering through the front of the LCD will simply hit the mirror and bounce right back out. But when the battery supplies current to the electrodes, the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle untwist and block the light in that region from passing through. That makes the LCD show the rectangle as a black area.

Backlit vs. Reflective

Liquid crystal materials emit no light of their own. Small and inexpensive LCD’s are often reflective, which means to display anything they must reflect light from external light sources. Look at an LCD watch: The numbers appear where small electrodes charge the liquid crystals and make the layers untwist so that light is not transmitting through the polarized film.

Most computer displays are lit with built-in fluorescent tubes above, beside and sometimes behind the LCD. A white diffusion panel behind the LCD redirects and scatters the light evenly to ensure a uniform display. On its way through filters, liquid crystal layers and electrode layers, a lot of this light is lost -- often more than half!

Passive and Active Matrix

Passive-matrix LCD’s use a simple grid to supply the charge to a particular pixel on the display. Creating the grid starts with two glass layers called substrates. One substrate is given columns and the other is given rows made from a transparent conductive material. This is usually indium-tin oxide. The rows or columns are connected to integrated circuits that control when a charge is sent down a particular column or row. The liquid crystal material is sandwiched between the two glass substrates, and a polarizing film is added to the outer side of each substrate. To turn on a pixel, the integrated circuit sends a charge down the correct column of one substrate and a ground activated on the correct row of the other. The row and column intersect at the designated pixel, and that delivers the voltage to untwist the liquid crystals at that pixel.

The simplicity of the passive-matrix system is beautiful, but it has significant drawbacks, notably slow response time and imprecise voltage control. Response time refers to the LCD's ability to refresh the image displayed. The easiest way to observe slow response time in a passive-matrix LCD is to move the mouse pointer quickly from one side of the screen to the other. You will notice a series of "ghosts" following the pointer. Imprecise voltage control hinders the passive matrix's ability to influence only one pixel at a time. When voltage is applied to untwist one pixel, the pixels around it also partially untwist, which makes images appear fuzzy and lacking in contrast.

Active-matrix LCD’s depend on thin film transistors (TFT). Basically, TFT’s are tiny switching transistors and capacitors. They are arranged in a matrix on a glass substrate. To address a particular pixel, the proper row is switched on, and then a charge is sent down the correct column. Since all of the other rows that the column intersects are turned off, only the capacitor at the designated pixel receives a charge. The capacitor is able to hold the charge until the next refresh cycle. And if we carefully control the amount of voltage supplied to a crystal, we can make it untwist only enough to allow some light through.

By doing this in very exact, very small increments, LCD’s can create a gray scale. Most displays today offer 256 levels of brightness per pixel.

Color LCD

An LCD that can show colors must have three sub pixels with red, green and blue color filters to create each color pixel.

Through the careful control and variation of the voltage applied, the intensity of each sub pixel can range over 256 shades. Combining the sub pixels produces a possible palette of 16.8 million colors (256 shades of red x 256 shades of green x 256 shades of blue). These color displays take an enormous number of transistors. For example, a typical laptop computer supports resolutions up to 1,024x768. If we multiply 1,024 columns by 768 rows by 3 sub pixels, we get 2,359,296 transistors etched onto the glass! If there is a problem with any of these transistors, it creates a "bad pixel" on the display. Most active matrix displays have a few bad pixels scattered across the screen.

3. Disassembly of a liquid crystal watch

This material has been adopted from:

- http://mrsec.wisc.edu/Edetc/background/LC/LCD_Watch_lab.doc
- http://mrsec.wisc.edu/Edetc/nanolab/watch/text.html

Introduction

LCDs use liquid crystals to alter the transparency of a region sandwiched between two pieces of glass. LCDs are not only used in wristwatches, but also in inexpensive clocks, in mobile phone displays, and in laptop-computer displays. LCDs eliminate the need for moving parts such as watch hands, gears, and motors in traditional watches. The elimination of these moving parts has dramatically reduced the cost necessary to produce a reliable wristwatch. This has lead in turn to the reduction in the retail price of the most inexpensive wristwatches to the point where a retail price of less than $2 is commonplace.

Objective

The objective of this experiment is to disassemble an inexpensive liquid crystal display (LCD) watch for testing several of the properties of the LCD panel.

