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Course: Senior Thesis
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Title: Molecular Alignment Using Corrugated Surfaces

Senior Thesis

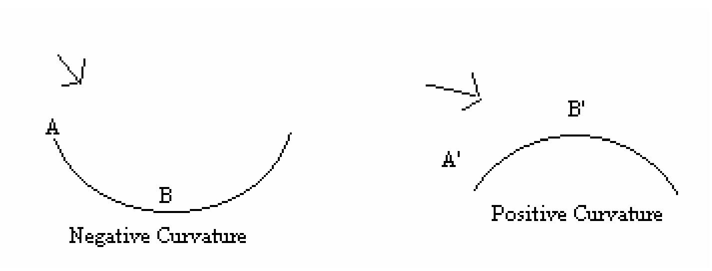
Abstract

It has long been recognized that a non-contact alignment method is essential for the production of high resolution Liquid Crystal Displays. Current methods of liquid crystal alignment utilized in the making of commercial LCD's involve rubbing a polyimide film with a velvet cloth roller. It is known, but not well understood, that the microscopic grooves made by velvet cloth can align liquid crystals (LC's) well. However, the rubbing process scratches the polyimide film and thus creates problems with image quality and production efficiency. In this paper, we introduce a non-contact alignment method using periodic grooves created by sputtering glass substrate rather than rubbing with velvet cloth. The grooves created by sputtering the glass substrate have been shown to successfully align liquid crystals in a parallel cell with results comparable to a cell using rubbed polymer. The evidence of the alignment comes from images of LC's on sputtered and unsputtered glass taken with a polarizing optical microscope and from light intensity data from photodiode. Although corrugated glass can align liquid crystals very well in a parallel cell, we have not yet successfully create a uniform twisted-nematic cell. The analysis of the twisted-nematic cell has revealed that the corrugated glass has weaker anchoring strength than rubbed polymer and further research is underway to improve the quality of the alignment.

Background Information

Liquid crystal displays, or LCD’s, have become prevalent in our everyday lives. With an industry valued at 20 billion USD$, LCD’s have established themselves as the primary flat panel display for computers, televisions, and instrumentation displays for avionics. Despite the enormous demand, LCD’s remain expensive compared to conventional Cathode Ray Tube Displays (CRTs). This is because manufacturers of LCD’s often reject about 40 percent of the panels that come off the assembly line and the level of rejection directly affects the LCD price. One of the factors that affects LCD yield is the process of aligning liquid crystals. Nowadays, the alignment is created by rubbing a polymer alignment layer coated on glass substrate with a velvet cloth roller. It is known, but not well understood that the microscopic grooves created by the roller can align liquid crystals. This rubbing process, although commonly used because it aligns the liquid crystal well enough, is dirty and hard to control. Rubbing the polymer film creates dust, which is a huge liability in a clean-room, scratches the polymer film, which can degrade image quality, and produces electrostatic discharge, which can be detrimental to the electronics below the glass substrate. Therefore, a non-contact alignment method is more suitable for the production of future LCD’s. Many different methods have been proposed to create similar microscopic structure and replace the rubbing process. This includes using microlithography to fabricate grating structure on a Langmuir-Blodgett film[1], oblique-angle deposition of SiO_2[2], and exposing polymer films to polarized UV radiation.[3] So far, none of the above method have been implemented in large quantity in the production of LCD’s because it is either not applicable to the current TFT-LCD manufacturing process or it has not yet produced good LC alignment. My research involves studying the potential of a non-contact alignment process that uses periodic grooves created by sputtering glass substrate rather than by rubbing with velvet cloth to align liquid crystals. These corrugations form as the result of sputtering glass at off normal angles and the mechanism is based on the phenomenon of curvature dependent erosion and smoothing.

