Inkjet Printing onto Liquid Crystal Thin Films

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I. Introduction

Liquid crystals are elongated molecules that have the tendency to align themselves in multiple dimensions. In this study we used 4-cyano-4'-octophenyl (8cb) to experiment with the possibility of printing droplets of liquid crystal onto a thin film of the same molecule. 8cb is a thermotropic liquid crystal that, at various temperatures, presents the phases smectic A, nematic, and isotropic (Figure 1).

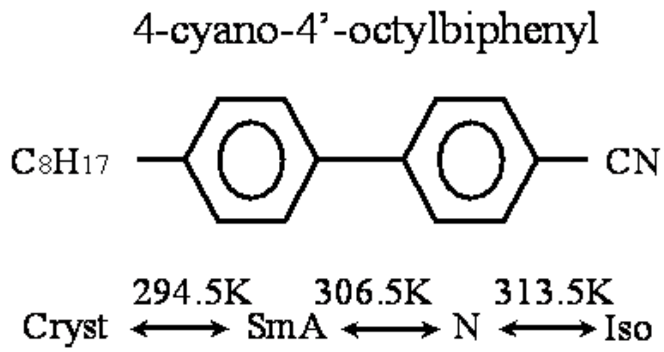

Figure 1. 8cb liquid crystal with phase temperatures specified [5]

When 8cb forms thin films of between two and ten layers it tends to have topological defects which are colloquially termed “islands.” (Figures 2 and 3) These defects can be as much as five times thicker than the surrounding thin film and assume a disk-like shape that moves through the film. These islands generally have diameters between 1 and 10 um and move freely through the film.

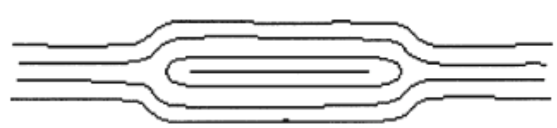

Figure 2. Profile of a 6-layered island on a 3-layered film [3]

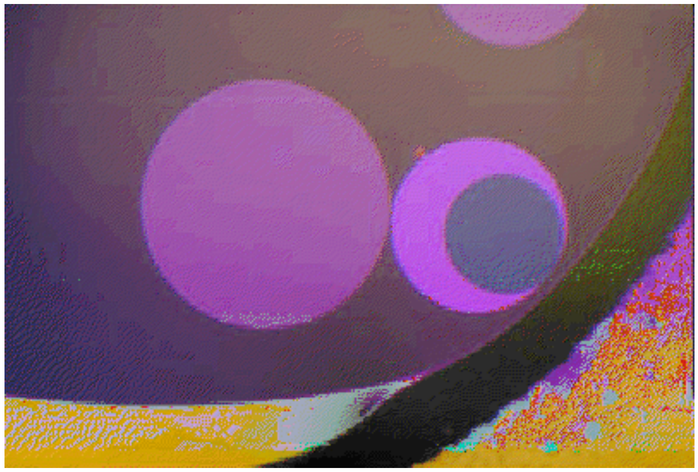

Figure 3. An image of islands and holes on a thin film of 8cb. The thicker the film or island, the more layers are present [1]

Our lab currently works with these islands to further our understanding of fluid dynamics. We are able to move the islands around using optical tweezers so that we can place two islands close together and observe the forces they exert on each other. It is easiest to examine the diffusion coefficients of islands that are of similar diameter and thickness. However, the current accepted method to induce islands to form on the thin film is to blow a stream of air over the surface of the thin film. This method, however, is imprecise. An uncontrollable number of islands are formed using the air flow technique, and they are of various thicknesses and diameters. Therefore an experiment was initiated to attempt to gain the ability to print islands onto the thin film using an inkjet printhead, as well as a MicroFab inkjet needle.

II. Experimental Setup

The liquid crystal 4-cyano-4'-octophenyl (8cb) was used exclusively in the inkjet printing experiments. We used it both at room temperature, in the smectic A phase, and in the heated isotropic phase, depending on the experiment which was being performed.

