UCCS

UNIVERSITY OF COLORADO
AT COLORADO SPRINGS

Ferroelectric Nanoparticles Suspended in Liquid Crystals

Sigma Pi Sigma Undergraduate Research Award Final Report

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Abstract

From wristwatches to the most advanced computer systems on earth, liquid crystals have made their way into every aspect of our lives. Since liquid crystals have been introduced to the industry there has been a great demand to reduce their energy consumption. This document shows the final research project performed by the Society of Physics Students at UCCS. The research was done in an effort to find new ways of reducing the energy consumption of such devices. Over the past year the Society of Physics Students created a mixture of BaTiO3 and liquid crystal 13739, applied it to several polarized cells and tested to see an increase in the dielectric anisotropy and in turn a reduction of the Freedericksz Transition Voltage in the liquid crystal cell. Through the support of the SPS national organization and the use of the UCCS Liquid Crystal Research Lab, it was shown that the use of the ferroelectric nanoparticle, BaTiO3, while suspended in a liquid crystal matrix shows a significant increase in the dielectric anisotropy of the liquid crystal cell.

Background

One of the most common applications of liquid crystals is their use in liquid crystal displays. The structure of the simplest one is shown in Figure 1. In normal state, light goes through a polarizer, a twisted liquid crystal cell, a second polarizer and an RGB filter and comes to a viewer's eye (Figure 1, top).[2] In an activated state, when electric field is applied to a pixel, liquid crystal molecules rotate perpendicular to the polarizers and no light comes through the system (Figure 1, bottom). Therefore, the electrical consumption of a display is determined by the sensitivity of a liquid crystal material applied electric field. The sensitivity of a liquid crystal in turn, is determined by a physical characteristic called the dielectric anisotropy, $\Delta\varepsilon$.[1]

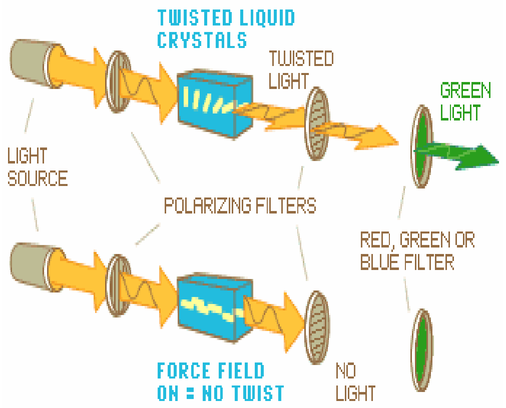


Figure 1: schematic representation of a twisted nematic liquid crystal display.

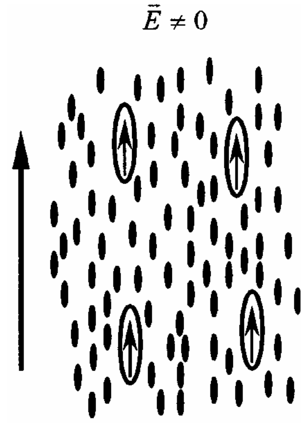


Figure 2: nematic liquid crystal doped with ferroelectric nanoparticles.

To lower the amount of energy used in an LCD we must find a way to increase the dielectric anisotropy of the liquid crystal. There are two ways to go about this, first would be to create a new liquid crystal material. This way is very costly and may not give the results needed. The other more feasible way is to take some material that is known to have a higher dielectric anisotropy and mix it into the liquid crystal matrix. One of the examples may be ferroelectric materials. Typically, ferroelectric single crystals have dielectric anisotropies on the order of $\sim 10^2$-10^4, while the dielectric anisotropies of a liquid crystal are $\sim 10^1$. One can make ultra-small particles of a ferroelectric material by milling them in a planetary ball mill. Then the particles could be mixed with a liquid crystal and the entire mixture would then be expected to have a higher sensitivity to electric fields: particles would react first and pull the entire liquid crystal matrix toward the applied electric field (Figure 2). The following research was done using the ferroelectric nanoparticle BaTiO3 and a liquid crystal, 13739 in an attempt to increase the dielectric anisotropy of the liquid crystal cell.

