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POLYMER THICK FILM CONDUCTORS AND DIELECTRICS FOR MEMBRANE SWITCHES AND FLEXIBLE CIRCUITRY

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DESCRIPTION OF THE MEMBRANE SWITCH

The membrane switch functions as a normally open, momentary contact, low-voltage pressure-sensitive device. Its design is a three-layer sandwich usually constructed of polyester film. Conductive patterns are deposited onto the inner side of top and bottom sheets by silk screening. The center spacer is then placed between the two circuit layers to form a sandwich, generally held together by an adhesive. When pressure is applied to the top layer, it flexes through the punched openings of the spacer to establish electrical contact between conductive pads of the upper and lower sheets, momentarily closing the circuit. Upon release of force the top sheet springs back to its normal open position.

The membrane touch switch is being used in a rapidly expanding range of applications, including instrumentation, appliances, electronic games and keyboards. Its broad acceptance results from its low cost, durability, ease of manufacture, cosmetic appeal and design flexibility.

The principal electronic components in the membrane switch are the conductor and dielectric.

CONDUCTIVE INKS

Polymeric conductive inks typically consist of three basic components: conductive metal powder, polymer and solvent. Silver is the predominant metal used It has the advantages of moderate cost and long-term conductive stability.

The polymer performs three key functions. It binds the conductor to the substrate, provides cohesion of the silver particles and protects the conductor from external chemical and enviornmental effects.

The role of the solvent in the conductive ink is to dissolve the polymer, control viscosity and wet the polyester surface. The screened ink is generally dried in a hot forced-air oven to remove solvent and bond the polymer to the substrate. Ideally, the solvent must evaporate rapidly from the printed circuit, yet at the same time also must have a limited rate of evaporation on the screen at ambient temperature to minimize viscosity change and screen clogging.

Processing has a pronounced effect on the performance of conductive inks. The processing of a conductor composition can be separated into two broad operations: screen printing and drying. Key parameters that affect printing are ink rheology, squeegee rate and pressure, surface tension, screen materials and residence time on screen.

Rheology is the principal property affecting the printability of polymeric thick films.

Another major consideration is the selection of appropriate screening materials. Various types of screen cloths, mesh sizes, screen emulsions, and squeegees are available. Mesh size governs the coverage area attainable by an ink, and that determines cost. Correlations have been developed that compare the coverage of conductive inks to sheet resistivity.

Air-dried silver inks are governed by a time/temperature relationship. The improvements in conductivity and flexibility that occur with increased temperature are attributable only in part to more efficient solvent removal. To a greater extent, the source of the improvements can be traced to stronger bond formation between polymer and film.

The property specifications and test methods used to evaluate initial and aged performance of polymeric thick films vary with manufacturers and specific applications. Some of the more important conductive ink properties tested for are: resistivity, adhesion, abrasion resistance, flexibility and use temperature.

Retention of these properties after long-term exposure to environmental contaminants and changes is critical to a reliable membrane switch. The impact of temperature/humidity cycling, thermal shock and vibration, moisture, sulfur and salt impurities on aged performance must be minimized under various industry conditions.

Du Pont's new generation of polymer thick film silver conductors, 5005 and 5007, were developed to meet the industry specifications.

Many membrane touch switch products do not require the low resistance supplied by all silver-based conductive inks. To cut costs, manufacturers use products containing less silver. A recent entry into this market is Du Pont 5006, a non-conductive aluminum-based polymeric ink. It was developed specifically to be blended with either Du Pont 5005 or 5007 silvers to give a variable resistance system. The blended product exhibits uniform printability and excellent electrical and physical properties. The operable conductivity range is 15 to 250 mΩ/sq/mil.