We used a reflected light telescope to view the thin films on which we were printing droplets of liquid (Figure 4(a)). In the first experiment we used the MJ-AL, 10um orifice MicroFab needle, a piezo-type device bought specifically for this project (Figure 4(b)). This device was controlled using an HP 33120A function generator, which was fed through an FLC F20A 20X voltage amplifier. The function generator was controlled using a LabVIEW program which I wrote (Appendix A).

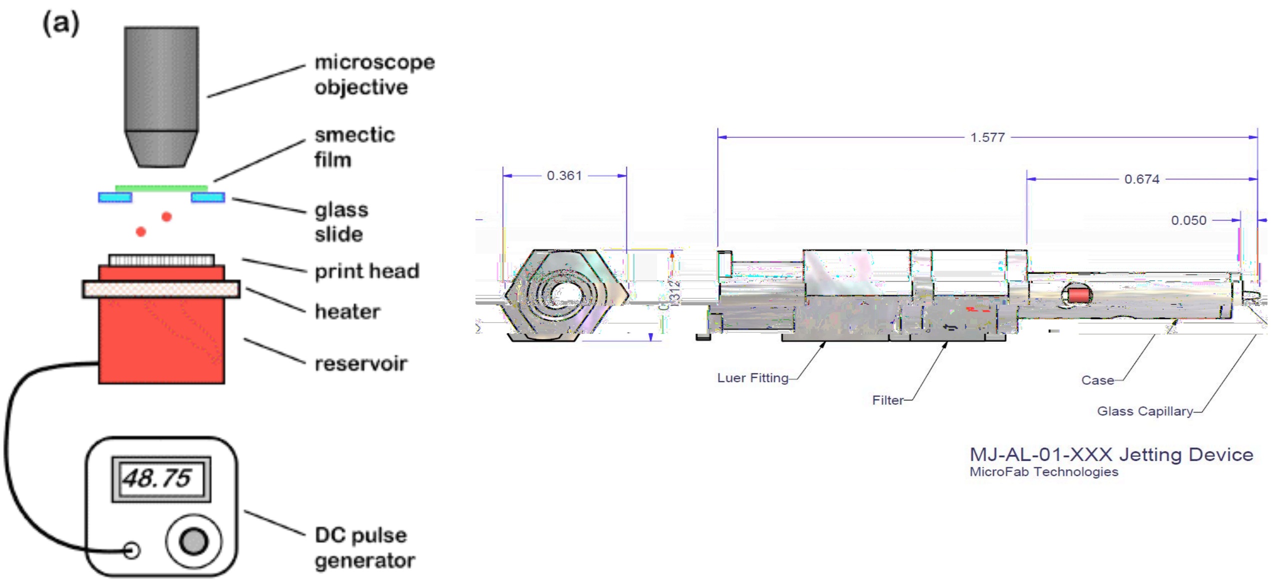

Figure 4. Experimental Setup (a) Setup with microscope (Printhead is interchangeable with MicroFab needle). Droplets of 8cb or water are deposited vertically onto a thin film of 8cb [1] (b) Diagram of MicroFab needle. Tip is 10um in diameter. Piezoelectric device is the red cylindar in the center of the needle. [4]

We experimented with using many different types of waveforms to control the voltage across the MicroFab needle or print head. The instruction manual for the MJ-AT needle, a similar device to the one which we used, was obtained from MicroFab's website and suggested a semi-square wave with rise and fall times of approximately 2 microseconds. (Figure 5). After several attempts to manipulate this waveform, including extending and contracting the rise and fall times, adjusting the ratio of positive to negative voltage, and adjusting the length of each of the plateaus, we were not successful in inducing a flow through the needle using this waveform.