Periodic surface corrugations due to sputtering have been observed on soda-lime and silica glass as early as 1962.[4] Since then, it has also been found to work on a variety of amorphous, crystalline semiconductors and metallic materials. The theory about the formation of these surface ripples was first proposed by R.M. Bradley and J.M. Harper. Their theory for the formation of corrugations is based on the phenomena of curvature dependent erosion and smoothing. The corrugations are able to form because regions of negative curvature will erode away faster than positive curvature by the ions. This phenomenon occurs due to the fact that incident ions in the vicinity of region B provide more energy for sputtering than those ions incident near region B'. The more energy the region receives from the ion, the more easily it is for the atoms in the region to leave the surface. The opposite of surface erosion is a smoothing process in which atoms in regions of positive curvature migrate to regions of negative curvature. The two opposing effects, erosion and smoothing, eventually reach an equilibrium shown by the periodicity of the corrugations.



Experimental Methods

(1) Sputtering glass

The first step in testing the alignment is to obtain the sputtered glass sample. The sputtered glass samples were made at the Cornell Nanoscale Facility (CNF) using Veeco Ion Mill. The glasses (Corning code 1737) have a thickness of 1.1mm. The samples were made with the following parameter:

Angle: 45 degree (Angle of incident ion relative to normal)

Running Pressure: $3.3 \text{ x } 10^{-4}$

Current: 74mA

Neutralizer: 69mA

Voltage: 300 – 1000 Volts

Exposure Time: 50– 90 min

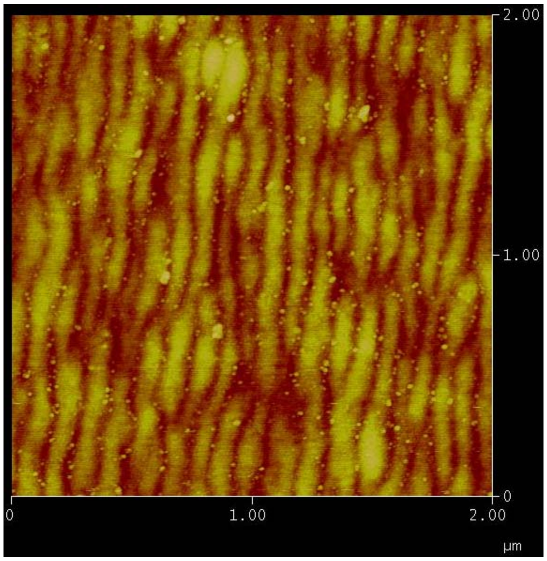


Figure 1 - Corrugations at 1000 Volts

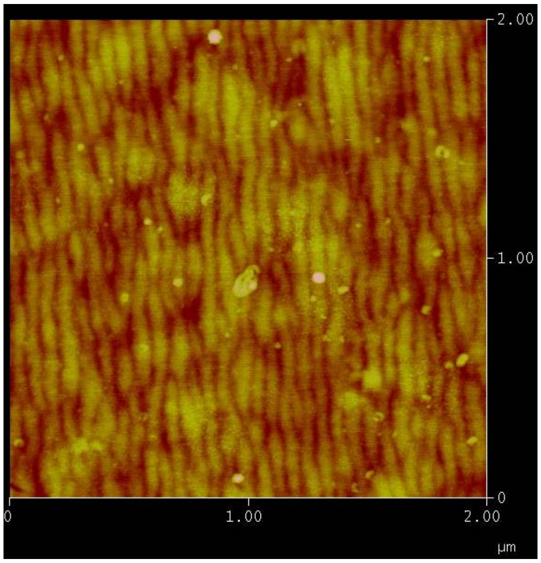


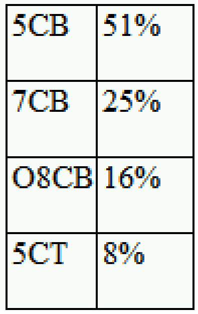
Figure 2 – Corrugations at 500 Volts

The depth and the wavelength of the corrugations are directly related to the voltage used. For example, operating at 500 volts, the above sputtering parameter creates corrugations with a wavelength approximately 60 nm and a depth of 2-3 nm (Figure 2). The 1000 volts corrugations have longer wavelengths, 80 – 90 nm (Figure 1)

Before depositing a liquid crystal onto the substrate, the glass is soaked in acetone for approximately 15 minutes to remove any organic residues, rinsed with methanol and dried. Then a plasma cleaner running for ten minutes is used to clean the sample.