Experimental Procedure

The following material outlines the exact procedures used in the construction of the liquid crystal cells:

I) Making the BaTiO3 enhanced Liquid Crystal

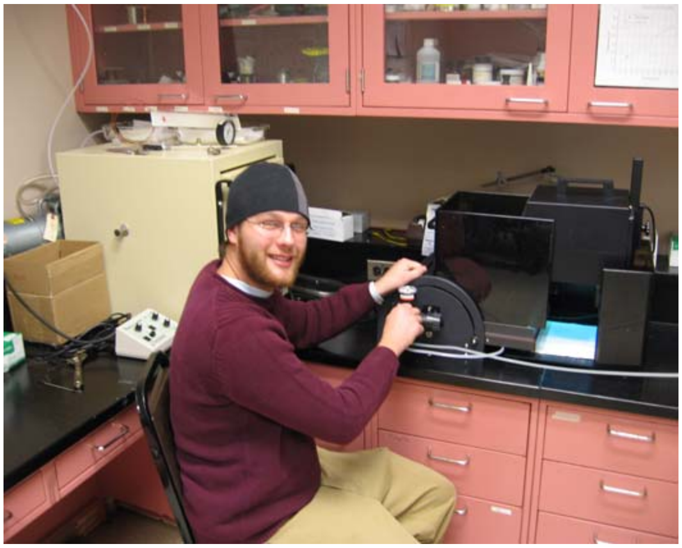
1.) Mill the BaTiO3 for 10hrs in a planetary ball mill, this produces a size distribution curve with the largest amount found around 3μm/
2.) The BaTiO3 is then stored in an oleic acid and Heptane mixture. Our mixture was stored in a mass ratio of 1mg BaTiO3 to 2mg Oleic Acid to 10mg of Heptane.
3.) We wanted a 1:100 mass ratio of BaTiO3 to liquid crystal, but with no heptane, so we measured out 200mg of liquid crystal and then added 26mg of the BaTiO3 to allow for a final mass of 206mg which would have a mass ratio of 1:2:100(BaTiO3:Oleic Acid:Liquid Crystal). We allowed the solution to sit under a vacuum hood for 2 days to allow for the Heptane to evaporate. No heat was applied for fear of altering the structure of the liquid crystal itself. After allowed to evaporate the mixture was weighed again to determine if all the Heptane ahd evaporated.

II) Cutting and Polymer Coating

1) Wearing gloves during the entire course of making the liquid crystal displays, cut 1 inch by 1 inch plates of ITO conducting glass with a glass cutting machine (cutting only on the ITO conducting surface). Be careful to grip the glass by the edges and corners at all times. The ITO side may be determined by a conduction tester.
2) Remove all dust from the substrate of the glass plates by means of a nitrogen gun. This will prevent contamination after the polymer coating process.
3) Transter four droplets of polymer pI5291 to the ITO conducting surface; distribute the polymer along the plate by spinning the plate at 2000 rpm for 20 seconds. Do not attempt to recoat any substrate.
4) Evaporate water from the polmer by allowing the plates to sit on a hot plate for two minutes at 100°C.
5) Heat the coated plates in a drying oven for precisely one hour at 175°C. Allow the coated plates to cool afterwards.

III) Making the Planar Liquid Crystal Cell

1) Remove all dust from the substrate of the glass with a nitrogen gun. Draw a velvet roll (with very minimal force) across the polymer-coated substrate twenty times. This polarizes the coating: use a marker on the opposite side of the glass to indicate the direction of rubbing.
2) Apply spacers of 10μm to half of the plates being used. These spacers will separate the two plates that the cell will consist of.
3) Remove large “clumps” of spacers with any simple low-pressure instrument.