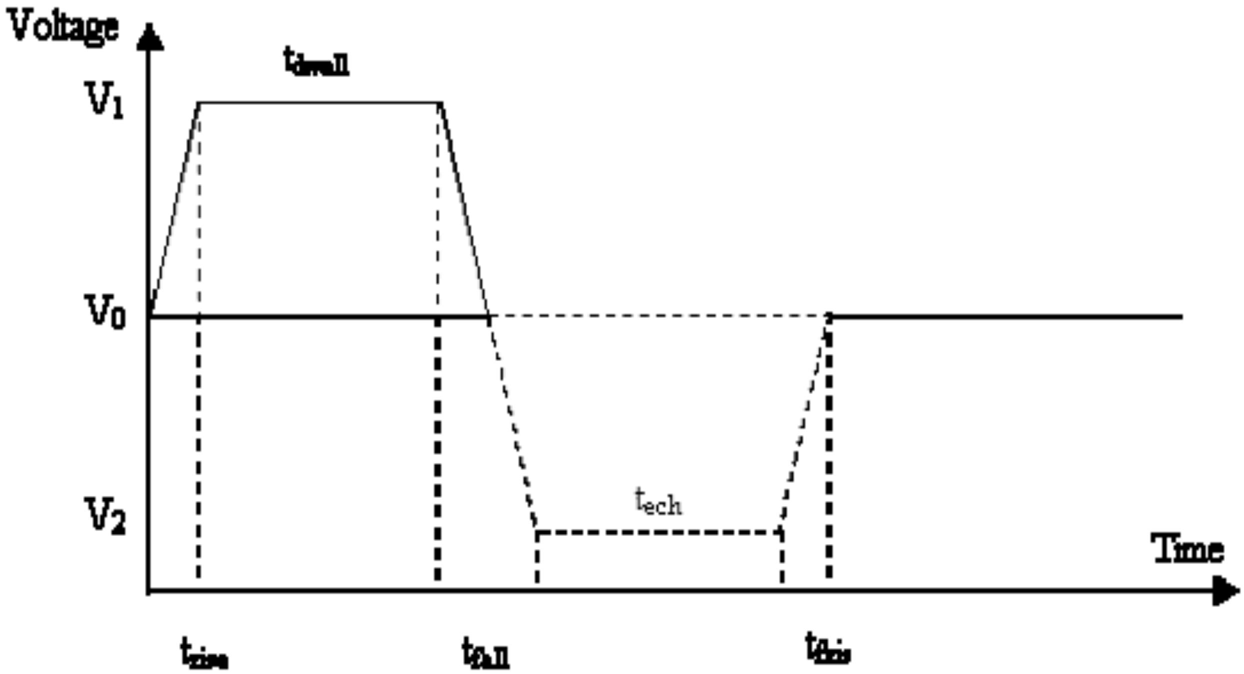

Figure 5. Waveform suggested by the MicroFab instruction manual for the MJ-AT needle. [4]

We were, however, successful in inducing a flow through the tip of the needle using a simple square wave. The peak to peak voltage which was put across the needle was 160V: an 8Vpp square wave which was routed through the 20X voltage amplifier. Any frequency between 1Hz and 1000Hz induced a flow.

We also performed experiments in printing water with the MicroFab needle. Again, a square wave was used, and a much smaller voltage was needed to induce flow through the needle. We were able to see printing with 80Vpp at a frequency of 10Hz.

One final experiment that was setup was one using a simple inkjet printhead from an Epson printer. This was used to print water containing 8um glass spheres. The setup was identical to our previous one (Figure 4(a)), with the printhead where the MicroFab needle was. We were able to achieve printing onto a thick film using this method. 24-30Vpp was passed across the printhead, (1.2-1.5Vpp routed through a 20X voltage amplifier) and we were able to print at much lower frequencies, maxing out around 10Hz.