Two types of liquid crystal cell are made in order to demonstrate that periodic grooves created by sputtering glass substrates are capable of dictating the direction of liquid crystals. The two types of cell are parallel cell (corrugations parallel to each other) and twisted-nematic cell (corrugations perpendicular to each other). The cell is made by sandwiching liquid crystals between two sputtered glass substrates. The two pieces of sputtered glass are separated by a uniform gap approximately 8μm. Using a pipette, a small drop of liquid crystal is deposited onto the sputtered glass and pressed down by the second piece of sputtered glass.

The liquid crystal used is a commercially available and commonly used in LCD mixture from Merck called E7. The mixture contains primary of the liquid crystal pentyl cyanobiphenyl (5CB) and its homologues.



5CB	51%
7CB	25%
O8CB	16%
5CT	8%

The actual percentages are listed on the left. The reason for using a mixture of different liquid crystals is to obtain a bigger temperature range for the nematic phase (liquid crystal phase). The nematic temperature of 5CB is 24-35˚C while the nematic temperature of E7 mixture is from -10 to 60˚C. This large range is more suitable for the use of commercial liquid crystal display.

Once the making of liquid crystal cell is complete, the cell is examined under an optical microscope between crossed polarizers. The first part of the experiment involves studying liquid crystal alignment in a parallel cell. This is done by rotating the sample 360 degrees under crossed polarizers to observe the change in light intensity (Figure 3).

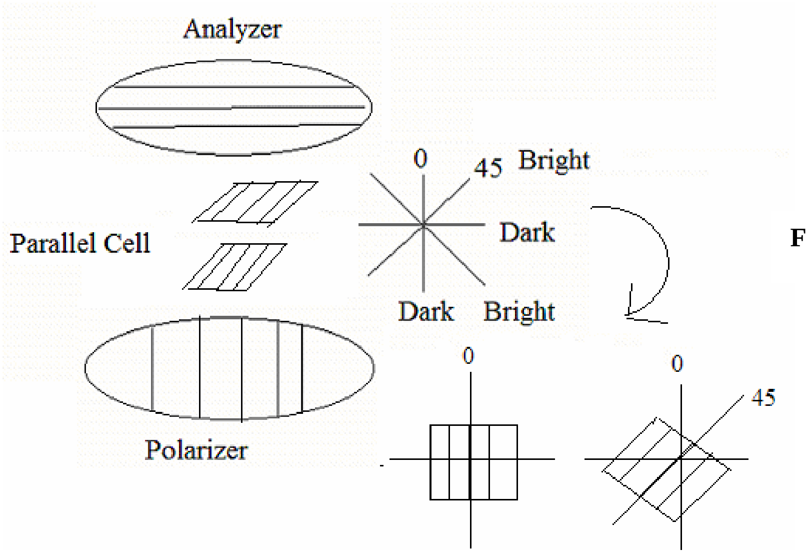


Figure 3

The optical microscope is an Olympus optical microscope with an attached CCD camera for taking images of the sample and a photodiode to obtain quantitative data for the intensity of the transmitted light. It is equipped with an adjustable analyzer and polarizer mounted above and below the sample holder, respectively.

The second experiment involves studying liquid crystal alignment in a twisted-nematic cell (Figures 4 - 5).

