ALL PAPER MEMBRANE SWITCH

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ABSTRACT

Printing of electronic circuitry on paper is a frontier being explored by many in the printing industry. The study was conducted to determine if conductive circuitry could be printed on paper with equivalent functional characteristics as traditional circuits printed on plastic substrates.

This four week study utilized both UV and conventional solvent based screen printing inks. Ink thicknesses were varied to determine the effect upon the circuit. Paper samples were pretreated with UV dielectric ink to determine if there was any difference between circuits printed on pretreated and untreated substrates.

Pretreatment with UV dielectric ink proved beneficial on uncoated paper stocks, but detrimental on coated paper stocks. Many untreated, coated paper stocks yielded circuits with equivalent or superior conductivity to circuits printed on polyester.

The final, assembled circuits functioned as membrane switches. Future tests need to be done utilizing other pretreatments and curing parameters to determine the ideal combination of printed layers and materials to produce cost effective and dependable circuits on paper.

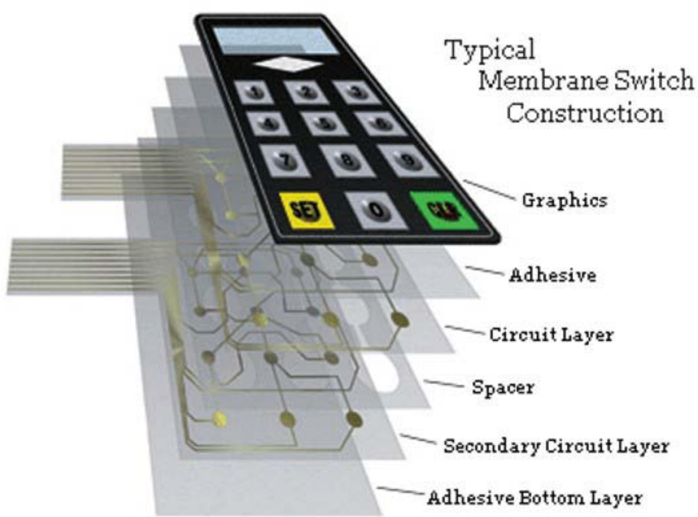
INTRODUCTION

One of the limitations of making functional packaging is that printed electronics are most commonly created using a plastic substrate, generally Heat Treated Polyethylene Terephthalate (HTPET). Relying upon printed electronics that must then be laminated or attached to packages makes them cumbersome and expensive to manufacture (ex.: Esquire Magazine's attempt to have a Printed Electronic cover). It would be more economical and advantageous to print conductive circuits directly on paper to create functional packaging. This is already being done to a limited extent with RFID printing on ticket stubs (DuPont, 2008) and there have been attempts to make everything from printed batteries to speakers out of conductive papers (Svensson, 2003).

The purpose of this research was to produce a conductive circuit on paper, utilizing dielectric coatings and conductive inks, with the same functional properties as a circuit produced on a HTPET substrate. By "functional" we meant similar conductivity and ability to produce an operational switch. We made no assumptions that a paper membrane switch would have had the same chemical, handling or abrasion resistance as a HTPET membrane switch. *Figure 1* illustrates the Anatomy of a Membrane Switch.

Figure 1

Anatomy of a Membrane Switch



Original image by American Graphics Enterprises (AGE)

Original image by TTKlavasnice

A membrane switch functions by having an open circuit design that is closed when the surface of the membrane switch is depressed with sufficient force.

We hypothesized that circuits printed on a dielectric pretreated paper will provide superior conductivity than circuits printed on untreated paper. The test circuit printed upon HTPET provided the benchmark to determine functionality of the paper circuits.