III. Results

When attempting to print 8cb droplets through the MicroFab needle we were able to induce flow, but not able to print onto a film. The 8cb would flow through the tip of the needle and form a meniscus over the tip, never leaving the actual glass needle (Figure 6). Theorized reasons behind this include that the function generator cannot easily control the back pressure inside the piezoelectric cavity of the needle. Bubbles were formed inside the needle and there was not sufficient back pressure to push the droplets off of the tip of the needle. This could also be due to the viscosity and surface tension of 8cb.

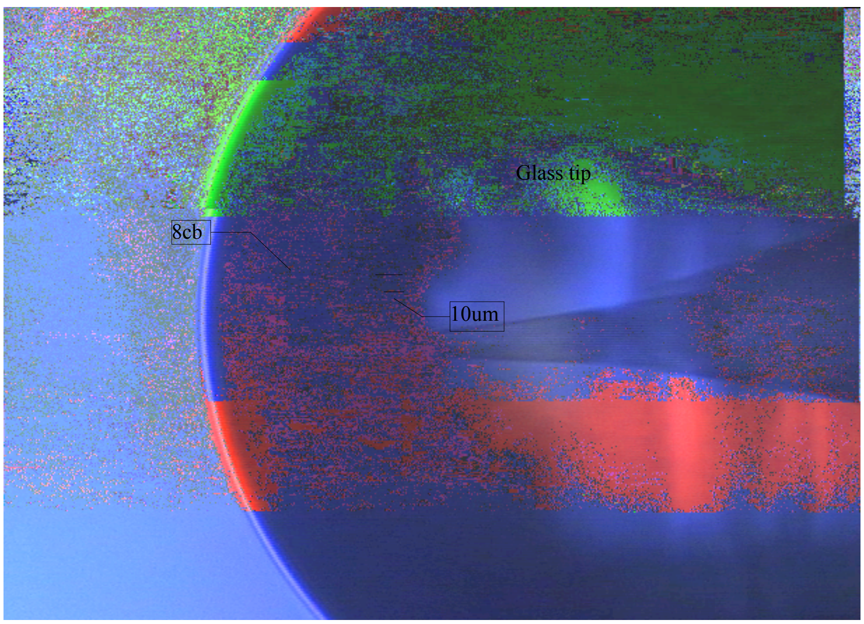

Figure 6. 8cb meniscus forming over the tip of the MicroFab needle. Needle is horizontal with the conical section being the cavity through which liquid flows.

Therefore, we attempted to do the same printing with water. We were much more successful this time, and were able to print droplets of water onto a glass slide (Figure 7). The droplets were approximately 40um in diameter, but were very irregularly spaced, and were not printed consistently in the same place on the slide. We were, however, excited that we were able to induce printing, no matter how irregular.

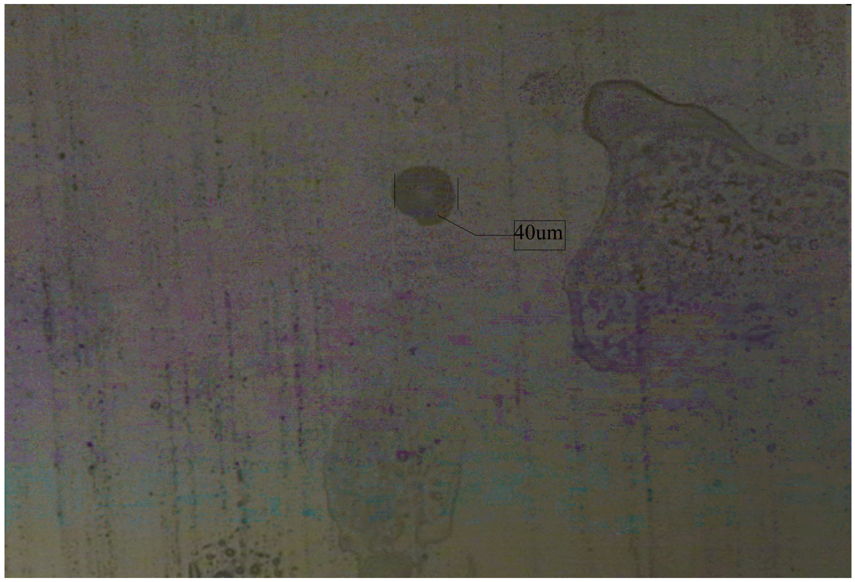

Figure 7. Droplet printed onto a microscope slide from underneath using MicroFab needle.