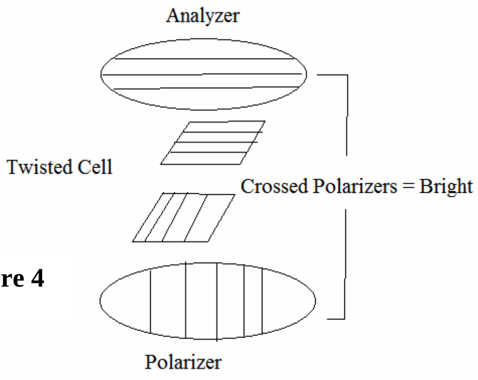


Figure 4

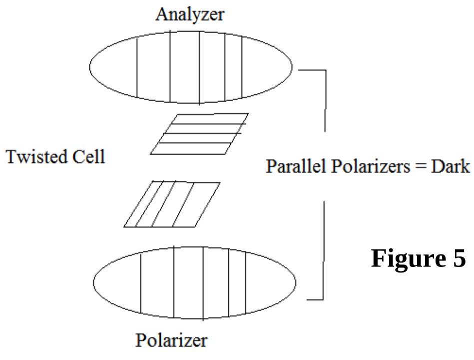


Figure 5

The direction of alignment is found by rotating the analyzer. The intensity of light will reach a maximum when viewed under crossed polarizers (Figure 4) and will have a minimum under parallel polarizers (Figure 5, Polarizer and analyzer in the same direction). Since this is a twisted-nematic cell, the direction of the bottom layer of liquid crystal is at 90° relative to the direction of the top most layer of liquid crystal. Therefore, theoretically, if the alignment is good, maximum transmission should be observed when the analyzer is crossed with the polarizer. By analyzing the intensity plot with the angle of analyzer, we can compare the quality of corrugated glass to that of conventional polymer (PVA) rubbed glass.

The intensity data is recorded using Labview software which receives data from the photodiode. The intensity is recorded as current vs. time. A small amount of light from the room, and from the crossed polarizer still enters the photodiode even without the liquid crystal; therefore a base value is always recorded prior to any measurements. The data are then plotted in excel and the images taken by the camera are stored on the computer as bitmap format.

Results and Discussion

Part I - Liquid crystal alignment in a parallel cell - Image size: 1.13mm by 1.54mm

Polyvinylalcohol (PVA) Rubbed Parallel Cell

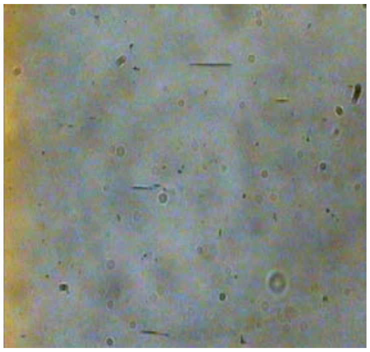


Figure 6 – Max brightness at 45º

Figure 7 – Min brightness at 0º

Sputtered Glass at 300 volts

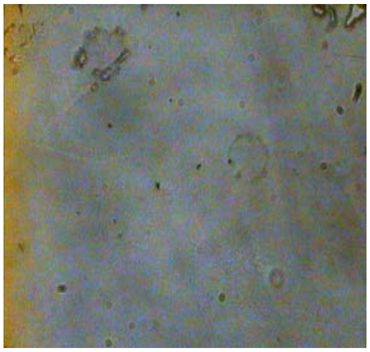


Figure 8 – Max brightness at 45º

Figure 9 – Min brightness at 0º

Unsputtered Glass

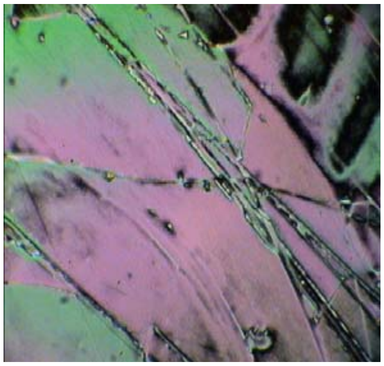


Figure 10 – 45º

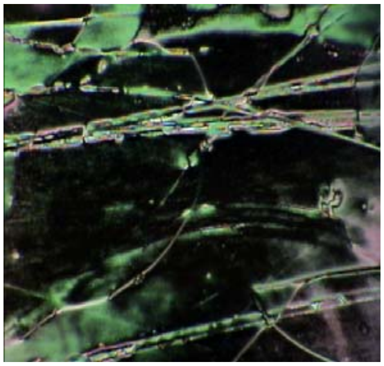


Figure 11 - 0º

The images above (Figures 6 – 11) show that corrugated glass create a more uniform liquid crystal alignment than normal glass and that the quality is comparable to rubbed polymer. The plot below (Figure 12) compares the intensity plot of a parallel cell constructed using sputtered glass and one with unsputtered glass.