Background

Liquid Crystals

Liquid crystals were first discovered over 100 years ago in studies of cholesterol and related molecules. Liquid crystals are another state of matter in addition to the most commonly encountered phases (gas, liquid, solid.

Liquid crystals have become very common in the last 20 years as displays for electronic devices. This is the result of the unusual optical and electrical properties of liquid crystals. The long thin liquid crystal molecules cause light to travel at different speeds along the molecular axis and perpendicular to that axis. This leads to their ability to rotate the plane of polarized light (see below).

These long thin molecules also have a tendency to align parallel to an applied electrical field. This response and their optical properties lead to their applications in various electronic devices ranging from watches and calculators to computers and televisions.

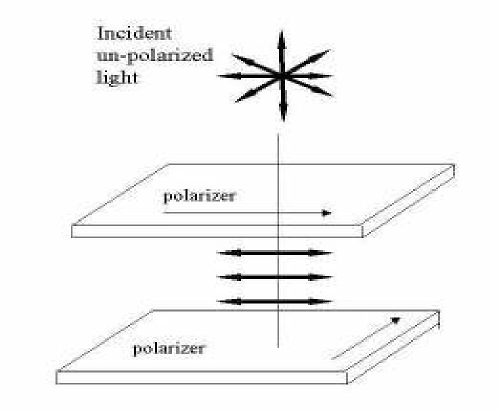


Figure 1. Initially unpolarized light passing through a polarizing filter becomes polarized. The polarized light will not be transmitted by a second polarizing filter turned at 90^o to the axis of the first filter.

Polarizing Filters and Polarized Light

As shown in Figure 1, polarizing filters are materials that allow only the passage of light waves that are vibrating in a particular plane. Non-polarized light passing through a polarizing filter becomes polarized: that fraction of the incoming light that is vibrating in the plane transmitted by the polarizer will emerge. Polarized light directed onto a second polarizer, oriented 90^o to the first polarizer, will not be transmitted. Many natural substances, including liquid crystal materials, have the ability to rotate the plane of the polarized light.

LCD Watch

Liquid crystal displays (LCDs) have become quite common in watches due to the low electrical power demands of the LCD panel. This panel is composed of two polarizers that transmit light in perpendicular directions, a mirrored surface and a layer of liquid crystal material between two glass plates. The liquid crystal material used is of the so-called twisted nematic type.

If the surfaces of the glass plates that will be in contact with the liquid crystal molecules are rubbed, the liquid crystal molecules will orient in the direction of the rubbing. Figure 2 shows that the molecules have been oriented in the direction in which the adjacent polarizer transmits light, and the intervening molecules gradually rotate their relative orientation to accommodate the 90^o change from one glass surface to the other.

In operation, non-polarized light passes through the top polarizer and the top glass plate and enters the layer of liquid crystal material. This layer of liquid crystal molecules causes the direction of polarization of the light to rotate by 90^o before reaching the second polarizer, allowing the polarized light to be transmitted by the second polarizer. The polarized light then is reflected off a mirrored surface and passes back through the two polarizers and the liquid crystal layer. This gives a silvery appearance to the panel, Figure 2.

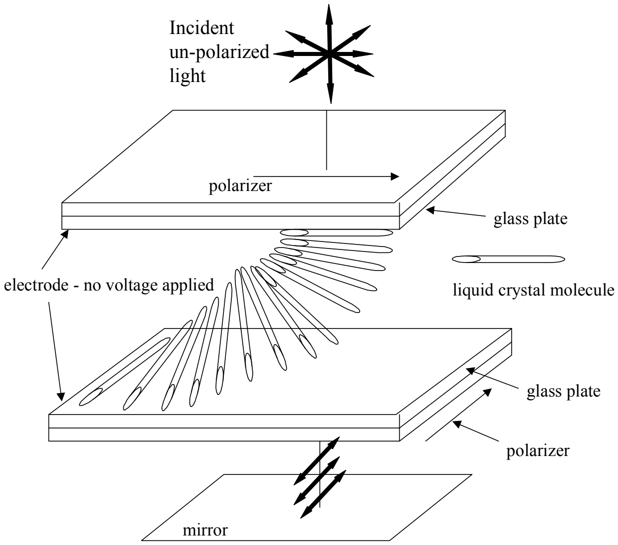


Figure 2. The liquid crystal molecules in all segments of the panel are precisely aligned in the absence of an applied voltage. Therefore, the entire panel appears silvery because light passes through both polarizers, reflects off the mirrored surface, and then passes through both polarizers.