DIELECTRICS

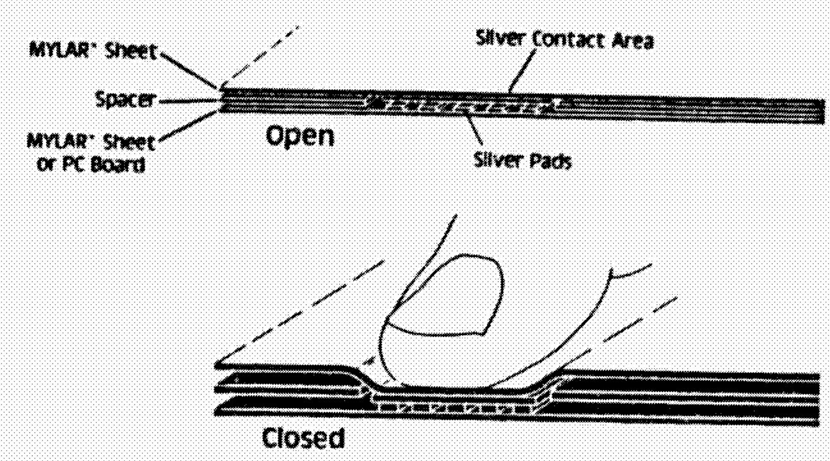
Current needs for dielectrics in touch switches are to insulate the switch tail from the environment and for construction of crossovers. The dielectric compositions must meet certain performance standards. They must cure to flexible, abrasion-resistant films, with good adhesion to both the substrate and to the conductive inks. They must be free of pinholes, have a low dielectric constant, high insulation resistance and high breakdown voltage.

Several different approaches can be used to process a polymeric dielectric which include air-dry, heat-cure and UV cure. UV cure systems offer several advantages - very rapid cure at near ambient temperature, no solvent emissions and excellent electrical properties.

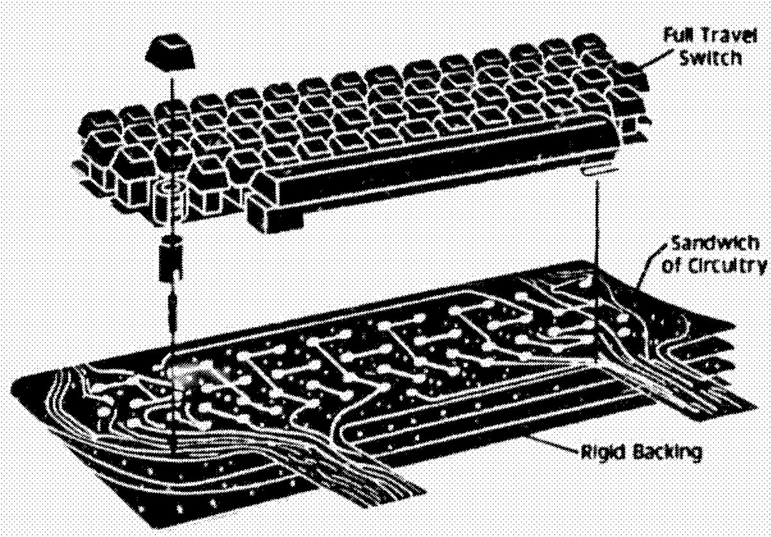
UV curing is the process by which a liquid changes to a solid under the action of UV light. To accomplish this, photoinitiators are used. These become activated by absorption of the UV energy, and in turn, initiate the photopolymerization of the monomer and oligomer, the main constituents of the UV curable formulation. The monomers and oligomers are selected so that the cured polymer has the desired physical and electrical properties.

As with conductors, optimum physical and electrical properties only will be obtained if the dielectric is processed correctly. UV light output and exposure time are the principal variables which govern curing efficiency. Du Pont's 5011, a recently developed UV curable dielectric meets the membrane switch industry property requirements if properly cured.