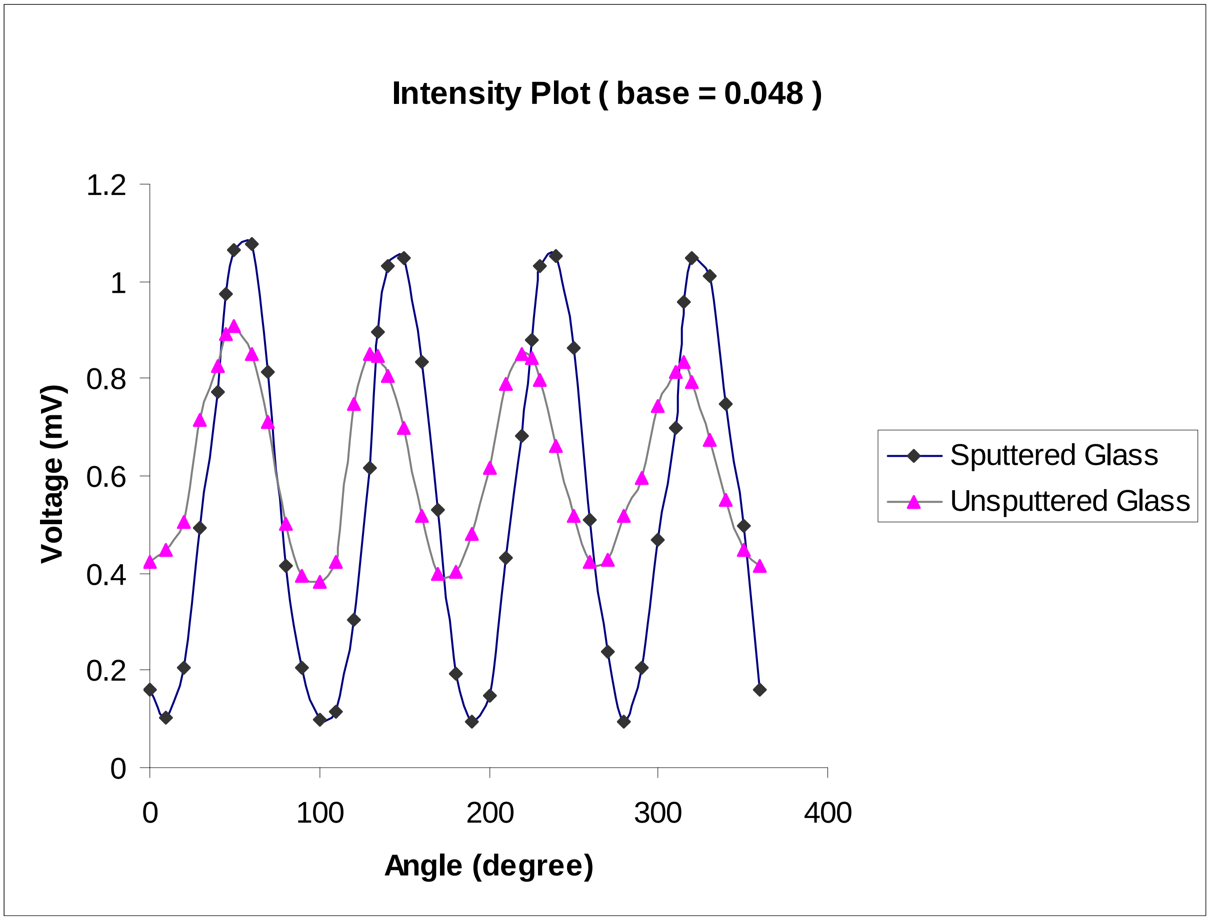


Figure 12 – Intensity plot comparing sputtered glass to unsputtered glass

The sinusoidal shape of the graph is the result of the existence of a dominant domain over others in a given area. In the sputtered sample, the director, in this case, are the ripples on the surface created by sputtering, governs the dominant domain of liquid crystal. Therefore we would expect liquid crystals to be lined up along the direction of the grooves. The position of the max and min on the plot for the sputtered sample indicates that the dominant domain of the sample is in a direction predicted based on the birefringence property of liquid crystal – Min at 0º and Max at 45º. A control experiment is conducted on an unsputtered sample under the same conditions. The plot for the unsputtered glass in Figure 12 also reveals a sinusoidal graph similar to that of the sputtered sample, although the intensity variation is not as large. This is because liquid crystals have a tendency to point towards a director. Although there is no uniform surface ripples on the unsputtered sample, there are still random surface defects on the glass that can make one domain more dominant than others. Liquid crystals will be inclined to align itself to the direction as dictated by the surface defects. The difference between unsputtered and sputtered substrates therefore is the amplitude of the