ELECTROLUMINESCENT CIRCUIT PRINTING

John Jay Jacobs, Joanna Church, & Jen Olberding
Fall 2008

ABSTRACT

Electroluminescent printing is an up and coming printing technology which is not clearly understood or extensively documented. The study was conducted to determine a dependable method for printing an electroluminescent circuit.

The 16 week study utilized both UV and conventional solvent based printing inks to determine printability and suitability. Ink thicknesses were varied to determine the effect upon the circuit. Three press tests were conducted with each test building upon the techniques learned from the prior test.

The thickness of the ink deposit is crucial for achieving the desired electrical conductivity, illumination, and insulation properties for each circuit layer. Sufficient cure is essential to achieve the necessary conductivity and insulation for each layer of the circuit. An adequate power supply and inverter are essential for a consistent, bright glow from the completed circuit.

The final print run produced dependable, bright, consistent electroluminescence. Future tests need to be done utilizing a illuminometer to accurately determine the amount of light produced by the circuit.

INTRODUCTION

Electroluminescent printing is presently as much an art as it is a science. Companies that have mastered or specialized in this kind of membrane switch printing have developed their own techniques and standards, and are keeping those techniques to themselves. Chemical and ink suppliers are able to provide some basic information on the materials and simple design considerations, but there is no comprehensive guide on the design and construction of an electroluminescent circuit. The purpose of this research was to determine the general parameters for producing an electroluminescent circuit, and to explore the possible applications of such circuits.

METHODS AND MATERIALS

Print Test One - five weeks

The initial press layout (10” x 16”) for testing the maximum area that can be illuminated with the inverters provided was determined. Patterns were designed to test for silver conductive ink. Five percent halftone swatches from five percent to 100 percent at 45 lpi were added, as well as the line weight target. The purpose of testing the conductive ink patterns was to find the most even-lit/even-energy pattern. The printing order of the inks was determined: silver conductive ink (trace one), clear conductive, phosphorus ink, dielectric ink, silver conductive (trace two), dielectric. See *Appendix A*.

The green was the most abundant of phosphorus ink received for the experiment; the first test was printed with that color. It was determined that the Kiwocol Quantum emulsion used in lab would suffice.

Six screens, five 305 mesh and one 160 mesh, were coated with five layers of Kiwocol Quantum direct emulsion: two coats on face, one on back. After the screens were dry, two more coats were applied to the face. Pre-punched .005" heat treated clear polyester sheets were printed in the following order:

first trace - Allied PhotoChemical UVAG0017
clear conductive - Allied PhotoChemical UVAG0025
green phosphorus - Allied PhotoChemical TGH1400 GN
dielectric - Allied PhotoChemical TGH1717
second silver trace - Allied PhotoChemical UVAG0017
dielectric - Allied PhotoChemical TGH1717

For registration, brass pins were utilized. The ink was cured using a 300 watt American UV curing oven with the belt speed at 25 feet per minute for the first trace and then 45 feet per minute for the subsequent layers. After all the layers were printed, the circuit was turned over and sent through the curing unit face up to ensure a complete cure and inter-coat adhesion.

The material from the first press run was tested and it was determined that maximum glow would be achieved with circular trace design.

Second Press Test - five weeks

Silver conductive traces were designed in circular patterns and then sent to Hallmark to be printed. See *Appendix C*.

The received printed silver traces were measured. Film was output with only solids and three screens were coated, two 305 mesh and one 160 mesh, using three emulsion layers: two on face and one on well. The three screens were then imaged. The clear conductive and dielectric layers were to be printed using the 305 mesh screens and phosphorus using the 160 mesh screen.

Clear conductive was the first ink to be printed on forty sheets from Hallmark. Then phosphorus was printed on twenty of the already printed sheets: five sheets each of the bright white, green, blue, and orange. The screen was washed in between each run. Next, a single layer of dielectric ink was printed on four sheets for each phosphorus color, and a double hit on the remaining sheet. 3M9703 (z axis conductivity only) was applied to a few sheets to bond the first and second switch layer together.

The printed sheets without adhesive were sent to Hallmark to print the second trace directly on the circuit. The sheets were tested. More clear conductive ink was ordered for third test run.

Third Print Test - six weeks

Multi-color vector image was designed to print: for the round switch, an earth using the green and clue phosphorus, and for the long switch, the word CLEMSON with a tiger paw O using blue and orange phosphorus. The screens were imaged for the press runs. See *Appendix D*.

Twenty sheets were printed with clear conductive: ten with double hits, ten with single hits. Green, blue, and orange phosphorus were printed on twenty sheets: ten sheets with double hits and ten with single hits. The print run resulted in five sheets each of: single clear conductive, single phosphorus; single clear conductive, double phosphorus; double clear conductive, single phosphorus; double clear conductive, double phosphorus.