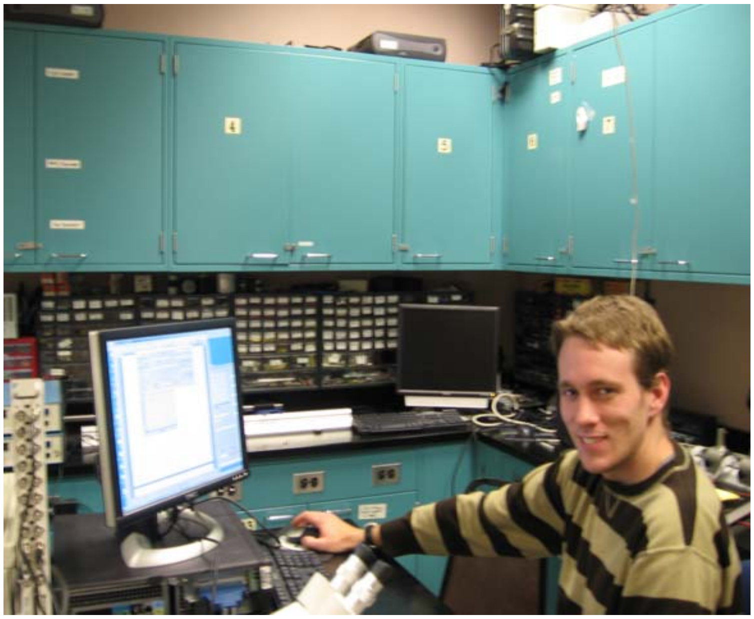


4) In a clear area, separate half of the plates on a Technicloth which have spacers on their surface and the others that do not. Apply glue to two corners on spacer-coated plate and carefully position a non-spacer-coated plate (with glue on two of its corners as well) on top of the other. Be sure to align the plates antiparallel to one another in the process of making a planar liquid crystal cell.
5) Position the “cell” between a vacuum-device and plastic wrapping to hold the cell in place. Be very careful not to move the two cells against each other; doing so will scratch the polymer and render the “cell” unusable. Rainbow lines indicate nonhomogeneous thickness between the plates of the cell: the two plates may be carefully shifted to reduce these lines.
6) Solidify the glue by placing the “cell” in an ultraviolet chamber for three minutes at 100% lamp intensity.
7) Glue two of the four edges per cell and solidify the glue in an ultraviolet chamber for six minutes at 100% lamp intensity. The two unglued edges will serve as a channel for the liquid crystal.

IV) Preparing the Cells

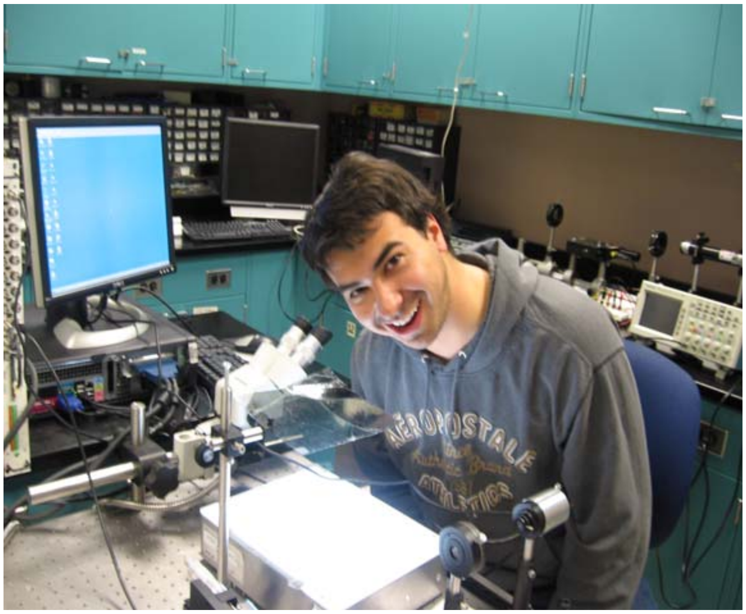
1) Organize a set of control cells (2) and a set of experimental cells (2). Apply liquid crystal LC13739 to the control cells.
2) Apply the liquid crystal/nanoparticle mixture (LC13739-BaTiO3) to the set of experimental cells. The mixture is prepared under these guidelines:

    a) BaTiO3 is grounded for ten hours to an average distribution function around 3.0 µm.
    b) The ratio of Oleic acid to BaTiO3 is 2:1
    c) The ratio of Heptane to BaTiO3 is 10:1
    d) The ratio of BaTiO3 to LC13739 is 1:100
    e) Mix the Heptane with the BaTiO3 particles for five to ten minutes. Then mix into the liquid crystal.



V) Measurements

1) The setup must consist of a laser, polarizer, compensator, analyzer, photodetector, and data collection software for electro-optic experiments.
2) Situate the liquid crystal cell between the polarizer and analyzer. For the purpose of a planar liquid crystal cell, adjust the polarizer to 45° and analyzer to – 45°.
3) Connect alligator clips to the cell, making sure that each clip is attached to one substrate and not both.
4) Verify that the maximum voltage is less than 10 V by rotating the compensator. Otherwise, the photodetector will be oversaturated.
5) Rotate the compensator such that the detector voltage reads at approximately 0 V. Perform five static response measurements for two control cells and two experimental cells (at a waveform repetition rate of 10, 50, 100, 500, and 1000hz).
6) Begin data collection. Repeat process for time response measurements (at the same repetition rates).