plot. The disparity between the amplitude of the two plots can be explained by the quality of the alignment between the sputtered and the unsputtered cell. If liquid crystals are aligned, there should be big change in the intensity of light as the sample is rotated 360 degrees under crossed-polarizers. The fact that the amplitude on the unsputtered sample is small indicates that although there is a dominant domain in a small region, there are still a lot of liquid crystals that are unaligned.

Part II – Twisted-nematic cell

In a twisted-nematic cell, corrugations are lined up perpendicular to each other. As a result liquid crystals form a helical structure. The images below (Figures 13 – 14) show that polymer rubbed alignment layer can create a stable twisted-nematic cell. The image appears bright under crossed polarizer and dark under parallel polarizers.

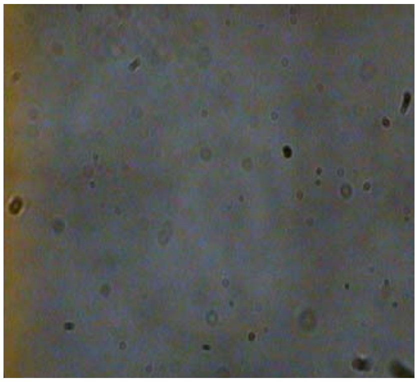


Figure 13 – Twisted-nematic cell made using rubbed polymer alignment layer viewed under crossed polarizers. Image size: 1.13mm by 1.54mm

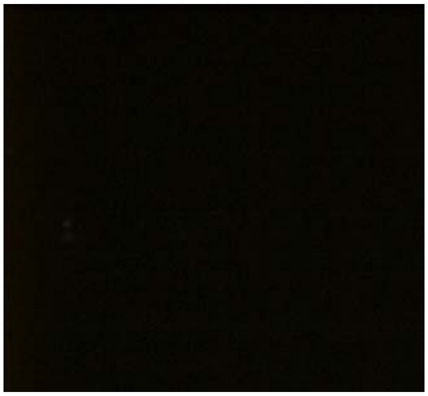


Figure 14 – Twisted-nematic cell made using rubbed polymer alignment layer viewed under parallel polarizers Image size: 1.13mm by 1.54mm

The images below (Figures 15 – 16) come from a twisted-nematic cell made using corrugated glass. The angle for maximum and minimum intensity is opposite that of polymer alignment layer.