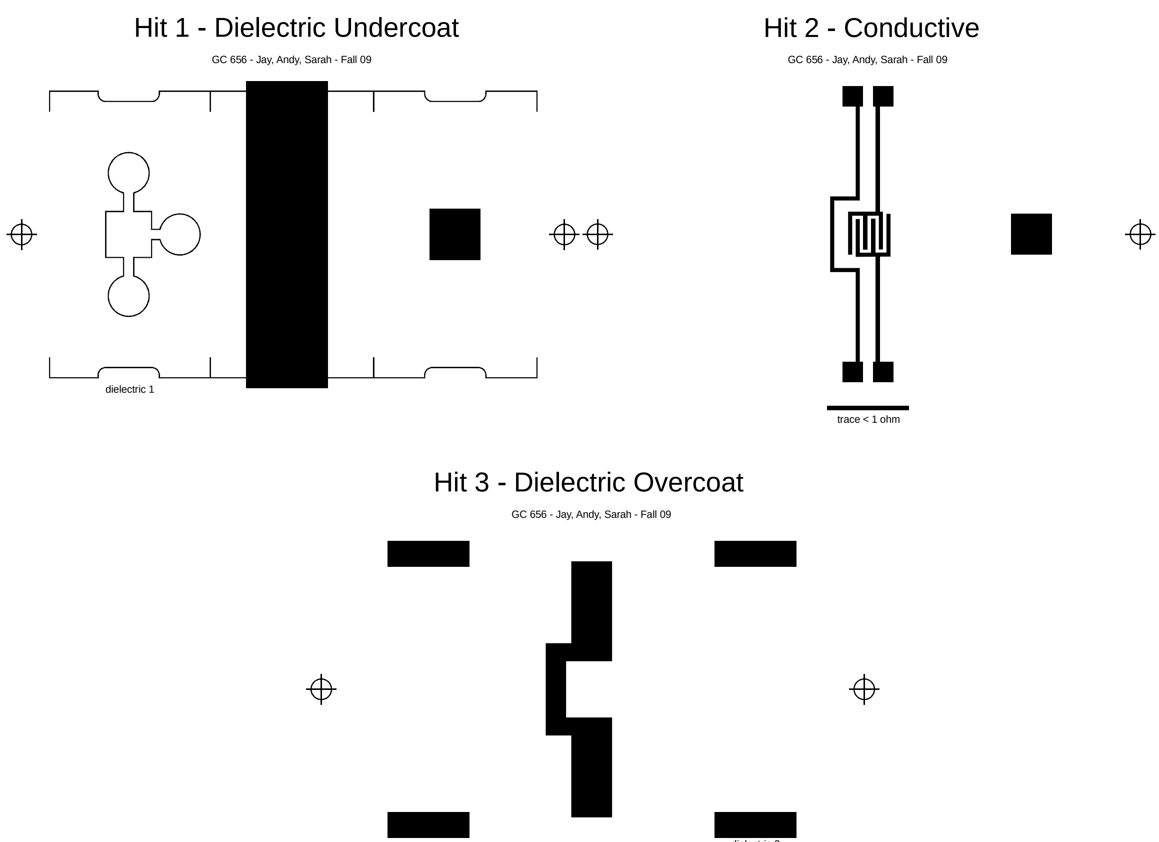
METHODS AND MATERIALS

Screen Preparation

Four 19"x25" Newman Roller frames were stretched, two with 305 mesh and two with 195 mesh, to a tension of twenty-two newtons. The stretched screens were allowed to stabilize over seventy-two hours and were then tensioned again to between twenty and twenty-two newtons. The screens were then washed, degreased, and dried.

Films for three hits were designed in CorelDraw X4 and output on an Agfa Selectset Avantra25. Alignment and trap of films were verified on light tables prior to imaging on screens. *Figure 2* shows the circuit design.

Figure 2
Circuit Design



Four and Six total coats of Kiwocol Polyplus S emulsion were applied to the screens; two coats to well and two coats to face were applied, and once the screens were dried, two more coats to face were applied to the 190 mesh screens. Once dried, the films were applied emulsion to emulsion on the face of the screens. The screens were exposed on a Richmond Screenmaker for 160 units and then washed out. Once dry, the screens were blocked out with ICC Chemical 763 Aqua-block and dried a final time. The second 190 mesh screen was created strictly as a spare were the first screen to fail; it was not used.

Material Preparation

Sheets of .005" thick HTPET were cut to 8.5"x11" to be used to benchmark the paper samples against a polymer substrate. Seven paper types were selected from inventory. The papers were cut down to 8.5"x11" sheets in sufficient quantity to yield at least thirty sheets of each type. The sheets were then marked with a sample number. The paper was run through a Hopkins International Conveyor Oven at 360°F for twenty seconds to heat stabilize the material before printing. The materials used were:

.005" HTPET (Bayer)
Hammermill 119MWT Uncoated Grey Offset (sample 1)
Mohawk 80lb Coated Soft White Text (sample 2)
Kromekote Castcoat (sample 3)
Sappi 366MWT Flowgloss Cover (sample 4)
Xpedx 272MWT Carolina 94-Brite Gloss (sample 5)
Royal Fiber 70lb Uncoated Goldenrod Text (sample 6)
Grandee 80LB Uncoated Charcoal Grey Cover (sample 7)

Material samples were chosen to provide a wide range of substrate thicknesses and surface textures. *Figure 3* provides material sample appearance. *Figure 4* provides surface analysis results of each sample material using an Emveco tester.