Data & Results

The points at which a liquid crystal cell align and rotate to allow varying degrees transmittance can be found by taking a series of measurements at different voltages applied across the cell as described in the experimental procedure section. It can be seen that the liquid crystal, 13739, performs a full transition which allows the maximum transmittance at 2V to 2.2V (Figure 4 Control Cell). When BaTiO3 was applied to the liquid crystal it can be seen that there is a reduction of that transition point by ~0.25V(Figure 4). The same results were also seen at 50hz, 100,hz, 500hz, and 1000hz(Figures 5-8). From the static response measurements we were able to determine the points at which the liquid orient themselves, and at what points to take time response measurements.

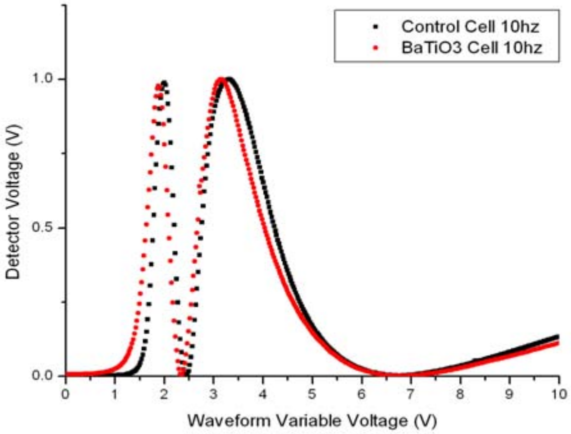


Figure4: Static response measurement comparison at 10hz

The time response measurements showed that for the frequencies measured there is a difference in the transition time of ~0.2 – 0.3sec (Figures 9-13) for the first full transition. The second transition happens at such a fast rate, around .025sec, yet it was still measureable difference between the BaTiO3 cells and the control cells. (Figures 14-18).