Figure 15 – Twisted-nematic cell made using corrugated glass viewed under crossed polarizers
Image size: 1.13mm by 1.54mm

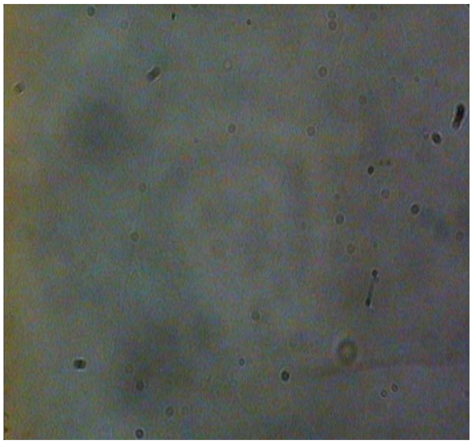


Figure 16 – Twisted-nematic cell made using corrugated glass viewed under parallel polarizers
Image size: 1.13mm by 1.54mm

The result showed that instead of having a twisted-nematic structure similar to the twisted cell made using polymer alignment layer, we get a very uniform parallel alignment as if the corrugations on lined up parallel to each other. See Figure 17 below for a graphical explanation.

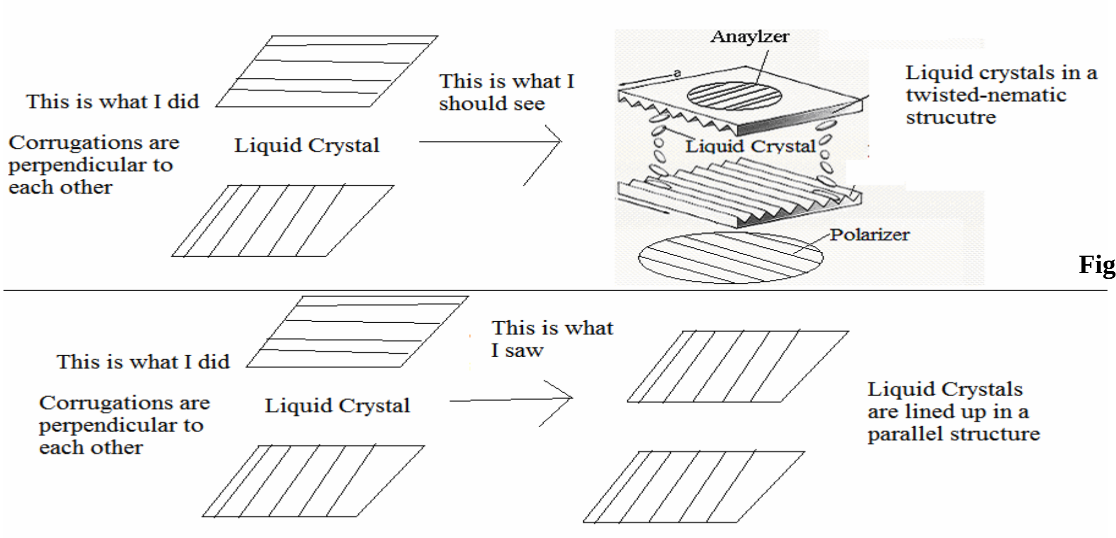


Figure 17

Repeated experiments have shown the same results not only occur on the 500 volts corrugated glass but also on the 1000 and 300 volts glass. Further experiment demonstrated that liquid crystals are indeed lined up parallel to each other, because it is possible to create the twisted structure by starting in the twisted-nematic geometry that results in parallel alignment and then rotating one piece of glass by 90 degrees relative to the other piece of glass. Although this is the conventional orientation of the corrugations for a parallel cell (the corrugation are now aligned), but the structure of liquid crystal is twisted-nematic. The data in Figure 18 shows that liquid crystals do form a twisted structure.