Conductive adhesive was applied to join the two layers of the switch.

The non-laminated sheets were sent to Hallmark to print the second silver conductive trace. The second conductive trace layer was redesigned to allow for selective energizing of the image area. The final conductive layer and dielectric layer were printed.

RESULTS AND DISCUSSION

Results from First Print Test

Three coats of silver conductive were necessary to completely fill in the gaps in the trace. There was a 48 hour post-cure time for the silver cross-linking. Even with solid traces and post-curing, the glow was not dim at best. Only the smallest and medium size traces provided dependable, visible results. See *Appendix G* for photographs of results.

Halftone printing of phosphorus was difficult. Dots printed from the15 to 45 percent patches, with an approximate dot gain of 50%. It was hypothesized that a 30 lpi halftone would allow a larger dot range, but was decided to utilize only solid printing for future tests.

There was a design problem that allowed the registration pins to be too close to the image area causing the squeegee to run over the pins. Even though the screen mesh did not pop, future switch layouts would allow a gap between the printed image and the pings to prevent the squeegee from passing over the pins.

The UV belt speed required to cure the final silver conductive ink was too slow for the other inks. 25 fpm speed caused the prior UV ink layers to overheat, warping the substrate. The belt was sped up to 45 fpm to prevent this warping, but made the final silver ink cure questionable.

The silver traces interfered with the ohm readings of the clear conductive. The closer the multimeter prongs were to the traces, the lower the readings. It was decided that the traces should be designed in circular patterns so as to keep a consistent distance an optimal electromagnetic field.

The emulsion was too thick on the initial screens. Future screens would be coated with only three coats of emulsion: two on face and one in well.

Due to the difficulty with conductivity, it was decided that Hallmark would print silver conductive layers using Acheson Electrodag 725A(6S-54) silver conductive ink for future test printings. See *Appendix B* for conductivity test data.

Results from Second Print Test

The one inch trace of the Hallmark printed silver measured 0.4 ohms, which was a drastic improvement over the 3.7 ohms of the silver trace equivalent on the first print test.

It was determined that a double hit of the first dielectric weakened the glow. Pressing the second trace layer to the back of the first trace layer resulted in glow. 3M9703 (z axis conductivity only) adhesion between layers resulted in a bright but mottled glow.

The single layer, completed switches had a significantly brighter, consistent glow. It was determining that a thicker layer of clear conductive would produce a brighter, more consistent glow.

The white phosphorus ink was completely consumed during the second print run. It was decided that the final multicolor print test could be designed without the use of white.

Results from Third Print Test

The adhesive laminated switches produced even brighter illumination than the second print test. The colors were very noticeable.

The glow was broken where different phosphorous inks butted into one another. This was caused by different ink film thicknesses and not being able to achieve full contact between layers with the adhesive. The materials were sent to Hallmark to print the second trace in order to eliminate the gap problem and achieve full glow.

There was difficulty printing a smooth, unbroken dielectric layer over the multiple phosphorous inks. The ink would not fill the gaps consistently. To fix this, the press speed was significantly reduced and the dielectric was printed twice, wet on wet, to fill in gaps.

The change in second trace layer design allowed for selective illumination of the globes. Unfortunately, the sheets were not kept free of contamination during the two weeks between the printing at Clemson and the final trace printing at Hallmark. This resulted in some delaminating of the second silver trace from the dielectric boundary. Any spot in the switch where delaminating occurred resulted in no illumination. See *Appendix G* for photos.

CONCLUSIONS

Electroluminescent switch design and printing requires precise control of the printing process, primarily for smooth, consistent ink lay down of appropriate thickness. The energy requirements for the UV curing unit are essential; anything below a 300 watt curing unit is insufficient. A 400 watt or higher unit is required to cure UV silver conductive inks.

The printing environment should be contaminant free, especially of dust, which will ruin the clear conductive layer. It is essential to keep chemical contaminants off of the printed layers; if contamination is found, alcohol can be used to clean the surface.

The required ink thickness was a half to one thousandth of an inch for silver traces, one thousandth for clear conductive, two thousandths for phosphorous, one thousandth for dielectric. No more than two thousandths of an inch was desirable for dielectric thickness. Clear conductive of up to two thousandths thick created an excellent magnetic field, but transparency was lost as ink thickness increased. Insufficient clear conductive resulted in limited illuminated area, see Appendix G. Insufficient dielectric between the phosphorous and the second trace layer resulted in shorting, see *Appendix G*.