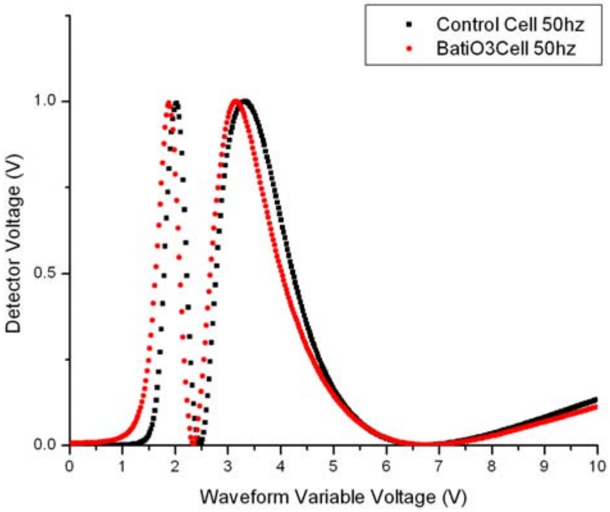


Figure 5: Static response measurement comparison at 50hz

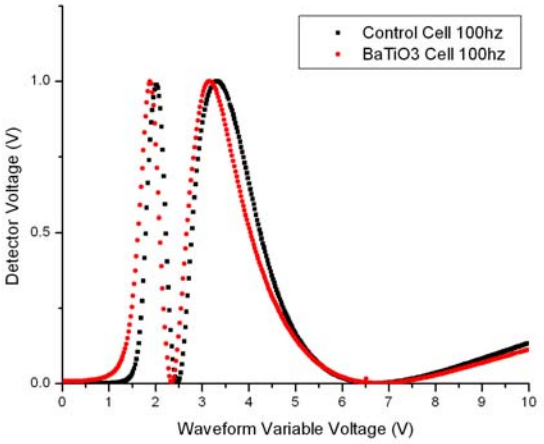


Figure 6: Static response measurement comparison at 100hz

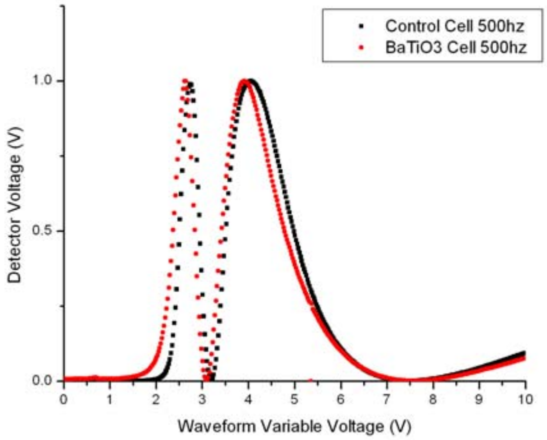


Figure 7 Static response measurement comparison at 500hz

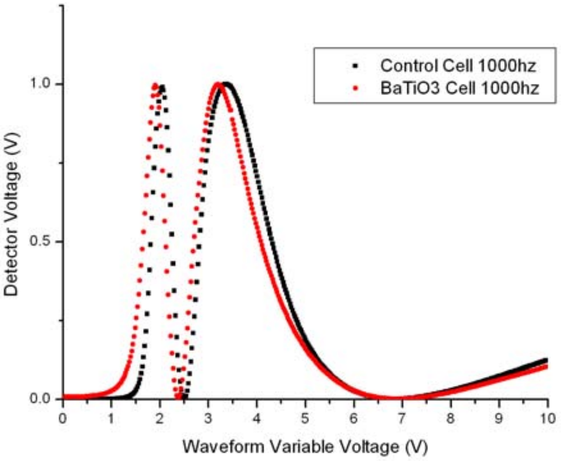


Figure 8: Cont5ol Static response measurement comparison at 1000hz

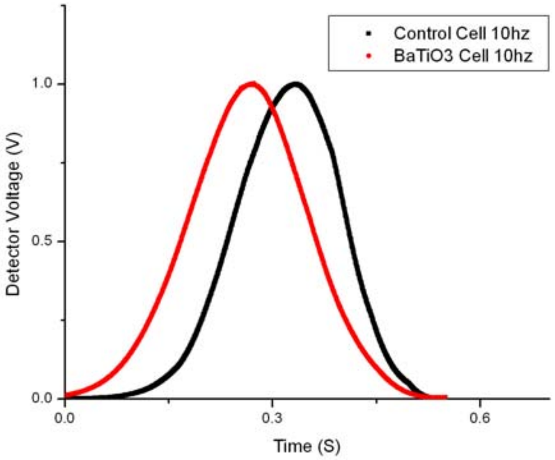


Figure 9: Time response of first transition measurement comparison at 10hz

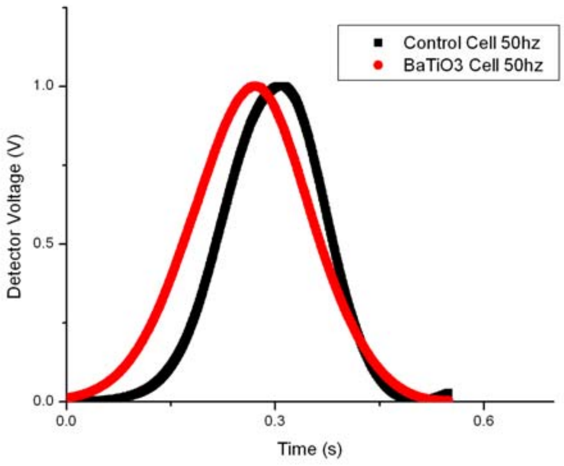


Figure 10: Time response of first transition measurement comparison at 50hz

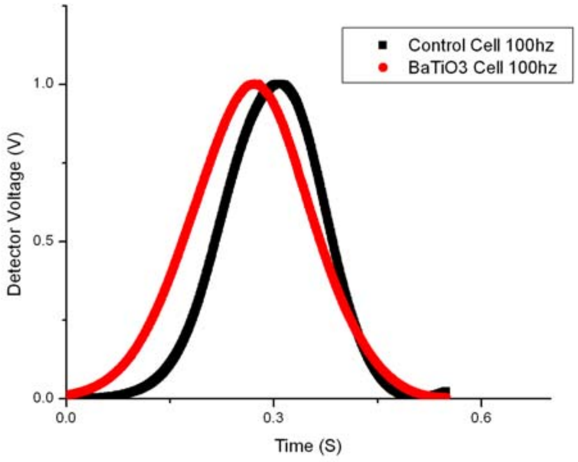


Figure 11: Time response of first transition measurement comparison at 10hz

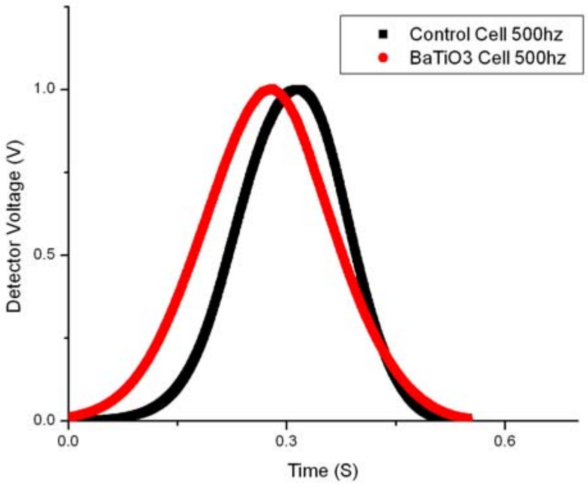


Figure 12: Time response of first transition measurement comparison at 500hz

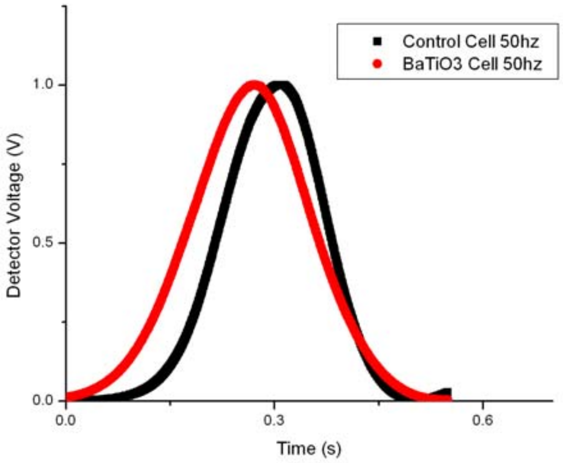


Figure 13: Time response of first transition measurement comparison at 100hz

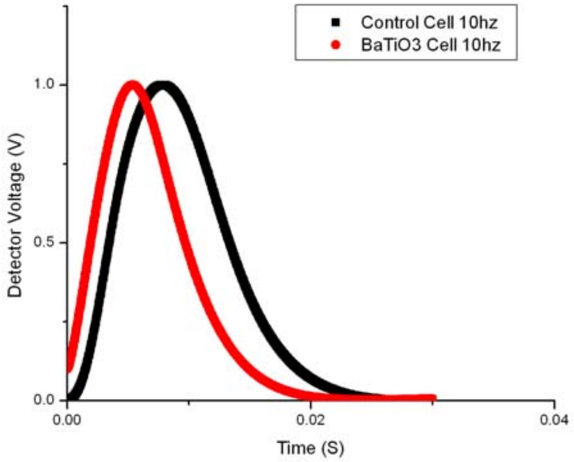


Figure 14: Time response of second transition measurement comparison at 10hz

