Polymer Thick Film Paste & Material Compatibility Discussion

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Agenda

• What is a Polymer thick Film
• Basic Thick Film Paste Technology
• Standard Processing (Printing & Drying)

• New Applications & Material Selection/Compatibility

• Other Processing Possibilities & Material Selection/Compatibility

• Conclusions
DuPont has developed over 1300 thick film compositions, sold into myriad applications.

- Self-Regulating Heaters
- RFID Antenna
- EL Backlights
- Membrane Touch Switch
- Biosensors
- Photovoltaic
What Is PTF?

Polymeric thick film (PTF) is a widely used technology for the processing of circuit patterns onto plastic and flexible substrates using screen printing technology.

PTF’s are in the form of a thick film “paste”.

Low temperature process (typically < 150 °C).

PTF was first used to manufacture MTS (membrane touch switch) circuits in the late 70’s.

Mature robust technology in use for >30 years.
“Thermoplastic” Polymer Thick Film Conductors

- Conductive particles pack together as ink dries, forming electrical pathways
- Conductive flake/particle ratio balanced for best conductivity at lowest cost
- Best overall balance of electrical & physical performance and printability
- Formulated with solvents that balance screen life with drying efficiency
- Thermoplastic inks can be re-softened with heat and/or solvent
- Part of a complete system with PTF carbons, dielectrics, & encapsulants
Cross Section of Dried Print

PE825 (≈ 26% Ag)  

5029 (≈ 80% Ag)
Function of Constituents

**POWDER:** Active element of paste, determines electrical properties of paste

**RESIN:** Provides adhesion to substrate, cohesion of the conductive powder together and protects conductor from external effects

**SOLVENT:** Controls viscosity, dissolves resin and wets substrate surface
Conductive Powder Technology

- **Silver**
  - Very high conductivity
  - Price linked by silver metal market price
  - Most widely used PTF conductor
  - Silver Oxide is conductive

- **Carbon**
  - Low conductivity
  - Used for high resistance applications
  - Very inexpensive

- **Other (Au, Pt, Zn, Cu, Ag Coated Cu, AgAgCl, etc)**
  - Customized for application
  - Wide range of properties

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## Conductor Choices

### Heat Map Showing typical trade-offs

<table>
<thead>
<tr>
<th>Type</th>
<th>Resistivity mΩ/□/mil</th>
<th>Resistance mΩ/□</th>
<th>Variety of Material Choices</th>
<th>Hardness/Adhesion</th>
<th>Cost $/gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver Coated Cu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nano Silver</td>
<td></td>
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</tr>
</tbody>
</table>
Critical Parameters for Conductors

Particle Morphology Critical

**Flake** vs. Spherical Particle

Surfactant Coating on Precipitated Particles

Interaction with Resin!

Maximize Particle Packing Density

PSD (1-15 microns)
Powder Morphology

Spherical Silver

Flake Silver
Silver flaking is controlled by a combination of process parameters

Powder must be tailored to the paste composition
Vehicle/Medium Manufacture

- Resins
- Solvents
- Modifiers

Vehicle
Resin Technology

- **Thermoplastic**
  - Shrinks during *drying* but softens on re-heating
  - Higher flexibility
  - Lower *drying* temperature $\Rightarrow 110-140^\circ C$

- **Thermoset**
  - Reacts during curing to form a rigid structure which cannot be changed with further heating
  - Rigid, more stable
  - High temperature curing $\Rightarrow 160-200 ^\circ C$
Critical Parameters for Polymers

Solubility Parameters

• Tg of Resin (>70 C; preferably >90C)
• Interaction With Conductive Phase (surfactant compatibility)
• Molecular Weight (10000-100000)
• Decomposition Temp (>150C; preferably >200C)
Paste Technology/Solvent

Solvent

- Many types
  - Glycol ethers, esters, alcohols
- Solubility
  - Must dissolve resin effectively
- Volatility
  - Balance between processing/screen life
- Environmental
  - Low odor
  - Non harmful
  - Low flammability
Testing of Paste Properties:

- Solids
- Viscosity (rheology)
- Fineness of grind (measure of powder dispersion)
- Functional properties (dependent on application)
  - Resistivity
  - Adhesion
  - Hardness/Flexibility
  - Brightness, Dielectric Constant
Typical Functional Testing

Conductors

- Printing properties
- Line resolution
- Resistivity
- Flexibility
- Adhesion
- Hardness
Industry Standards for Conductors

ASTM (Printed Electronics) & IPC (Printed Electronics)