When a voltage is applied to a segment of the display, the precise alignment of the liquid crystal molecules is lost. This results in the polarized light from the first polarizer not being rotated by the required 90^{o} to align with the second polarizer. The second polarizer blocks the passage of light and causes that segment of the panel to appear black, Figure 3.

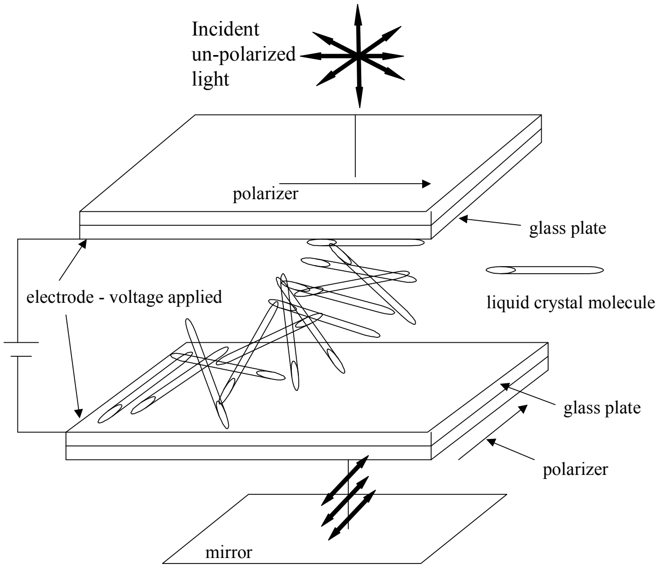


Figure 3. The initial alignment of the liquid crystal molecules is lost when a voltage is applied to a segment of the panel. That segment will then appear black against a silver background.

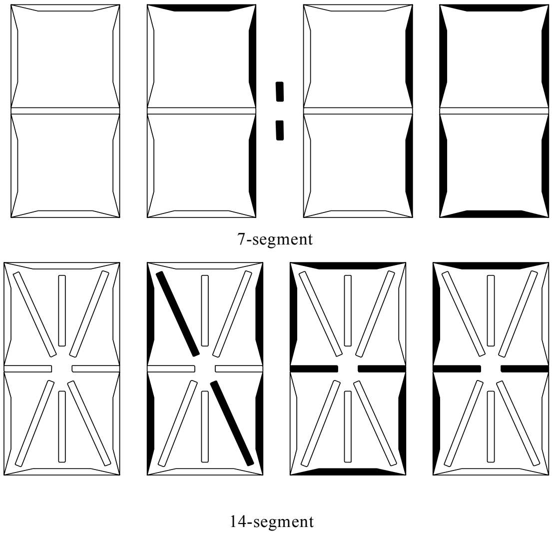


Figure 4. Examples of 7-segment numeric and 14-segment alphanumeric displays.

Most of the displays in LCD watches are composed of several 7-segment sections. Each 7-segment section can display one number. The combination of these sections can display the date or time, Figure 4.

Apparatus

- An inexpensive LCD watch
- Small screwdriver
- 9-Volt battery and battery snap
- Tongs and hot water
- Thermometer

Experimental Procedure

- Remove the front or back plate to access the interior of the watch. Your watch may be slightly different from the one shown here. In some case your watch may not have any screws. If screws are removed, place them in a small container for safe keeping since tiny parts can be easily lost.

- Remove the watch assembly from the band.

- Our main objective in this stage is to obtain the LCD panel as carefully as possible without destroying the watch. The disassembling process may vary depending on the type/model of watch you are disassembling; however the parts will be the same. Remove the tiny screws holding the printed circuit board and battery retainer to the white plastic inner case. The figure below shows the back of the watch after removal of the battery retainer and the circuit board.

- Remove the electrically conducting pad and the LCD panel. Place the screws, switch contacts, and battery contacts into a small container for safe keeping.