The circuit can be constructed in a single or dual layer, see *Appendix F* for details. There are several disadvantages to the dual layer construction. Lamination flaws are instantly visible in the consistency of illumination. The thickness of a dual layer circuit is over twice that of a single layer circuit. Registration of the conductive adhesive and the circuit layers is critical and the adhesive increases the cost of the circuit.

Brightness of illumination is greatly determined by the inverter used to power the circuit. A 480 hertz inverter was sufficient to illuminate the globes, but the 800 hertz inverter was necessary to power the larger, Clemson circuit. When designing a circuit, consideration must be made as to the total square inches of illumination so that the correct inverter can be utilized. An overpowered circuit produces an audible hum and the traces can be burned. An underpowered circuit will produce either insufficient or inconsistent illumination.

Further studies are required to determine the limits of producing halftones with phosphorescent ink. The selective illumination results indicate that it should be possible to create variable displays, such as seven segment displays, with an electroluminescent circuit. It may also be possible to create an animated display by utilizing variable thicknesses of the dielectric layer and selective trace design. When combined with a standard membrane switch printing, it may be possible to create an illuminated, flexible keyboard.

ACKNOWLEDGEMENTS

Our sincere thanks to Gary Stura of Hallmark Nameplate, Inc. for providing the funds for this research, and for providing the materials and press time for our tests. We thank Ricky Lynch of Inverter Designs, Inc. for his help determining the necessary power and inverter requirements. Our special thanks to Mike Kelly of Allied PhotoChemical for his continued advice and support.

Finally, we thank Dr. Liam O'hara and Dr. Sam Ingram of Clemson University's Department of Graphic Communications. Without their advice, encouragement and support, this project could not have happened.

REFERENCES

Billings, Scott. On the Button (2008). *Design Week*, May. Retrieved from http://web.ebscohost.com.proxy.lib.clemson.edu:2048/ehost/pdf?vid=11&hid=102&sid=3bb75ab3-2c11-4836-bd8c-cb2f180ee218%40sessionmgr104.

Allied PhotoChemical Awarded 17th U.S. Patent for UV Technology (2008). *Finishing Today*, April. Retrieved from http://web.ebscohost.com.proxy.lib.clemson.edu:2048/ehost/pdf?vid=11&hid=102&sid=3bb75ab3-2c11-4836-bd8c-cb2f180ee218%40sessionmgr104.

Siden, J., et al. Printed Antennas With Variable Conductive Ink Layer Thickness (2007). *IET Microwaves, Antennas & Propagation*, April. Retrieved from http://web.ebscohost.com.proxy.lib.clemson.edu:2048/ehost/pdf?vid=11&hid=102&sid=3bb75ab3-2c11-4836-bd8c-cb2f180ee218%40sessionmgr104.

Conductive Ink Used on Land's End Backpacks (2006). *Finishing Today*, September. Retrieved from http://web.ebscohost.com.proxy.lib.clemson.edu:2048/ehost/pdf?vid=11&hid=102&sid=3bb75ab3-2c11-4836-bd8c-cb2f180ee218%40sessionmgr104.

Nickel-Kailing. Putting Stuff on Stuff: Ink and Paper at Graph Expo (2006). *WhatTheyThink?*, October. Retrieved from http://members.whattheythink.com/home/ge061020gail.cfm.

Flint Ink Lauches PRECISIA (2003). *WhatTheyThink?*, August. Retrieved from http://members.whattheythink.com/allsearch/article.cfm?id=12602.

Metallic Conductive Inks (2004). *Printed Electronics World*, October. Retrieved from http://printedelectronics.idtechex.com/printedelectronicsworld/articles/metallic_conductive_inks_00000086.asp.