- Cross Hatch Tape Test Adhesion
- Pencil Hardness
- Crease Test (180° blend)
- Flex Testing (bending around mandrel)
- Silver Migration Resistance
- Resistance
Technology of Screen Printing

Advantages:

- Additive process for electronic circuitry on various substrate types
- Thicker ink deposits in far fewer passes versus inkjet or flexo / gravure
- Broad base of manufacturers and process knowledge; mature industry
- Continually updated technology for new and current applications
Screen Printing Diagram

- Squeegee moves ink across & through screen mesh
- Emulsion defines & gaskets printed pattern
- Mesh count, wire diameter, & emulsion affect deposit

Substrate

Fine Mesh

Coarse Mesh
Processing Polymer Thick Film Composition

Drying / Curing
Electrical Properties

Effect of Curing Time/Temp on Resistivity

Box Oven

Temperature 120°C

Resistivity vs. Time / minutes

IR Oven

Temperature 135°C

Resistivity vs. Time / minutes
Dryers for Processing PTF Compositions

UV oven

Forced Air & UV Oven

Tower Dryer on Roll-to-Roll line
When Choosing Ink Materials Consider

• Material Compatibility
• Substrate & Printing Process
• Metallurgy
• Sample Size Requirements
• Drying / Curing Option
• Thermal vs. Photonic Curing
• Cost Constraints
• End Product Value Proposition
Traditional Printed Electronics

Materials (>95% Screen Print):
Conductors: Silver, Gold, Copper, Alloys
Dielectrics – Multilayer, Cross-over, Encapsulant
Resistors – Carbon, Ruthenium
Specialty – PTC, Phosphor, ITO

Applications / Substrates
Membrane Switch, EL / PET film
Rear Window Defogger / Glass
Hybrid Microelectronics / Alumina
Photovoltaic / Silicon

RFID Antenna
EL Lamps/Backlight
Membrane Touch Switch
Bio Test Strip
Battery Tester
Chip Resistors
“Hybrid IC” on Alumina
Photovoltaic Si Cells

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Primary Substrates for Printed Electronics - 2014

DuPont Printed Electronics
DuPont Low-Silver Printed Conductors

Low Temperature

High Temperature

PVC
Polyethylene
Polypropylene
Polystyrene
Acrylcs
EVA
PET
Polycarbonate
TPU
Stabilized PET
PEN
High Temp EP
Polyimide
Transformations in Printed Electronics - 2016

DuPont PE 827/828 Inks for Low Temperature Printed Electronics

DuPont PE Stretchable Electronic Materials

DuPont ME In-Mold Electronic Materials

DuPont™ Kapton™ KA Inks for High Temperature Electronics

Low Temperature

High Temperature

PVC
Polyethylene
Polypropylene
Polystyrene
Acryls
EVA
PET
Polycarbonate
TPU
Stabilized PET
PEN
High Temp EP
Polyimide
# Substrate Temperature Stability for Printed Electronics

<table>
<thead>
<tr>
<th>Substrate (Common Name)</th>
<th>Max Drying Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyimide (Kapton)</td>
<td>180 - 220°C</td>
</tr>
<tr>
<td>Polyetherimide (Ultem)</td>
<td>170 - 190°C</td>
</tr>
<tr>
<td>Polyethylene Napthalate (Teonex)</td>
<td>150 - 160°C</td>
</tr>
<tr>
<td>Stabilized Polyester Film (Melinex)</td>
<td>130 - 140°C</td>
</tr>
<tr>
<td>Thermoplastic Polyurethane (TPU)</td>
<td>100 - 120°C</td>
</tr>
<tr>
<td>Polycarbonate Film</td>
<td>80 - 120°C</td>
</tr>
<tr>
<td>Polyvinyl chloride (PVC)</td>
<td>60 - 85°C</td>
</tr>
<tr>
<td>PVDF Film (Piezoelectric)</td>
<td>60 - 85°C</td>
</tr>
<tr>
<td>Polyolefin (Tyvek)</td>
<td>60 - 90°C</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>60 - 80°C</td>
</tr>
</tbody>
</table>

*Chart indicates maximum drying temperature of substrates for **dimensional tolerances**, NOT maximum operating temperature of the substrates or inks*
New low-temperature inks are optimized to dry efficiently at 80ºC and can cure as low as 60ºC with good electrical performance.
DuPont™ PE827 and PE828 do not dry rapidly on the screens.

However, at 60°C, their unique chemistry causes them to quickly cure, providing excellent electrical performance.