Figure 3

Sample Substrates

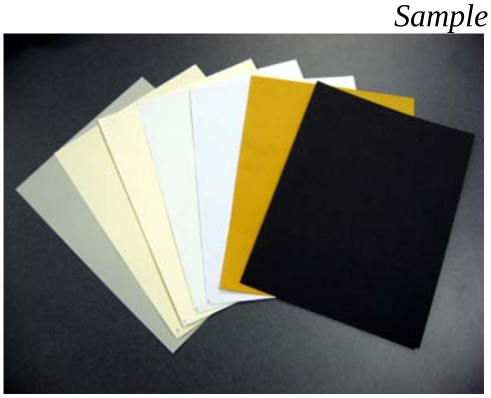
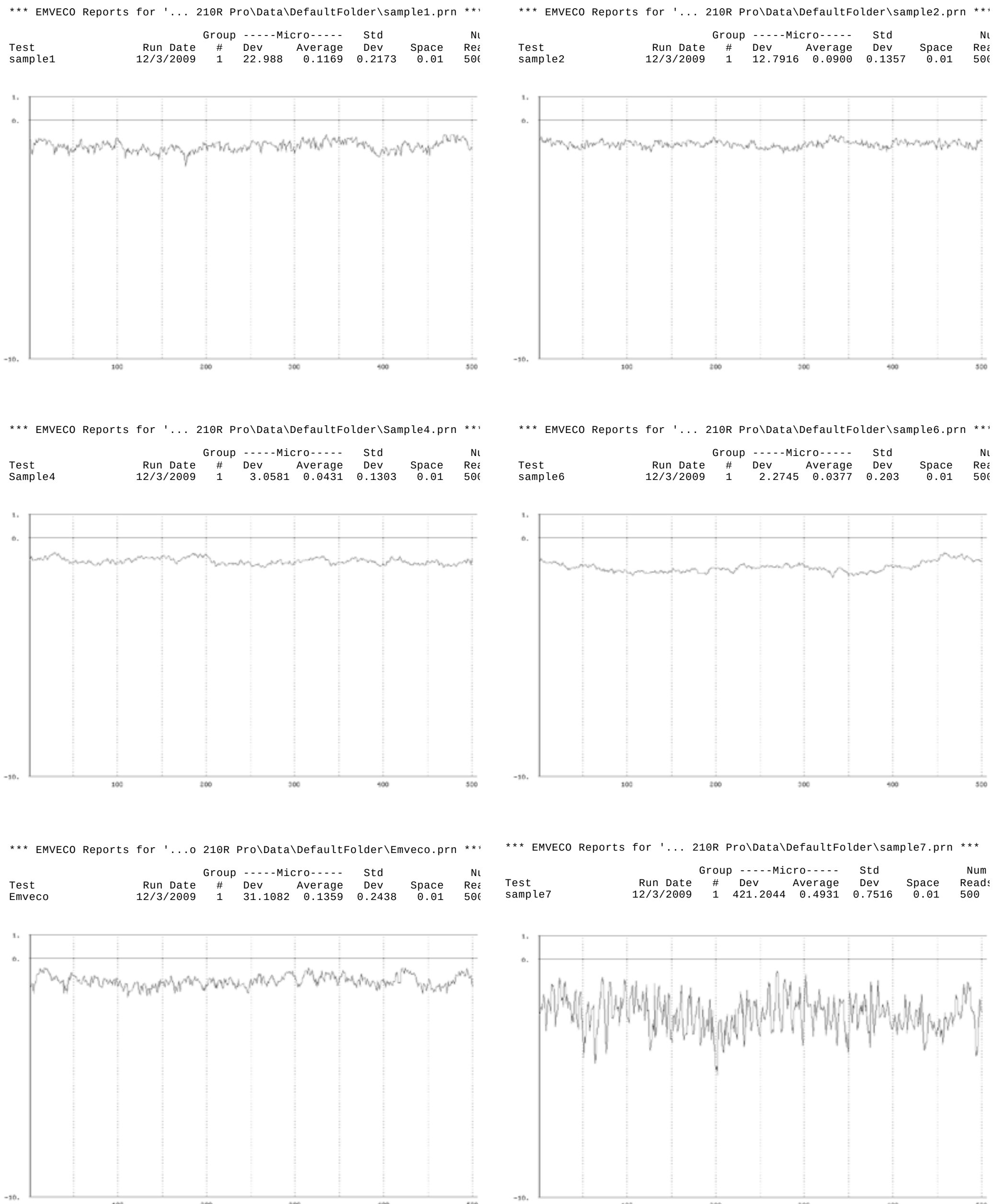


Figure 4

Emveco Graphs



First Printing

The material samples were separated into two sets; a pretreatment set and an untreated set. The first set was pretreated by printing UV dielectric (Allied Photo Chemical TGH1705 CL +.05% jcb-11b-kb Orange) using a 305 mesh count screen imaged with Hit 1 (see Figure 2) on a SIAS Clamshell Press and cured on the American UV 300watt drier at a speed of 300fpm, with an exposure of 460mJoules UVA. The energy of the cure was measured using a DDU UVA Puck. The second set was left untreated. See *Appendix C* for print metrics.