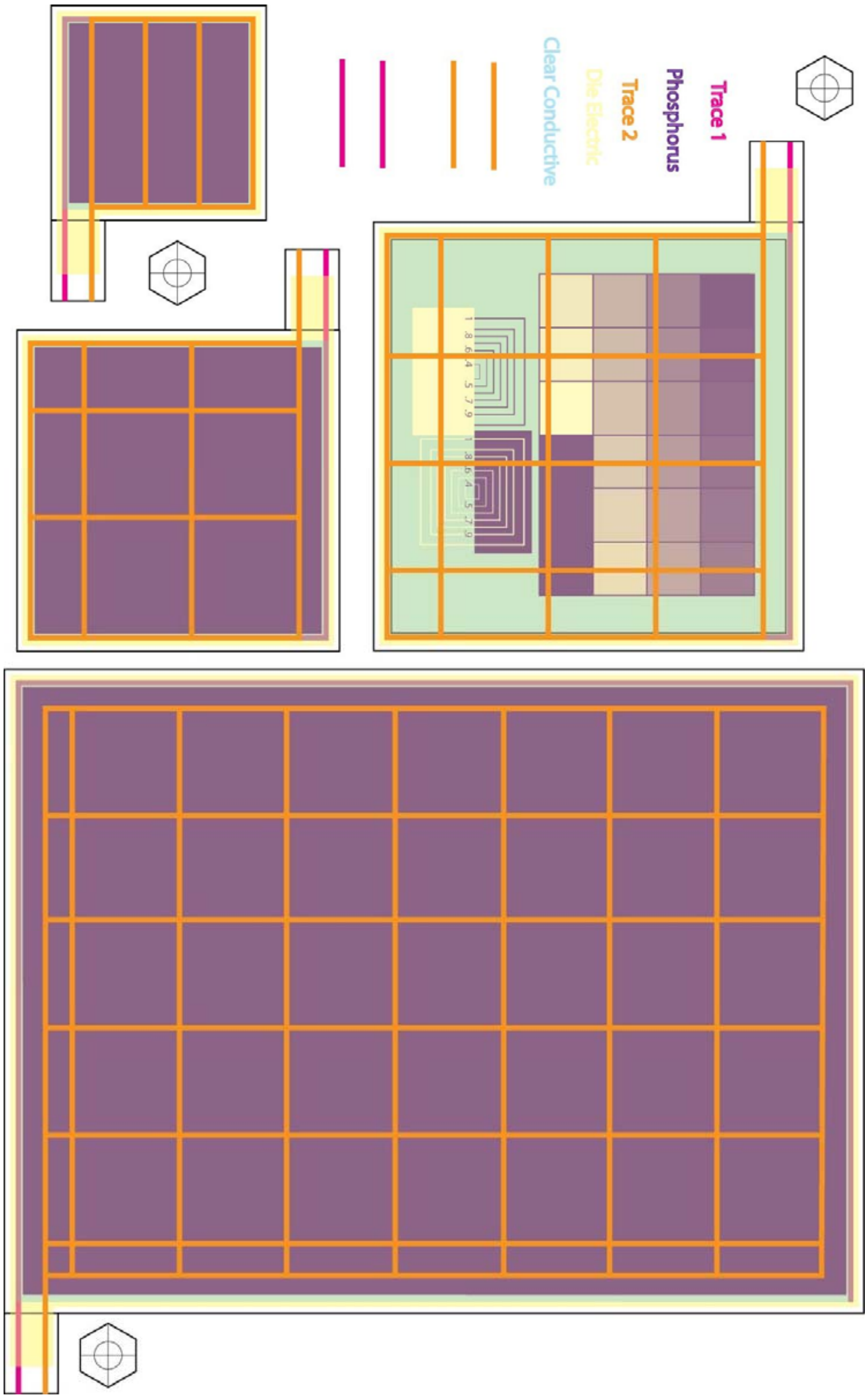
Conductive Inks. *Tekra*. Retrieved from http://www.tekra.com/products/conductive_inks/index.html.

ELG Design Artwork Guide 2. *NorCote*. Provided by Allied PhotoChemical.

E-L Lamp Construction (2008). *Allied PhotoChemical*. Provided by Allied PhotoChemical.