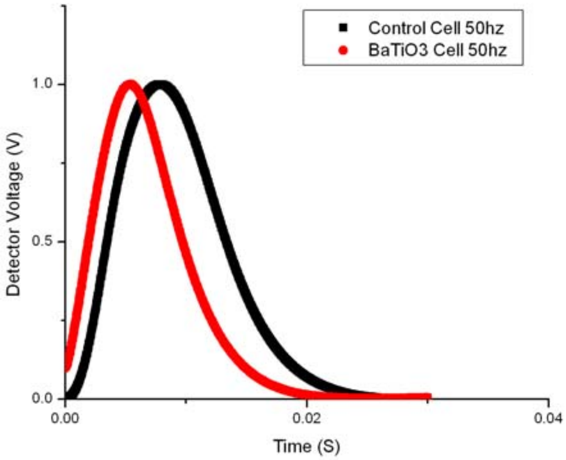


Figure 15 Time response of second transition measurement comparison at 50hz

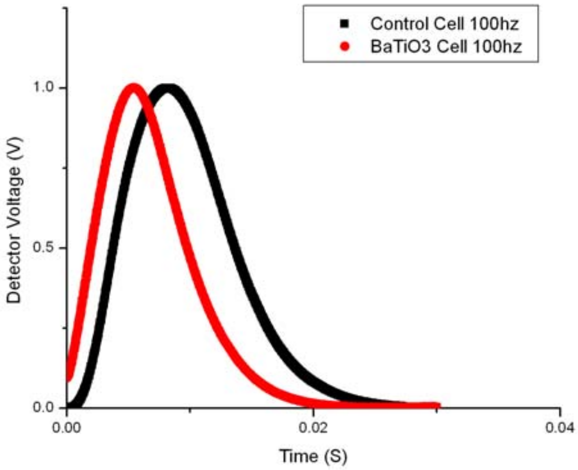


Figure 16: Time response of second transition measurement comparison at 100hz

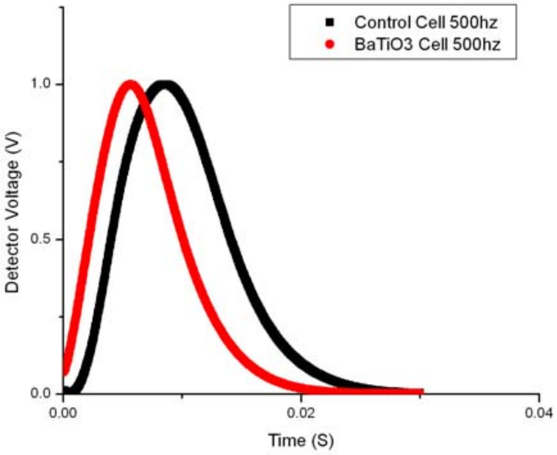


Figure 17: Time response of first transition measurement comparison at 500hz

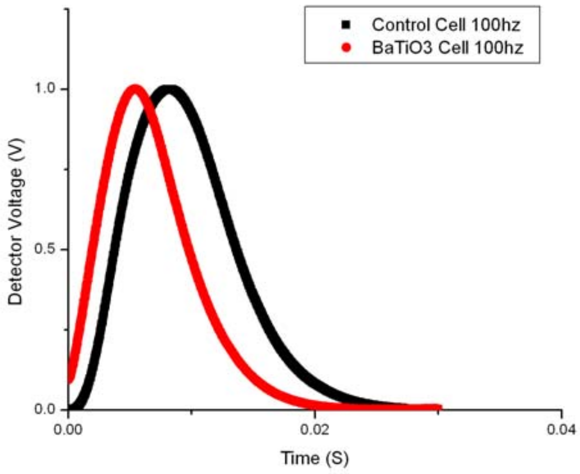


Figure 18: Time response of second transition measurement comparison at 1000hz

Conclusions

The results show that there was an average reduction of ~0.25-.0.30V for the liquid crystal enhanced with BaTiO3 for all frequencies measured. The results also showed that the time it took for the liquid crystal to go through a complete transmittance phase took ~ 0.2 – 0.3sec less time for the first transition peak. The second transmittance peak also completed the transmittance phase at a rate that was ~.002sec faster. This was very promising and promotes further study into different liquid crystal and ferroelectric materials.

Acknowledgments

We would like to thank the The Society of Physics Students National organization, and the University of Colorado at Colorado Springs Liquid Crystal Research Lab without whom none of our research would have been possible.

References

[1] Glushchenko, A., Cheon, C., West, J., Li F., Buyuktanir, E. Rezinkov, Y., Buchnev, A.,(2006) Mol. Cryst., Vol 453, 223-237.
[2] H. Fountain, (2001)*The New York Times Circuits: How Electronic things work*, 44-47

Budget

Use:	Amount:
LCESP-9: 9”x9” Press for Liquid Crystal Cell from LC Technologies Inc.	$1495.00
Shipping	$25
Total:	$1520.00

We have decided to spread the research over a period of 2 years instead of one to give further incentive for students to join the SPS at UCCS. So we have budgeted for the following year:

Projected Use:	Amount:
Ferroelectric materials will be purchased from Aldrich	$300.00
School/Community outreach program starting August '09 (includes printing cost of fliers, mailing costs to local schools k-12, and day parking passes for visiting schools)	$100
4 pair of Ultra Violet Safety Goggles for SPS student use @ $6 each from scientificsonline.com	$24
Various supplies ie: lab notebooks, lab coats, and other various safety equipment.	$56