All the substrates, including the pretreated first set, the untreated second set, and the .005" HTPET were printed using Screen 2 on a SIAS Clamshell Press with Acheson Electrodag 725A(6S-54) silver conductive ink. The substrates were printed and then flash cured in the Hopkins International Conveyor Oven at 360F for 20 seconds in sets of eighteen. Five of each substrate were marked and printed with a second layer of silver conductive ink and flash cured a second time. See *Appendix C* for print metrics.

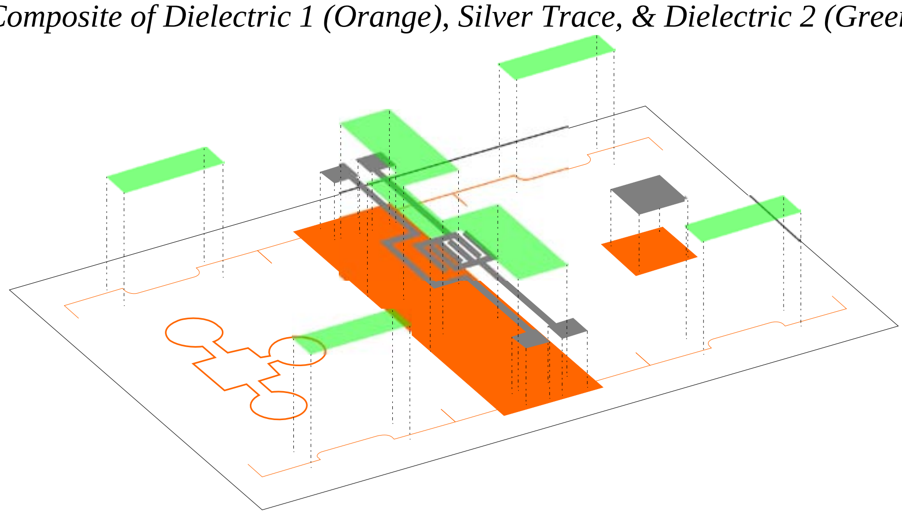
All printed materials were cured in sets of twelve in a conventional oven at 200°F for fifteen minutes.

Second Printing

All material samples were printed using the Screen 3 on a SIAS Clamshell Press with a coating of UV dielectric (Allied Photo Chemical TGH1705 CL +.05% jcb-11b-kb Orange) and cured on the American UV 300watt drier at a speed of 300fpm, with an exposure of 460mJoules UVA. See *Appendix C* for print metrics. Figure 5 illustrates the composited printing layers of the circuit.

Figure 5

Composite of Dielectric 1 (Orange), Silver Trace, & Dielectric 2 (Green)



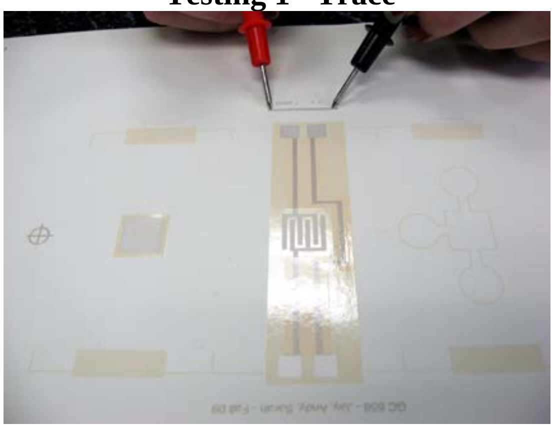
Testing

All printed samples were tested for conductivity. This test involved three conductivity measurements; measurement of a standard .050" wide, 1" long test target, measurement of the long trace of the circuit, and measurement of the closed switch of the circuit. A Craftsman Digital Multimeter 82141 was used to measure the ohms of all three targets. *Figure 6* illustrates the conductivity tests for the traces and closed circuit.