- Once the LCD panel is obtained, examine it using the following approaches;

1. Examination of the LCD Panel with a Polarizing Filter

- Examine the LCD panel with a polarizer by holding the polarizer above the face of the panel. Slowly rotate the polarizer. Record and discuss your observation.

2. Effect of Energy on the Order of Liquid Crystal Molecules

2a. Effect of Electricity on the LCD Panel

Using the 9-V battery and the battery clip with leads, address various segments of the LCD panel: hold one of the battery leads against the contact area at the left end of the panel while rubbing the other lead along the contact area, Record your observations.

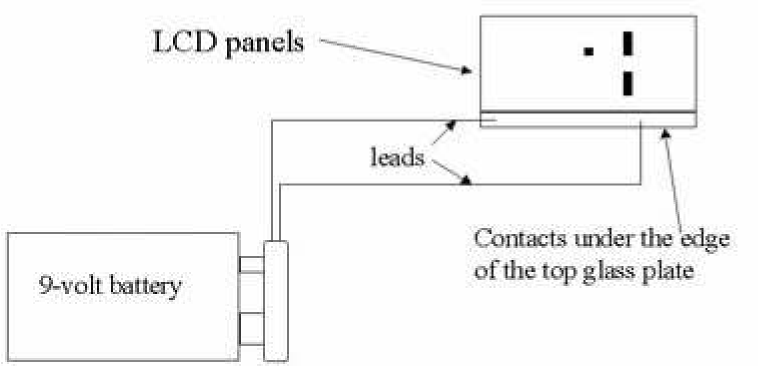


Figure 5. The various segments of a LCD panel can be addressed with the use of a 9-V battery and the leads from the battery clip. By rubbing the two leads against the contact area of the cell, numbers and characters can be displayed.

2b. Effect of Pressure on the LCD Panel

Under pressure liquid crystal materials, such as used in LCD watches, undergo dramatic color changes. Press, with your finger, the LCD panel against a firm surface and look carefully at the area near your finger. Now release the pressure. Record your observations.

2c. Effect of Heat on the LCD Panel

When heated, liquid crystals can melt much like more normal solids. Upon melting the ordering of the molecules in the liquid crystal display changes from order to disorder. In this case, the disorder is throughout the cell not in certain segments as in the case of an applied voltage. Therefore, the entire region that is heated turns black. This is a reversible property, if the heating is not too severe.

To test this property of the LCD panel, gently grasp the LCD panel with crucible tongs and immerse it in 70-80°C water. The panel should turn black over the entire area that was immersed. As the LCD panel cools, it should return to its silvery appearance. Record your observations.

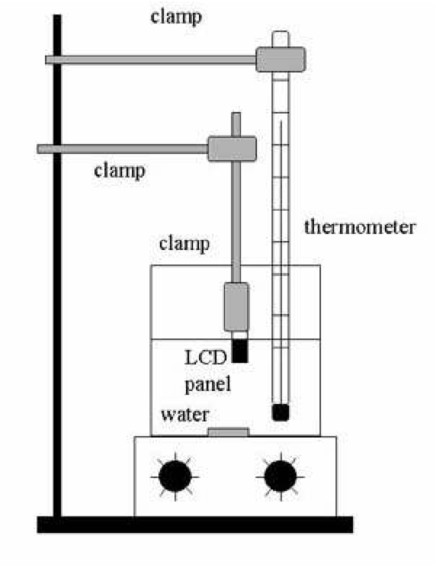


Figure 6. The set up for observing the phase transition of the liquid crystals. Clamps or crucible tongs are used to hold the LCD panel in the water bath.

- Reassemble the Watch - With care, the watch can be reassembled to working order.
  If it is not working, ask for assistance. Leave the watch in good working order for the next lab group to disassemble.

Discussion

As your final written report and/or oral presentation, answer the following questions and discuss your observations and findings during the experiment.

Questions:

1. What is meant by the term polarized light?
2. Why is this unusual phase of matter called the liquid crystal phase?
3. What type of liquid crystal molecules are used in watch displays?
4. What condition causes the panel segments to turn black?
5. What color does the panel turn when the temperature of the LCD panel is above the melting point of the liquid crystal molecules?