Typical Membrane Touch Switch Configuration



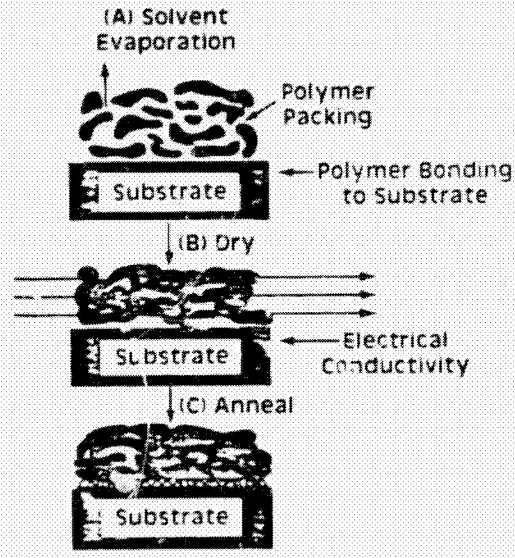
Membrane Switch With Optional Keyboard



Key Components of Polymer Thick-Film Conductive Inks

- **Metal Powder**
- **Polymer**
- **Solvent**

Air-Dry Process of Screen-Printed Polymer Silver Ink



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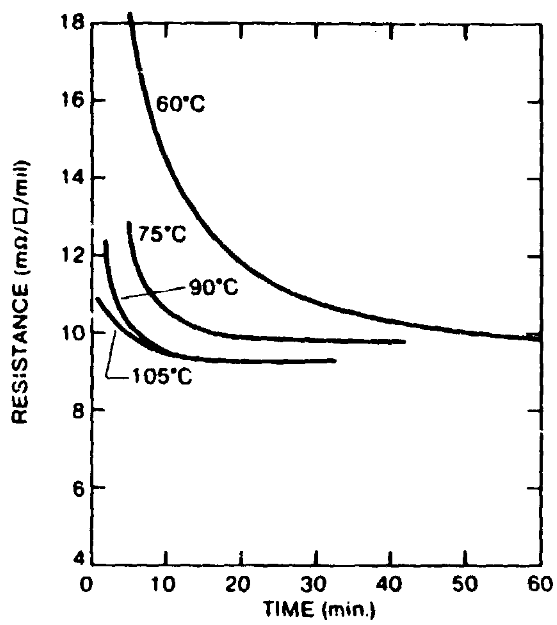
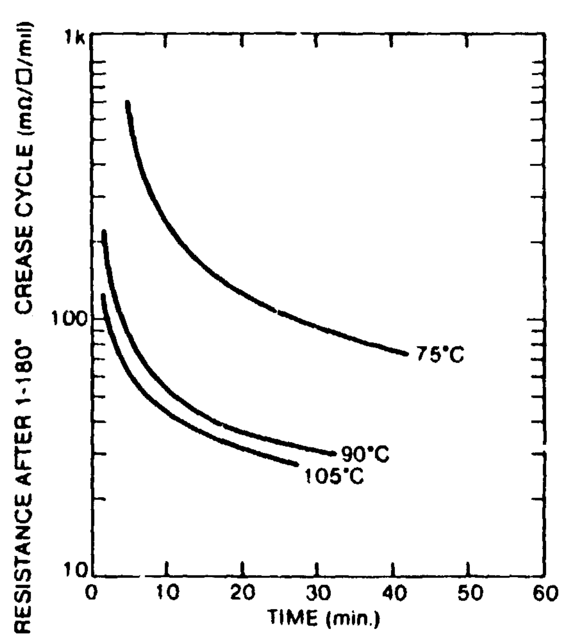
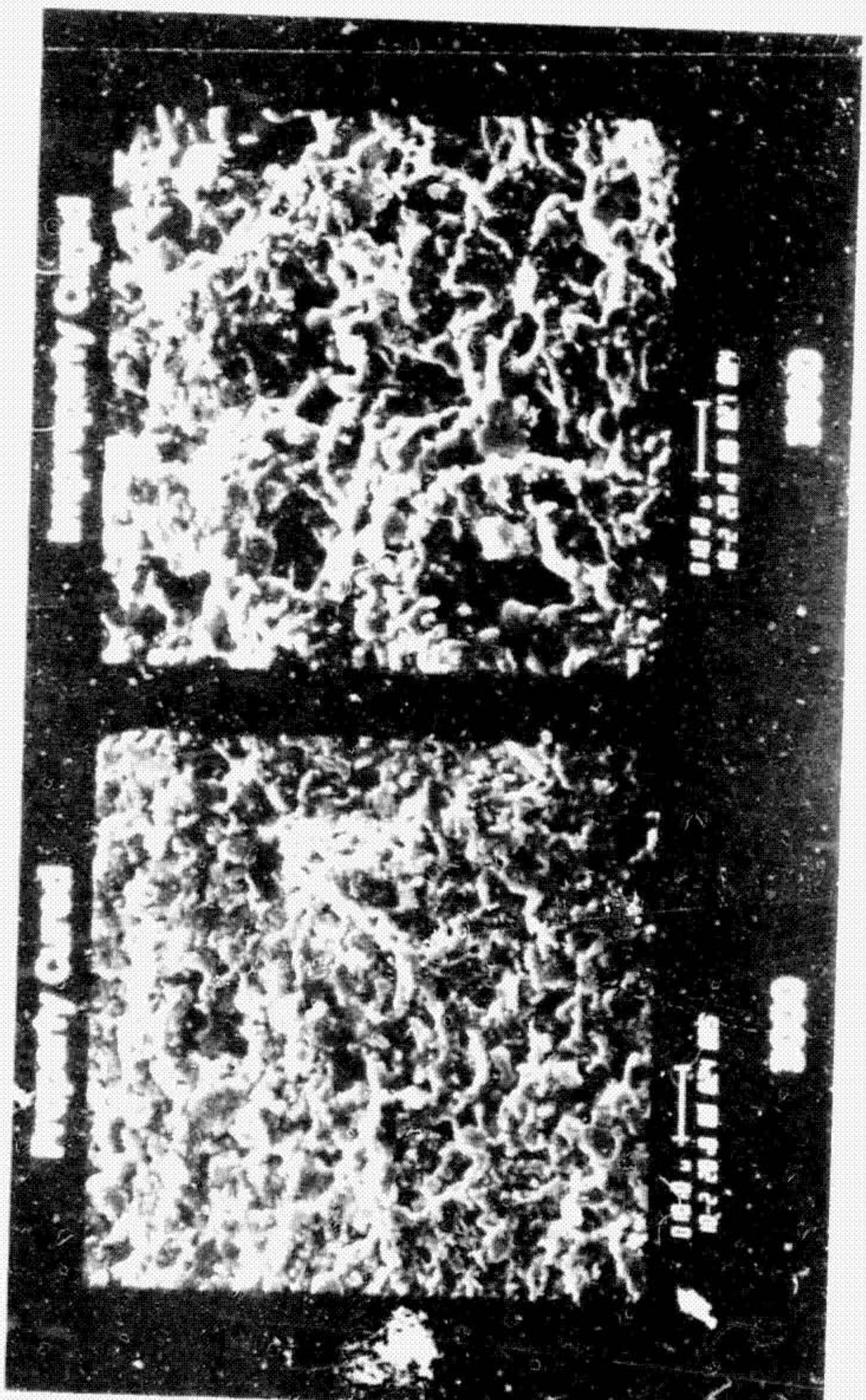
5005 Silver Resistivity vs Drying Conditions