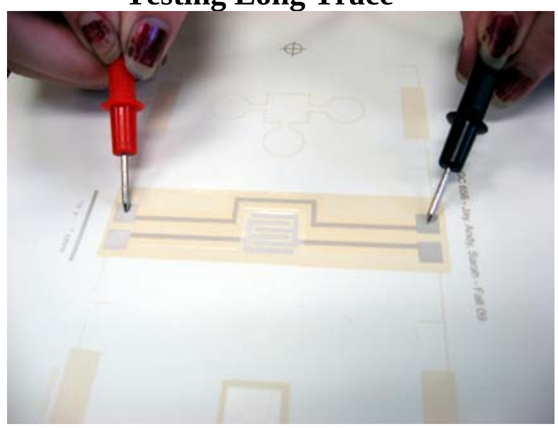
Figure 6

Testing Photos

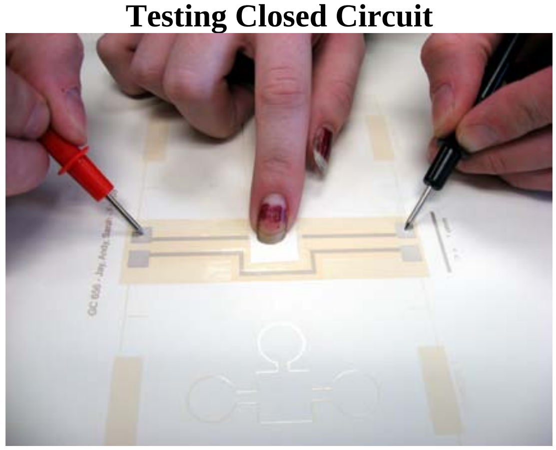
Testing 1" Trace



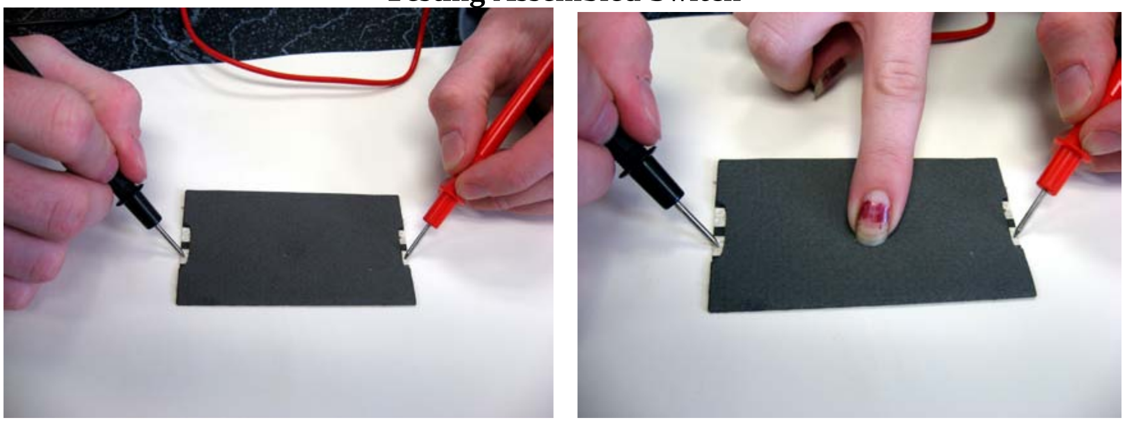
Testing Long Trace



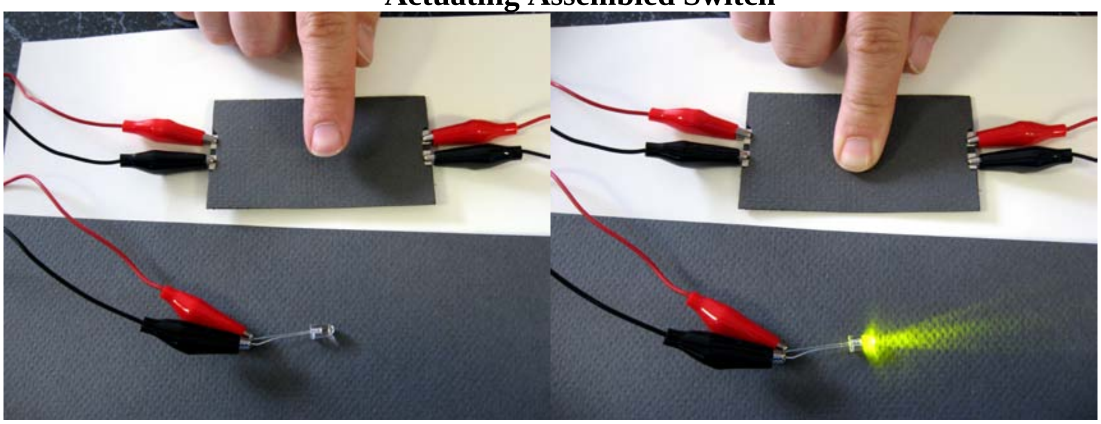
Testing Closed Circuit



Testing Assembled Switch



Actuating Assembled Switch



The paper substrates were tested for smoothness on an Emveco 210R Electronic Microgage using a .001" radius stylus. See *Figure 4* for graphs.

Switch Assembly

The printed samples were cut, folded and assembled into functioning membrane switches. Actuation force was determined by depressing the switch with an index finger in order to close the circuit. After numerous depressions, a relative actuation force was assigned to each switch construction. The heavier weight papers created switches that required more force to actuate, and the light weight papers required minimal force to actuate. When properly assembled, even the lightest weight papers yielded functional switches that remained open when no force was applied to them, even after over 100 actuations. *Figure 7* illustrates the assembly process of the membrane switch, and *Figure 8* shows an example of an assembled switch out of each paper substrate.