We worked with the inkjet printhead to try to print glass beads enclosed in a droplet of water. We were quite successful with this, and able to deposit the glass spheres onto the surface of the thin film. The idea behind this experiment was to deposit a glass bead onto a thin film inside a droplet of water. The water would evaporate within seconds and leave behind the glass bead.

The majority of the time that we printed a droplet of water, there was no bead enclosed. This was largely due to the small ratio of beads to water, but could also be a result of settling of the beads in the bottom of the needle. The droplets of water with no glass beads would evaporate to leave behind a miniscule (1-2um) droplet of water that became enclosed in the thin film. However, occasionally there was a glass bead inside of the droplet of water. When the water evaporated what appeared to be an 11um circle was left behind on the film (Figure 8). We theorize this to be the 8um glass bead surrounded by that tiny bit of water that we had been observing to be left behind.

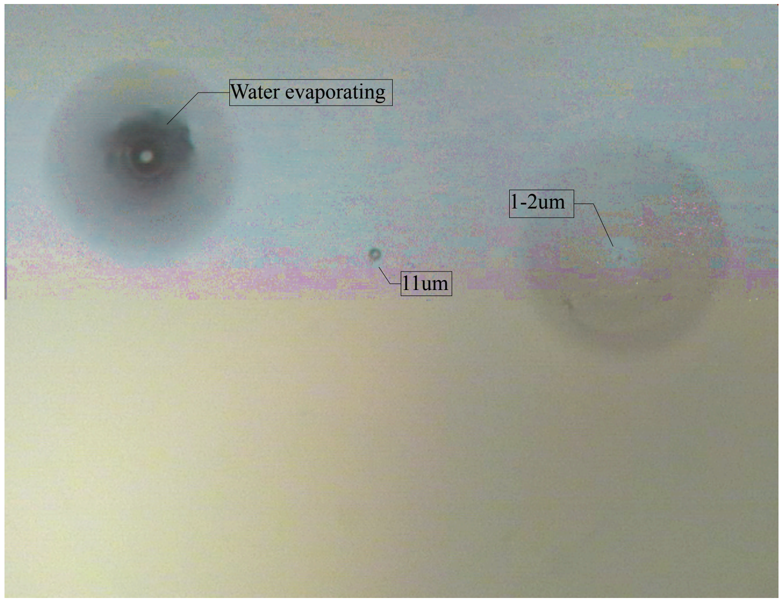

Figure 8. A glass bead remains behind on the thin film after the water around it evaporated away.

We ran into one problem when printing using the inkjet printhead. This problem was that we were only able to print onto thick films with many layer steps. Any of the thin films that we attempted to print onto, the droplets broke the film immediately. The problem with using these thick films is that because of the layer steps we are not able to observe the diffusion coefficients of the particles properly. Instead of moving around freely like they would on a thin film, the particles and droplets of water would move towards the layer steps and get caught in the curve of the step (Figure 9).