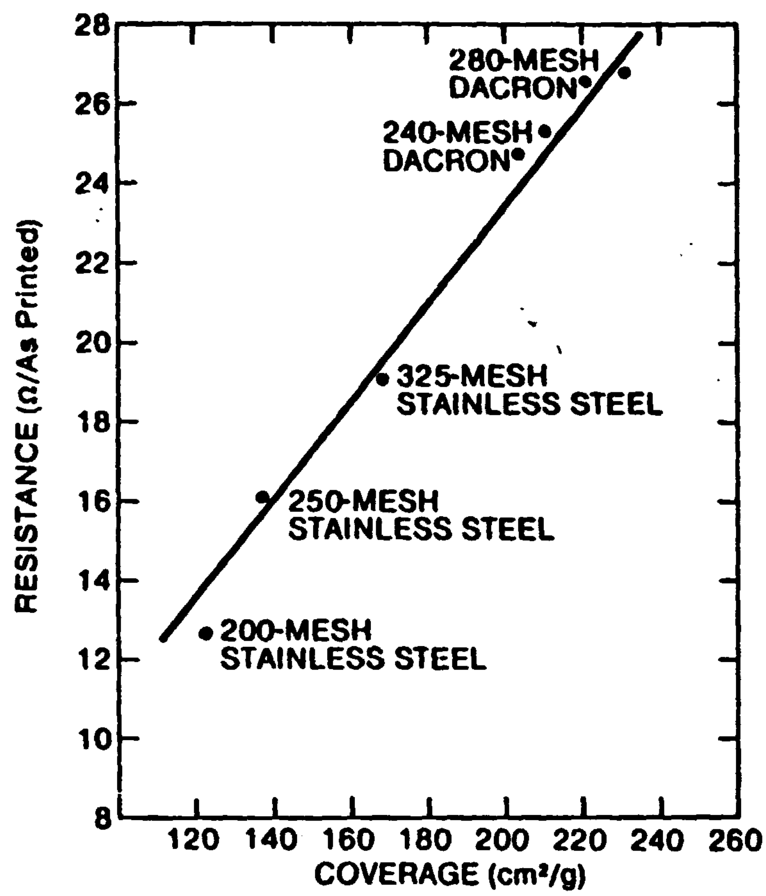
5005 Silver Conductor Crease Resistivity vs Drying Conditions