Figure 7

Assembly of Membrane

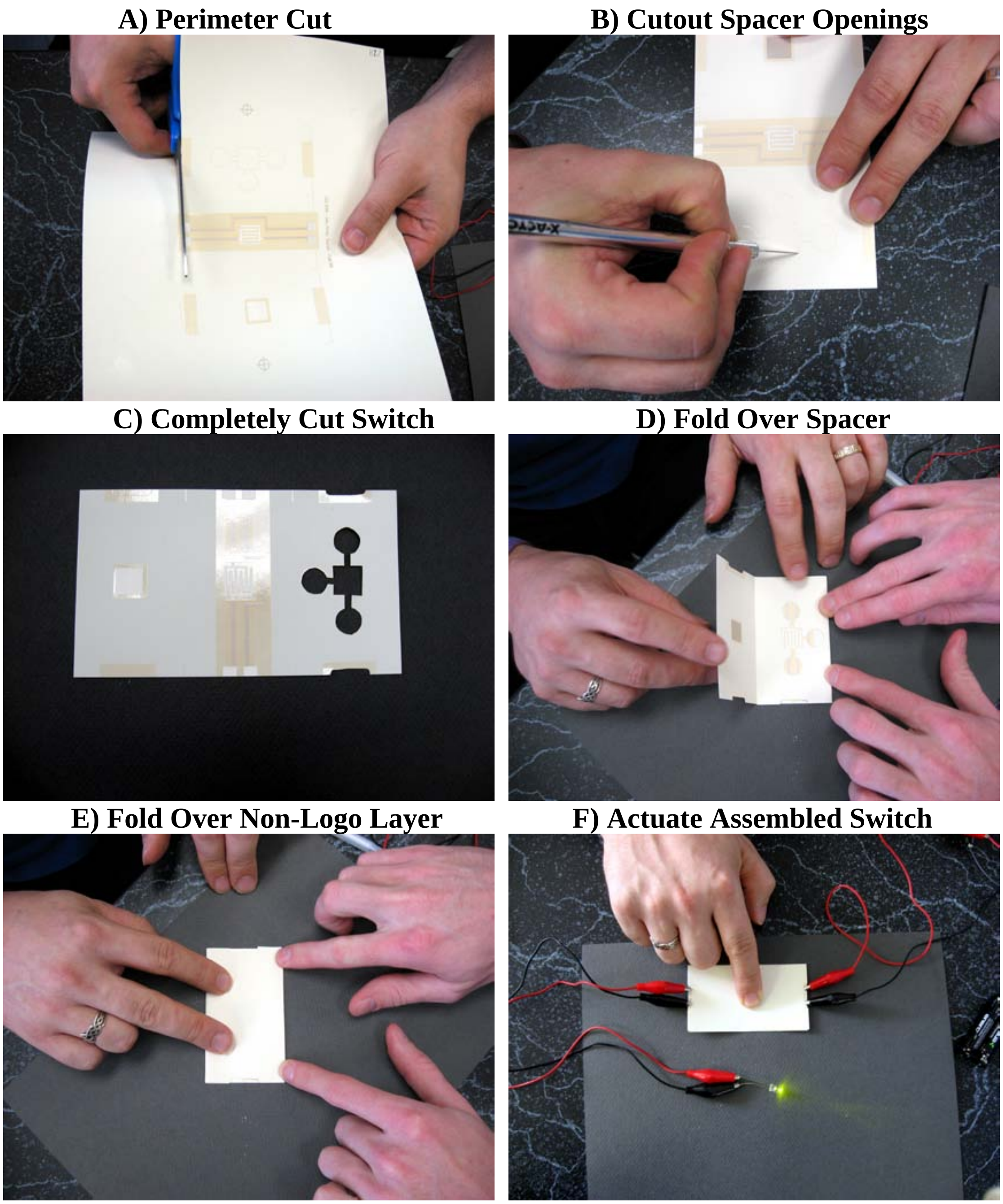


Figure 8

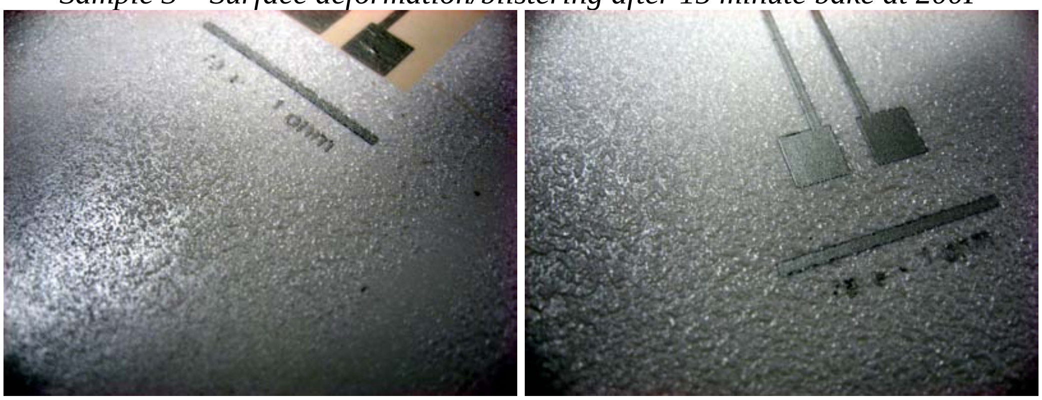
Constructed Membranes

RESULTS AND DISCUSSION

During the fifteen minute, 200°F oven cure cycle, sample 3 failed. Specifically, the surface of the Kromekote Castcoat bubbled up in all locations where there was no printing. Because the material could not withstand the minimum curing cycle for the silver conductive ink, it was eliminated from further processing and testing steps. *Figure 9* shows the blistering of the substrate surface.

Figure 9

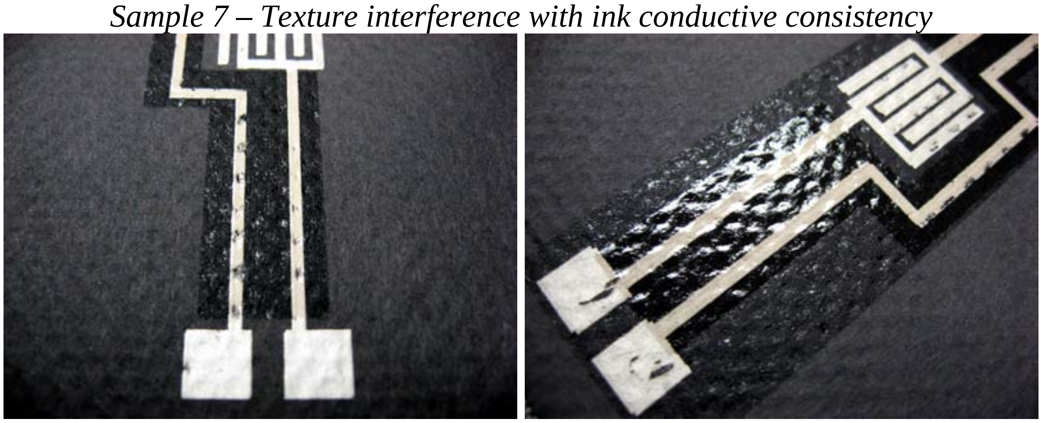
Sample 3 – Surface deformation/blistering after 15 minute bake at 200F



Printing of a solid trace on sample 7, Grandee 80LB Uncoated Charcoal Grey Cover, proved inconsistent. No amount of press speed or pressure adjustments would eliminate the problem. Double hits of the conductive ink proved no more successful in creating a smooth, continuous trace. Printing a pre-coat of UV dielectric did not change the failure rate. Over fifty percent of the single hit traces and thirty percent of the double hit traces failed due to breaks or thin spots in the traces caused by the heavy texture of the paper surface. *Figure 10* shows the inconsistent traces.

Figure 10

Sample 7 – Texture interference with ink conductive consistency