The drying test to the right provides an indication of screen life performance.

Grind Gauge Drying Test

Blue = minutes to dry at room temperature, higher depth correlates to more screen clogging.
Emerging Printed Electronics

In Mold Electronics: Capacitive Touch Technology

Materials:
- Polycarbonate Substrate
- Printed Silver Conductors that are flexible
- Other printed materials

Flat Sheets

View “A” Side

View “B” Side

Thermoformed

View “A” Side

View “B” Side

View “B” Side

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Wearable Electronics
Printing on TPU

- Thin option providing exceptional comfort
- Rugged and washable
**Emerging Printed Electronics**

Printed Heaters that replace “wires”
Lower cost, improved safety
PTC Carbon and Low Resistivity Silver:

(Automotive)
Seat Heater Technology Comparison

<table>
<thead>
<tr>
<th>Category</th>
<th>ITW PTC Heater</th>
<th>Wire Type Heater</th>
<th>Carbon Type Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self Regulation</td>
<td>Yes</td>
<td>Sensor Required</td>
<td>Sensor Required</td>
</tr>
<tr>
<td>Short Circuit Result</td>
<td>Self-Cauterizes</td>
<td>Burn Potential</td>
<td>Burn Potential</td>
</tr>
<tr>
<td>Fold Over Result</td>
<td>&lt;5°C Increase</td>
<td>30°C Increase</td>
<td>15°C Increase</td>
</tr>
<tr>
<td>Conductor Temp</td>
<td>55°C</td>
<td>90°C</td>
<td>60°C</td>
</tr>
<tr>
<td>Current Draw</td>
<td>2.5A steady state</td>
<td>4.5A steady state</td>
<td>3.9A steady state</td>
</tr>
<tr>
<td>Independent Diagnostics</td>
<td>Not Required</td>
<td>Required</td>
<td>Required</td>
</tr>
</tbody>
</table>

Source: ITW
What is a PTC Carbon Resistor?

Resistance vs Temperature Comparison of 7282 & -151A

- Reference 7282
- Development PTC -151A
KA801 & Kapton® heaters demonstrations

at ~207 °C = ~405 F, held >1000 hours, cycled daily on Kapton® RS

DuPont™ encapsulant Kapton™ KA701
Kapton® film (conductive side) 100 ohm/square
DuPont™ silver paste Kapton™ KA801 0.1 ohm/square

Conductive

Dielectric

Rivet or clamp connection
To external power source (isolated)

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Force Sensor: Carbon Conductor

When Pressure is Applied the Resistance Decreases
Lamination of Conductors to Lower Resistance

Smart Card Processing
High Conductivity “Silver Alloy” for Smart Cards

Processing Conditions: 325-mesh, 0.9 mil wire, PE815 printed on ST505 PET; dried 130C/10-min; Hot-Roll Calendered 80C, 25 m/min
Other Deposition Techniques

- Spray
- Pad Printing
- Brush or Band
- Dip
- Decal
- Ink Jet
Curing Techniques for Printed Electronics

Thermal
Traditional, may require high temps for extended times

UV
Limited Mostly to Dielectrics; Not Efficient for Conductors

Photonic
Pulsed light, rapid sintering of particles

Other
- Laser
  Selective exposure by scanning with focused laser
- Microwave
  Rapid sintering, low penetration depths (approx 1.5 µ)
- Electrical
  Apply voltage across a printed structure, rapid sintering possible
- Plasma
  Sintering by exposure to low pressure plasma, e.g. argon
- Chemical
  Room temp process, chemically induced coalescence
Pulsed Photonic Curing/Sintering

High intensity strobe sinters metal containing inks on a variety of conventional and low cost substrates

Sintering times are in the millisecond range

High temperatures achieved locally for short periods of time, low temperature substrates are not damaged

Convenient: noncontact process, ambient conditions

Process variables are adjusted to accommodate ink and application (strobe energy, pulse length, number of pulses, web speed)

Commercial Units:
   NovaCentrix PulseForge®
   Xenon SINTERON™
   Holst Center / Philips Aachen
Before / After Photonic Curing

Thermal Cure 140C / 10min

Photonic Cure

Ag Flake

Ag Sphere
When Choosing Ink Materials Consult the Paste Supplier

- Substrate & Printing Process
- Material Compatibility
- Metallurgy
- Sample Size Requirements
- Drying Options
- Thermal vs. Photonic Curing
- Cost Constraints
- End Product Value Proposition
- Consult your Paste Vendor
Thank you,

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