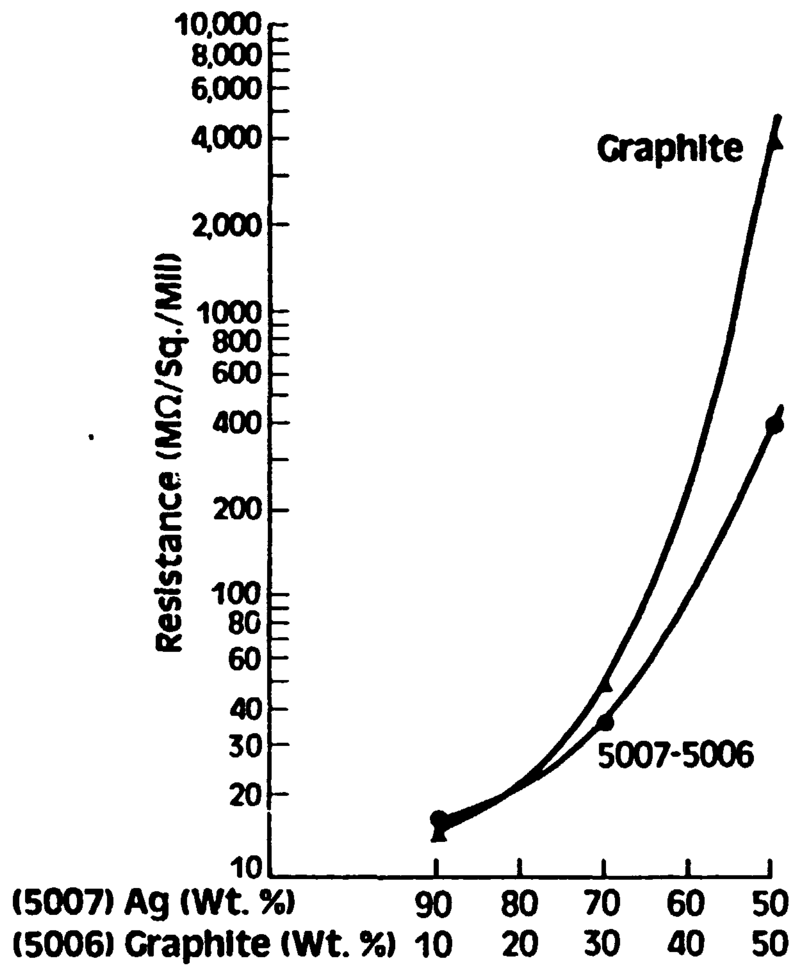


Silver Ink

Resistance vs Coverage of 5007



Blend Curves of 5007-5006 vs Graphite Dried at 120°C 10 min



Key Industrial Property Requirements
for Polymer Thick-Film Conductors

Physical	Test
Sheet Resistivity:	Expressed mΩ/sq/mil
Adhesion:	ASTM D3359-78
Abrasion:	ASTM D3363-74
Flexibility:	ASTM D2176-69
Circuit Temperature Limit:	Tg (DSC)
Contact Resistance:	Mil Std-202, Method 307

Environmental	Test
Thermal Shock:	Mil Std-202F, Method 107D, Test Condition A
Salt Spray:	ASTM B117
Silver Migration:	1000 hr/1V DC/mil gap at 40°C/90% RH
Sulfur:	1000 hr, 500 mg S in 9 liter chamber, 45°C/90% RH
Life at Elevated Temperatures:	1000 hr/85°C
Boiling Water:	2 hr
Humidity:	Mil Std-202E, Method 102 (1000 hr, 60°C/95% RH)

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Performance of PTF Conductors