The single hit traces printed on uncoated paper, without a pre-treat of dielectric, resulted in resistances significantly higher than the HTPET standard. Applying a second hit of silver on the traces on uncoated paper resulted in resistances between the single and double hit traces on HTPET. Pre-treating the uncoated paper samples with dielectric resulted in a significant drop in resistance in the final trace. The single hit silver trace printed on the dielectric treated uncoated paper measured thirty percent greater than the resistance of the HTPET standard, and the double hits measured within twenty percent. *Figure 11* provides averaged conductivity results.

Figure 11

Conductivity Test Results

Substrate	# Hits Silver	Dielectric Pre-coat	1" trace Ohms	Long Trace Ohms	Circuit Ohms
Mylar	1	N	1.25	3.32	2.46
	2	N	0.70	1.70	1.35
Sample 1	1	N	2.23	10.08	6.98
UC	1	Y	1.60	4.36	3.38
	2	N	0.80	2.53	1.98
	2	Y	0.70	2.28	1.73
Sample 2	1	N	1.09	3.26	2.49
C	1	Y	1.11	4.96	3.79
	2	N	0.60	1.63	1.23
	2	Y	0.63	2.05	1.60
Sample 4	1	N	1.17	3.07	2.37
C	1	Y	1.09	3.86	2.94
	2	N	0.67	1.60	1.27
	2	Y	0.68	1.93	1.50
Sample 5	1	N	1.21	3.23	2.46
C	1	Y	1.17	4.36	3.29
	2	N	0.68	1.55	1.23
	2	Y	0.67	1.97	1.53
Sample 6	1	N	1.47	5.72	4.05
UC	1	Y	1.38	3.98	3.04
	2	N	0.90	2.55	1.95
	2	Y	0.80	2.30	1.80
Sample 7	1	N	1.98	5.78	4.13
UC	1	Y	1.90	4.53	3.30
	2	N	0.90	2.42	2.07
	2	Y	0.86	2.50	1.67