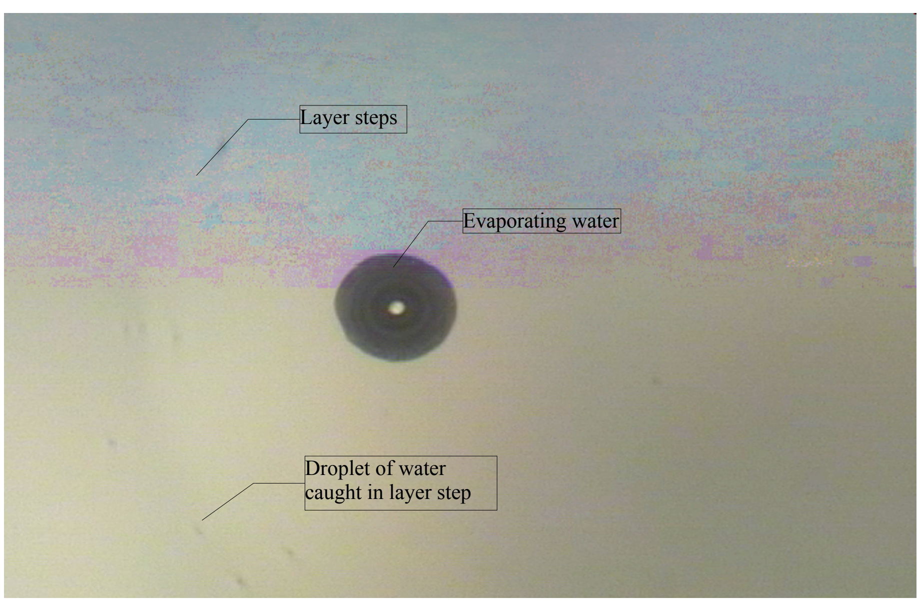

Figure 9. The 1-2um remainder droplets of water are being caught in the curved layer steps on the left side of the film

IV. Future Work

No conclusions were able to be drawn from these experiments because we did not have enough time to gather conclusive diffusion coefficient data. We were, however, able to set ourselves up for plenty of future work on the project.

We need to continue to work with the MicroFab needle to attempt to get it to print 8cb droplets. We should attempt to obtain a pneumatic control device so that we can properly control the pressure inside the piezoelectric cavity. The pneumatic control device distributed by MicroFab Technologies also works as a vacuum so that we can properly clean the needle and avoid clogs.

We can deal with the problem that the MicroFab needle printed irregularly when we printed water. When the inkjet printhead was acting similarly we were able to fix the situation by systematically lowering the voltage that we put across the device. This method should be attempted on the MicroFab needle to see if we can more readily control where the droplets are being printed.

The inkjet printhead, working as it is, should be used to deposit more glass beads onto the surface of thin films. Because we were only able to induce printing without breaking the film onto thick films, more work should be done to try to get printing on thin films. This way we can examine the diffusion coefficients of particles and compare them with the diffusion coefficients of liquid crystal droplets. We also are planning to deposit irregularly shaped particles such as glass squares onto the thin film. With these squares we can examine the rotational diffusion coefficients of the particles.

Appendix A: LabVIEW Program

For this project I was asked to develop a LabVIEW program to control the function generator which is used to induce a voltage across either the MicroFab needle or the Inkjet Printhead. This Appendix will serve as an instruction manual to use my program.