APPENDIX A

Trace Layout 1



APPENDIX B

Conductivity Test Results from first print run

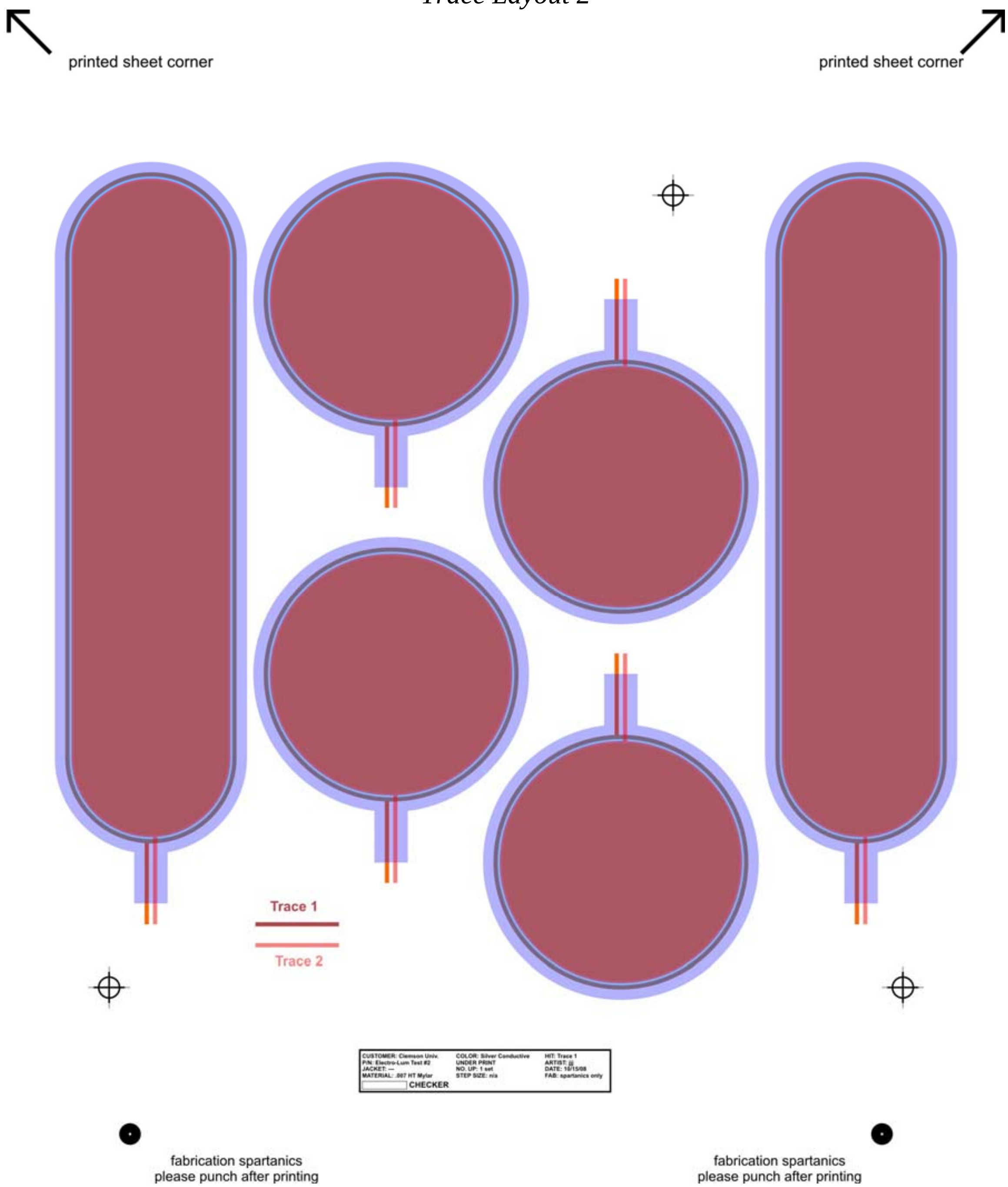
Silver Trace
One inch strip of silver: 5.5 ohms (we wanted <1 ohm)
Silver trace on smallest design: 65 ohms (we wanted <10 ohms)

From sheets with a single hit of clear conductive
Smallest: 450 ohms
Medium: 500 ohms
Next to largest: 600 ohms
Largest: 600 ohms
Using just the prong tips with consistent pressure:
Smallest: 300 ohms
Medium: 500 ohms
Next to largest: 600 ohms
Largest: 600 ohms

From sheets with double hit of clear conductive
Smallest: 300 ohms
Medium: 300 ohms
Next to largest: 250-300 ohms
Largest: 200 ohms
Using just the prong tips with consistent pressure:
Smallest: 330 ohms
Medium: 330 ohms
Next to largest: 340 ohms
Largest: 360 ohms