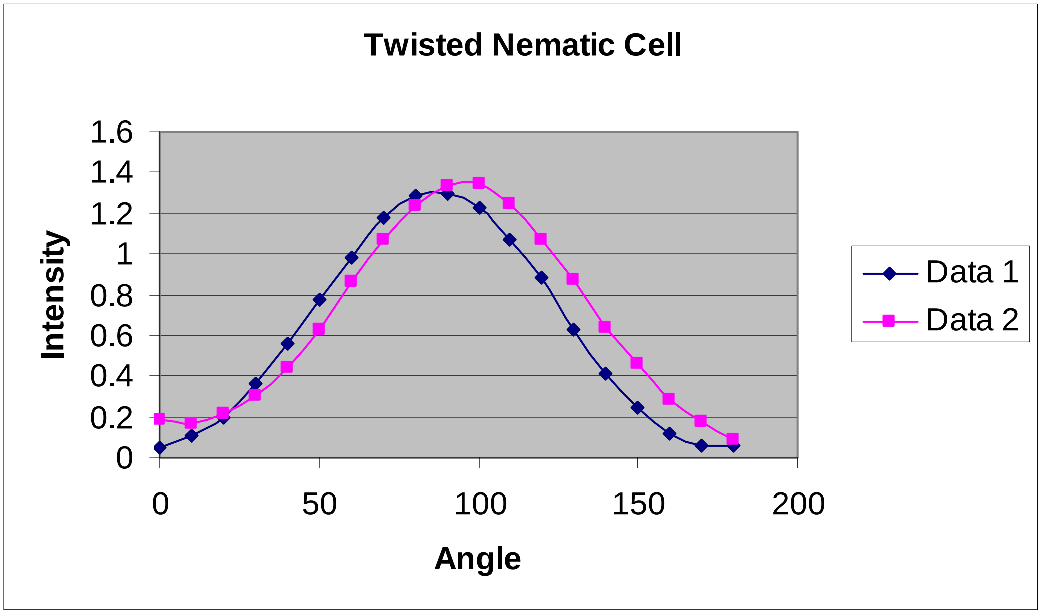


Figure 18

Data 2 is the parallel sample that exhibit twisted nematic structure, and Data 1 is the successful twisted-nematic structure made using polymer alignment layer. The two data are nearly identical in intensity with only a slightly different director angle. The images in Figures 15-16 and the data in Figure 18 shows that liquid crystals in the twisted-nematic cell made using corrugated glass appear to break off the anchoring surface and line up against the corrugation. We know that in order for liquid crystals to form a twisted-nematic structure, the top and bottom layer must anchor well to the surface. It is possible that the anchoring strength of the corrugated glass is not strong enough to maintain a stable twisted structure. However, further improvement in the cell construction demonstrated that it is still possible to create a stable twisted-nematic structure. Figures 19 – 20 below show that there are some regions on the corrugated glass capable of forcing liquid crystal to twist when the corrugations of the two pieces of glass are oriented 90˚ degrees relative to one another. The bright patches in Figure 19 shows twisted liquid crystal alignment and the dark region shows parallel alignment and vice versa in Figure 20.

Figure 19 – Twisted-nematic cell made using corrugated glass viewed under crossed polarizers. Bright areas indicate twisted alignment and dark areas indicate parallel alignment

Figure 20 – Twisted-nematic cell made using corrugated glass viewed under parallel polarizers. Dark areas indicate twisted alignment and bright areas indicate parallel alignment

This result shows that because liquid crystals do not anchor strongly on the corrugated surface, they can break off more easily than on rubbed polymer surface and thus form a parallel structure. However, since there are still some regions where liquid crystal can form a stable twisted structure, it is possible therefore to optimize the cell structure to improve the stability of twisted-nematic alignment.

Conclusion

My research has demonstrated that liquid crystals can be aligned by corrugated glass. The results show that the corrugated glass can create a uniform liquid crystal alignment in parallel cell comparable to using a polymer alignment layer. However, since the anchoring strength of corrugated surface is weaker than that of polymer alignment layer, it is more difficult to create a stable twisted-nematic cell. Images taken of twisted-nematic cell made from corrugated glass show that liquid crystal tend to break off from the surface and form a parallel structure. We are still trying to understand how and why liquid crystals break off from the surface in some regions while forming stable twisted structure in other. Although the weakness of the anchoring strength of corrugated glass maybe not be applicable to modern day LCD, understanding how liquid crystals interact with corrugated glass may be important in other applications such as Bistable Nematic display and In-Plane Switching display in which a weaker surface anchoring and a parallel liquid crystal cell is required.[5]

References

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