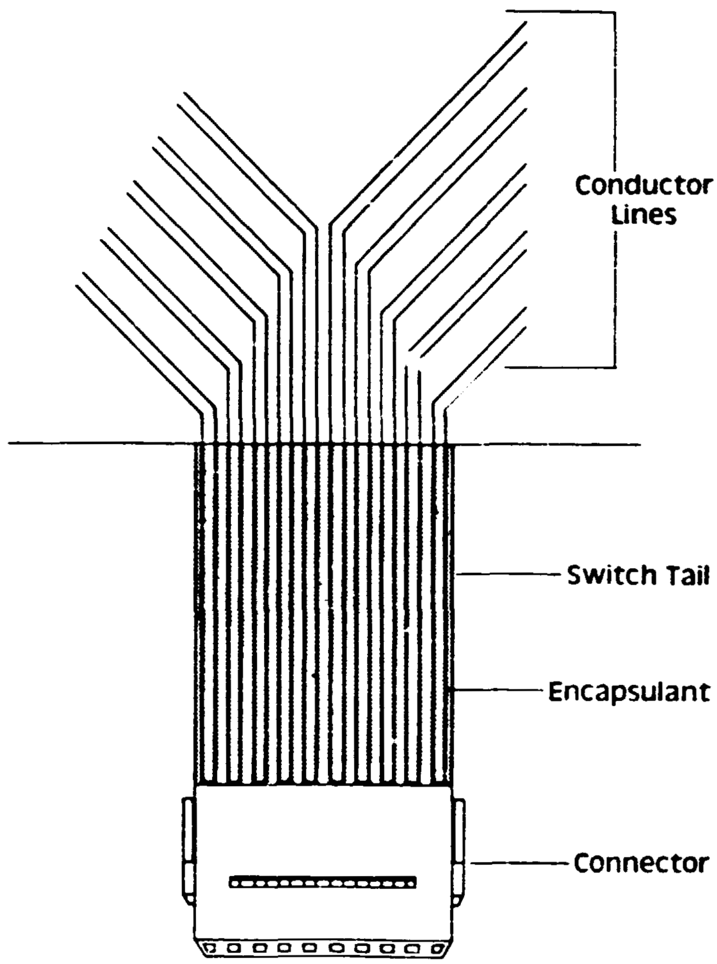
Processing	Du Pont 5005	Du Pont 5007
Screening equipment	High speed, low temp.	Semi-automatic
Substrates	Polyester, polyimide, epoxy glass, polycarbonate	

Properties on Mylar® Film	Governed by time and temperature	
Dry Conditions:	90°C/5 min.	120°C/5 min.
Initial Sheet Resistivity, mΩ/sq/mil	≤15	≤15
Resistivity After Crease Test	90	40
Adhesion (Cross-hatch)	100% pass	100% pass
Abrasion Resistance	≥2H	≥2H
Circuit Temperature Limit	≥70°C	≥70°C

Environmental Results of 5007 Conductor: Initial Circuit Resistivity = 14.4 ohms

Test	Sheet Resistivity After Test (Ω)	% Change
Elevated Temperature (1000 hr)	14.1	-2.1
Sulfur (1000 hr)	14.3	- .7
Humidity (1000 hr)	14.2	-1.4
Ag Migration (1000 hr)	No migration	N/A
Boiling Water (2 hr)	14.0	-2.8
Salt Spray (500 hr)	13.9	-3.5
Thermal Shock (5 cycles)	14.1	-2.1