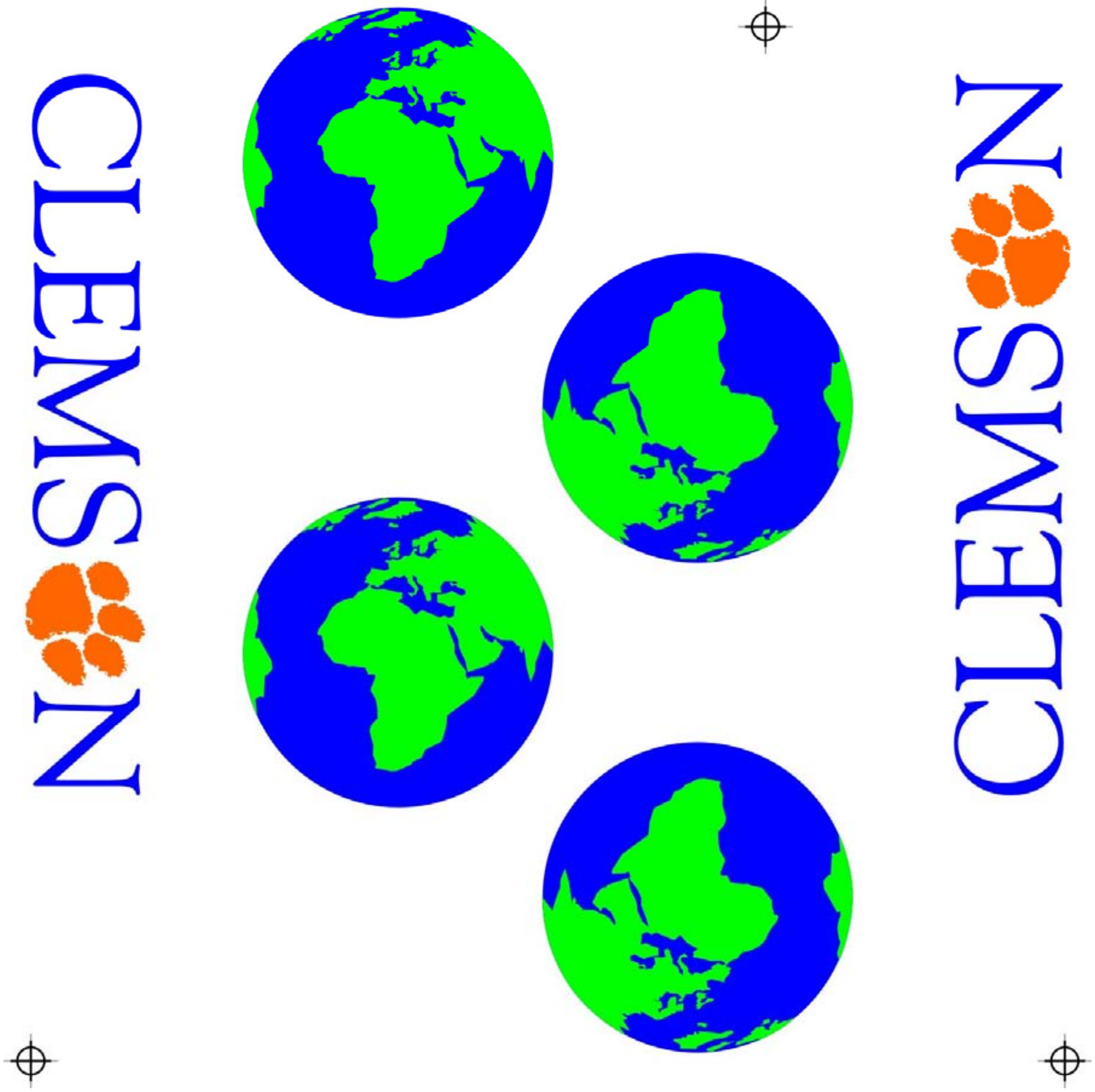
APPENDIX C

Trace Layout 2



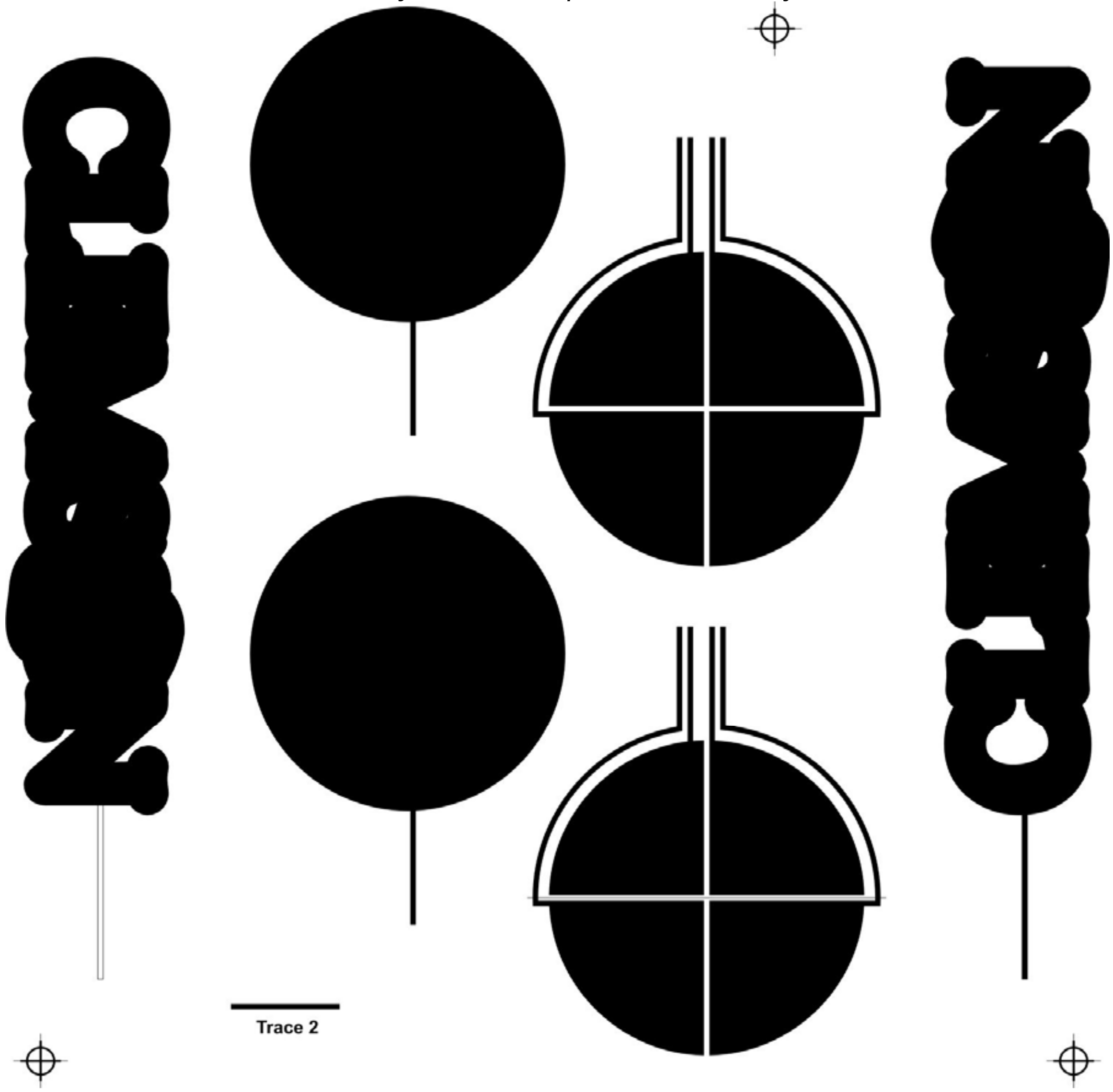
APPENDIX D

Trace Layout 2 - Modified Phosphorescent Layers



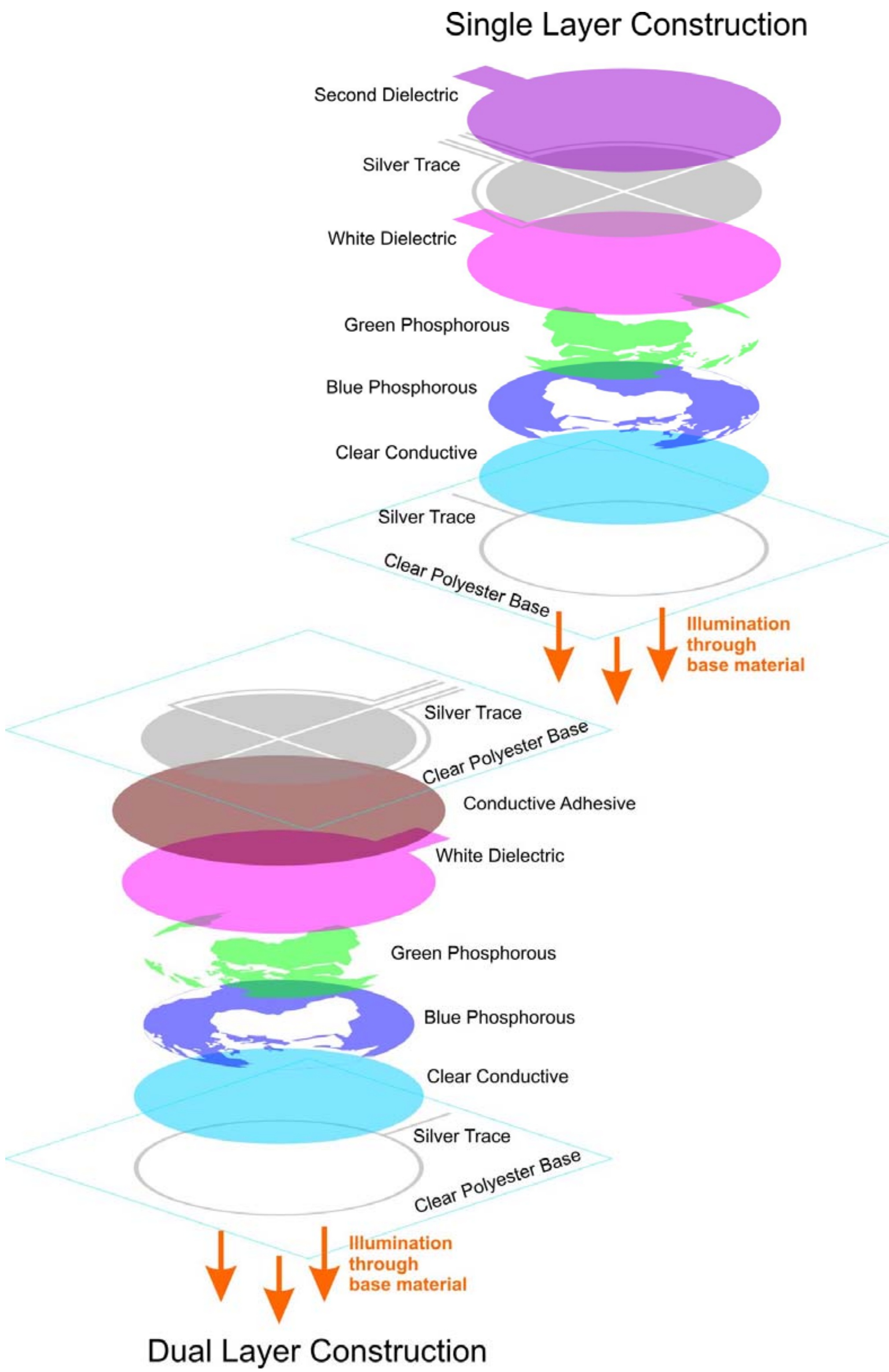
APPENDIX E

Trace Layout 2 - Modified 2nd Silver Layer



APPENDIX F

Electroluminescent Switch Construction Layer Breakout