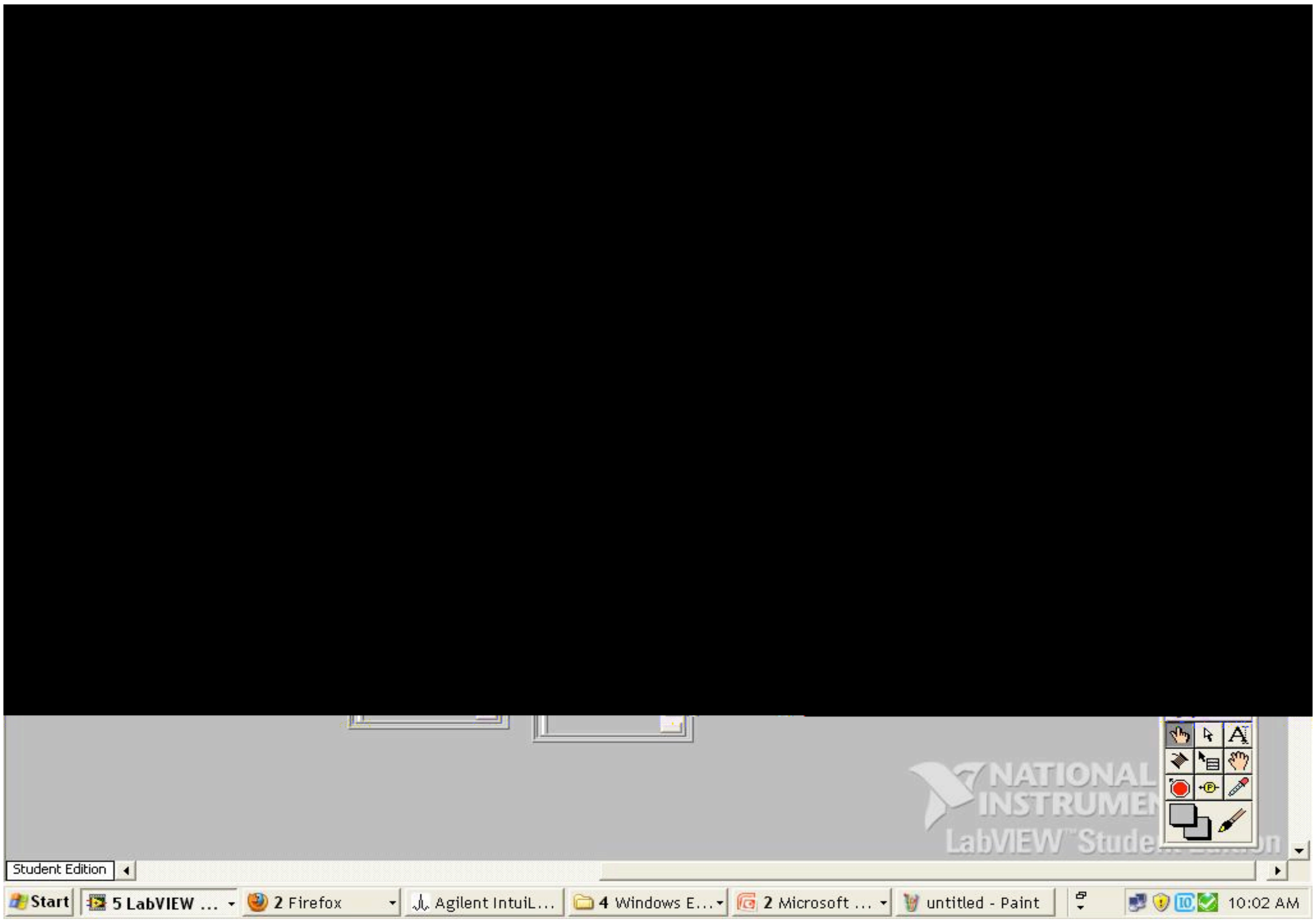

Figure A1. Front Panel of LabVIEW Program

All adjustments to the parameters should be done when the program is stopped and not running. Before running the program, there should be no voltage flow to the MicroFab needle or the printhead, whichever is being used. Usually, I keep the voltage amplifier turned off until the program has initiated.

When setting the parameters one must decide which type of wave to use (square, sine, triangle, etc.), the frequency to be used, as well as the voltage (not peak-to-peak) to be induced. All of this is fairly straightforward. What isn't however, is the trigger function.

The button labelled “trigger” is what must be clicked to send a pulse through the device. Every time the trigger button is pushed, a number of pulses equal to the “Burst Count” will be sent through the device at the specified frequency. If you wish to send a series of triggers, that is what the “Trigger Count” field is for. Say I wanted to send 3 different sets of 10 bursts, which each set being 5 seconds apart. I would set “Burst Count” to 10, “Trigger Count” to 3, and “Milliseconds between triggers” to 5000. This would be the same as having “Trigger Count” set to 1, and just manually pushing “trigger” every 5 seconds.

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Also, I want to thank Chuck Norris. Just in case.

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