Both the single and double hit traces printed on coated paper resulted in lower resistance traces than the HTPET standards. However, pre-treating the coated paper resulted in trace resistances of as much as thirty percent higher than the HTPET standard on single hits, and fifteen percent higher resistance than the HTPET standard on double hits.

The assembled paper circuits functioned as anticipated. As with assembling conventional membrane switches, care had to be used to laminate the layers accurately and to prevent collapsing the circuit layers during assembly. It was essential that the layers were laminated smoothly and that the air gap between the upper and lower circuits was maintained – loss of the air pillow resulted in shorted circuits.

CONCLUSIONS

Printing of circuitry on paper, and specifically in the regard to the production of all paper membrane switches, is possible. The smoother, coated papers yielded functionally superior circuits with the least processing. One challenge for printing circuits on paper is the curing requirements of the conductive ink, which limits the production speeds or requires extremely long curing tunnels.

Selectively treating uncoated papers with UV dielectric prior to printing of the circuit allows for the use of less expensive papers, or even perhaps printing circuits upon corrugated boards. This, however, is still problematic if the surface is too uneven or rough.

Curiously, the data suggests that curing of the solvent based conductive ink was more complete on untreated, coated stocks. This seems to indicate that the solvents could evacuate through the surface of the ink and through the porous paper stocks, and the UV treatment functioned as a barrier to solvent evacuation through the paper. This feature may be useful to rapid cure silver conductive ink on papers, as untreated paper would allow a faster cure than treated.

Future experiments should include testing different coatings on papers to determine the ideal balance between smoothness and rapid ink cure. It would also be useful to test other selective coating options other than UV dielectric to treat the uncoated paper stocks to see if there would be a benefit to printing that did not slow the cure.

Although an all paper membrane switch is not currently a practical product, circuitry printed on paper and board substrates is a key step in producing functional packaging. Paper circuitry cannot at this point replace conventional circuits for most electronic devices, but may provide significant cost reductions on electronically enhanced point of purchase displays, interactive and functional packaging, and much more.

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APPENDIX A

Materials

Chemicals

Acheson Electrodag 725A(6S-54) silver conductive ink
Allied Photo Chemical TGH1705 CL +.05% jcb-11b-kb Orange
Kiwocol Polyplus S Liquid Emulsion
ICC Chemical 763 Aqua-block
3M Super77 Multipurpose Spray Adhesive

Supplies

Sefar 305-34 Y PW mesh
Sefar 195-55 Y PW mesh
AA & AAA Batteries
LED/Lightbulbs (Radioshack)
Alligator clips and wiring (Radioshack)
Battery housings (Radioshack)

APPENDIX B

Equipment & Software

Equipment

SIAS Clamshell Screen Printing Press
American UV 300 watt curing unit with H-bulb
Newman Roller Frames
Pro Motocar Products Electronic Thickness Gauge
Craftsman Digital Multimeter 82141
DDU UVA Puck
Conventional Oven
Hopkins International Conveyor Oven
Laser Thermometer
Richmond Screenmaker
Emveco 210R Electronic Microgage
Dell XPS Studio 16
Macbook Pro
Agfa Selectset Avantra25

Software

Microsoft Excel
CorelDrawX4
Illustrator CS4
Microsoft Word

APPENDIX C

Screen, Press and Curing Metrics

American UV 300 Watt w/HBulb
Belt Speed 30fpm
UVA mJoules/cm2 460
UVA mWatts/cm2 1090

Hopkins International Conveyor Oven
330-360F for 20 sec

Screen 1 – UV Dielectric
305 Mesh
1.8mil mesh
1 mil emulsion – Polyplus S
APC TGH1705 CL +.05% jcb-11b-kb Orange
.3-5 mils thick

Screen 2 – Silver Conductive
195 Mesh
3mil mesh
1.3 mil emulsion – Polyplus S
.4-7 mils thick

Screen 3 – UV Dielectric
305 Mesh
1.8mil mesh
1 mil emulsion – Polyplus S
APC TGH1705 CL +.05% jcb-11b-kb Orange
.3-5 mils thick