Membrane Touch Switch Termination Tail Encapsulant



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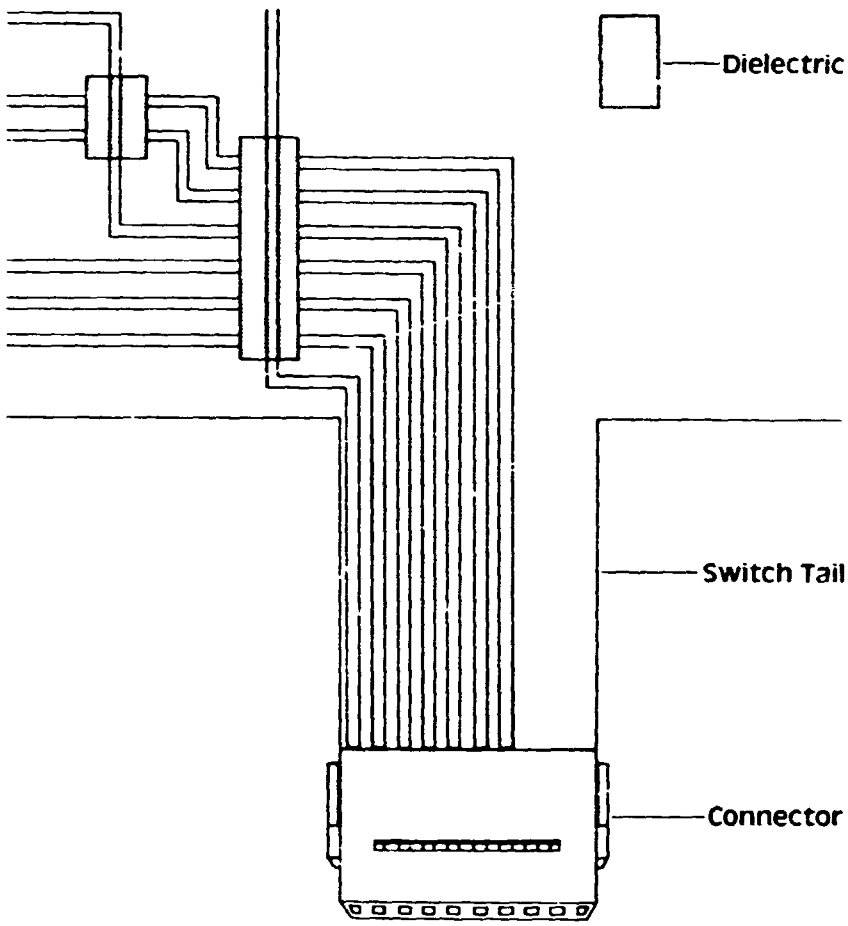
Membrane Touch Switch Insulator to Allow Conductor Crossovers



Advantages of UV-Curable Dielectric

Processing

- Rapid Low Temperature Cure
- No Solvent Emissions
- Equipment:
  - Minimal Space Requirements
  - Low Energy Cost

Physical Property

- Pinhole-Free
- No Solvent Diffusion into Conductor
- Excellent Electrical Properties

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Key Industry Requirements for Polymer Thick-Film Dielectric

Physical	Test
Abrasion:	ASTM D3363-74
Flexibility:	ASTM D2176-69
Adhesion:	ASTM D3359-78
Pinhole-Free	
Screen Printable	
Low Temperature, Rapid Cure	

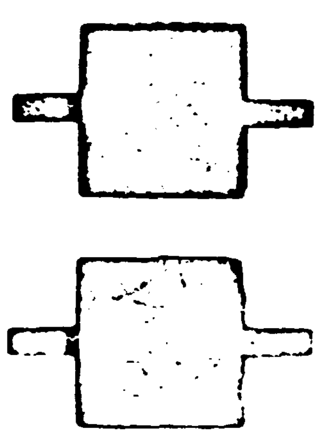
Electrical	Test
Breakdown Voltage:	ASTM D150
Dielectric Constant (K):	ASTM D150
Surface Resistivity:	ASTM D257
Dissipation Factor:	ASTM D150

Environmental	Test
Thermal Shock:	Mil Std-202F, Method 107D, Test Condition A
Life at Elevated Temperature:	1000 hr/85°C
Humidity:	Mil Std-202E, Method 102, (1000 hr, 40°C/90% RH)
Salt Spray:	ASTM B117
Ag Migration:	1000 hr; 1V DC/mil gap at 40°C/ 90% RH
Sulfur:	1000 hr, 500 mg flower of S in 9 liter, 45°C/90% RH

Effect of Proper vs Improper Cure of Dielectric

Correctly Cured Print

Incorrectly Cured Print



Performance Results of Du Pont UV-Curable Dielectric 5011
(Properties of Mylar Film With 5007 Conductor)

Physical	
Abrasion Resistance:	≥2H
Flexibility:	No Cracking
Adhesion — (Tape Pull)	
Dielectric to Polyester:	Excellent
Conductor to Dielectric:	Excellent
Odorless	
Electrical	
Breakdown Voltage:	>600 V/mil
Dielectric Constant:	<5 at 1KHz
Surface Resistivity:	$>10^{11}$ Ω/sq
Dissipation Factor:	1.2%

Environmental	
Thermal Shock (5 cycles)	
Humidity (1000 hr)	• Surface Resistivity Decreases 10 to 100 Ω/sq
Salt Spray (240 hr)	•Capacitance, DF, Adhesion and Hardness, Show No Change
Ag Migration (1000 hr)	•No Ag Migration
Sulfur (1000 hr)	

DISCUSSION

QUESTION: What is the ratio of inorganic constituents to constituents?