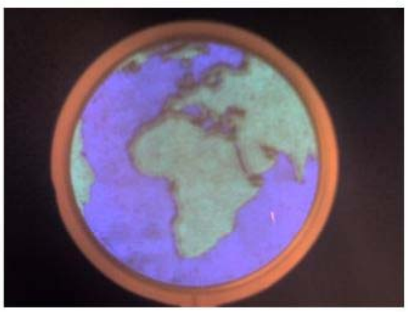


APPENDIX G

Photos of Electroluminescent Switch Printing Results

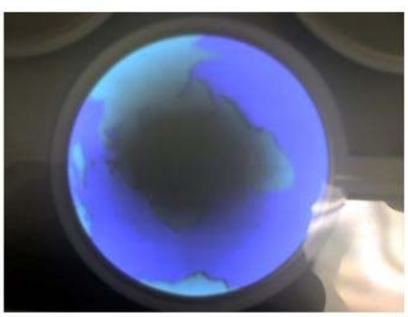
First Print Test
Smallest test pattern
faint glow seen in total darkness.

Second Print Test
Fairly strong glow
visible in dim ambiant light.



Third Print Test
Mottled appearance using
adhesive laminated layers
viewed in full room light.

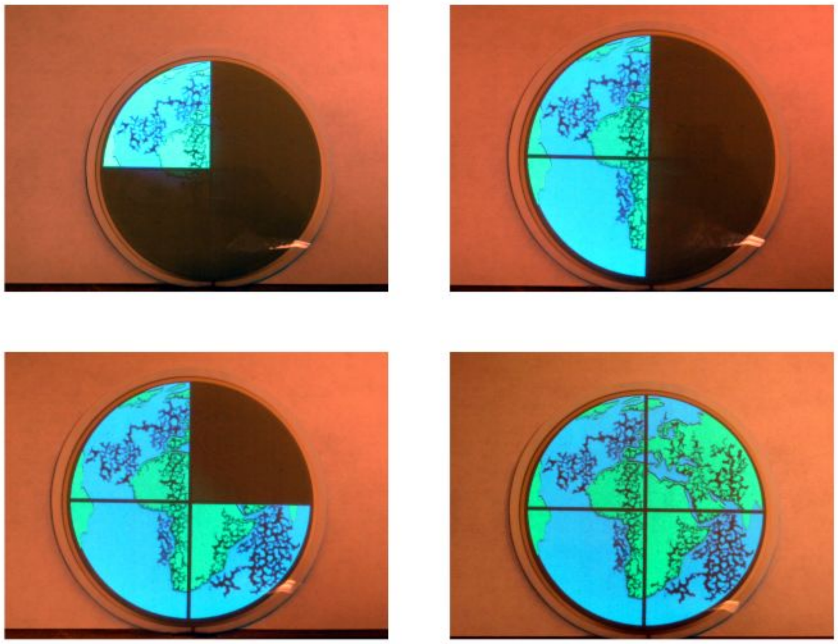
Third Print Test
printed circuit on one layer
viewed in full room light.



Typical Error
not enough clear conductive
to carry the charge

Typical Error
short through the
first dielectric layer

Segmented Display



Typical Error
the crackled black areas are where the ink delaminated
resulting in no illumination.