NAZARENKO: It has less than 1% -- well, I think it is an inorganic -- it is a pigment to give it color. That is the only reason it is there, and it could be organic. I am not sure exactly what the composition of the pigment is. We have a clear version also, which is 5012, which has no inorganics in it at all.

ROYAL: I think I heard you say that the silver migration problem that apparently went away because there were no ionic impurities that came out -- is that the solution to silver migration?

NAZARENKO: That is one of them, and when I use the term ionic impurities, I am comparing it with a fired system where we have glass frits, and there you have a lot of ionics, which are needed to initiate the silver migration mechanism. In this system we don't use glass frits so we have avoided one potential problem. The other difference is that in fired systems you burn off the organics so you have just metal, sintered metal that is really ready for moisture penetration and reaction. Here we have polymer as a barrier, and because of those two factors we explained, the absence of migration.

WONG: Do people in this area, the thick-film polymer conductor area, usually use thermoplastic polymer?

NAZARENKO: Yes. There are thermoplastics and thermosets. Here we are using thermoplastics because we need flexibility, and thermosets which are crosslinking materials, usually result in a brittle or inflexible product. Thermoplastics are usually more flexible.

WONG: How about from a processing point of view?

NAZARENKO: Also from processing -- crosslinking materials are usually one parts, two parts. The problem with two parts is that they have short pot life. One part usually takes longer to cure than the times that we are indicating here. The industry is driving to faster processing. That is where they see a saving.

WOLF: I noticed that the conductivity in your films is 1/20th of bulk conductivity. It seems the glass-frit, high-temperature-fired inks give you about 1/3 of part conductivity.

NAZARENKO: No. We are talking about 10 to 15 milliohms per square per mil --

WOLF: That makes about 1/20th of bulk conductivity. If you used a bulk conductor you would have 0.6 milliohms.

NAZARENKO: We have polymer in here. So we are never going to achieve the type of conductivity that you are going to get in bulk or fired.

WOLF: I just wanted you to be aware of that.

NAZARENKO: That's right.

WOLF: With solar cells, very high conductivity is necessary.

SOMBERG: People talked earlier about the silver migration problem and people mentioned that possibly what is needed is a coating for the base-metal systems. Would you suspect that the polymers you are using in your system might be applicable to coating a glass inorganic system? Would that be applicable?

NAZARENKO: Possibly. Yes. We have tested the silver migration up to 1000 hours at 60°C/90% RH. I don't know if that is long enough for your application but we feel confident that that silver migration is not a problem.

LANDEL: I didn't get the conditions of that test. What is the voltage applied there?

NAZARENKO: Voltage is applied according to the spacing between the conductive lines. So we did two cases. We did one where the spacing was 8 mils so we applied 8-volt potential. In another pattern we had a 30-mil spacing so in that kind of pattern we used 30 volts. So it is applied to the particular separation.

GALLAGHER: You showed an adhesion test, and you had in parentheses cross-hatched. I am not familiar with that. Could you explain that?

NAZARENKO: This is an ASTM test. It is a Scotch-tape test. But you can semiquantitate it by cutting squares into it, you just lightly etch, say, a grid of 100 squares all the way through, then you put the tape on, and then you pull it off, and then you could count how many squares you pull off. So you can now talk to someone -- otherwise, it is difficult to define what is a pass-test and what is a fail-test.

GALLAGHER: What size are the grids?

NAZARENKO: It depends on your pattern. If you have --

GALLAGHER: Is there any set pattern?

NAZARENKO: No. You just want segments.

HOGAN: Has anyone been successful in utilizing the polymer in thick-film conductor for solar cells?

NAZARENKO. No. I haven't heard of any. The polymer thick-film -- one of the problems with it is that it has poor solderability. Because you have a barrier; you have a layer of organic above the silver particles, say, to wet those silver particles, the silver has to diffuse and get up above this barrier to accept the solder, and that is a problem.

HOGAN: Is there also a barrier at the interface? At the surface -- at the top surface?

NAZARENKO: Yes. At the top surface. So there are ways -- we have a program now going on to try to solve this problem to make these materials solderable. I think you can add to the material system to move the silver up to the surface.

BLAKE: Could you give us a rough idea of the cost per gram of the silver polymer?

NAZARENKO: Again, it depends on the market price, but at $10 for silver, it's between 40 and 45 cents.