Polymer Thick Film Paste & Material Compatibility Discussion

John Crumpton

September 14, 2015

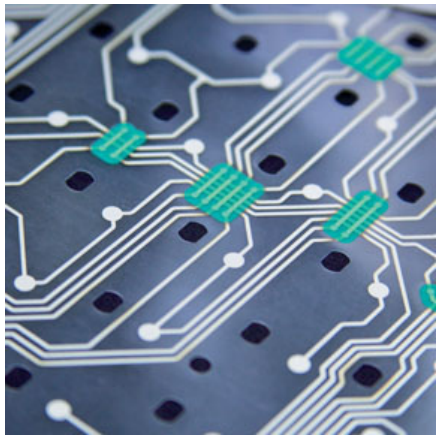
Agenda

- 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





Photovoltaic



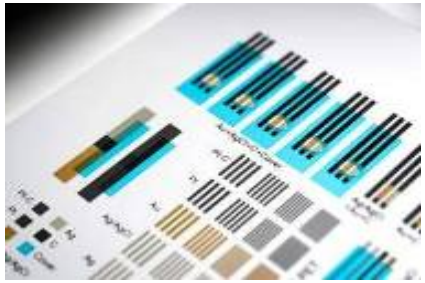
RFID Antenna



EL Backlights



Membrane Touch Switch



Biosensors

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**”

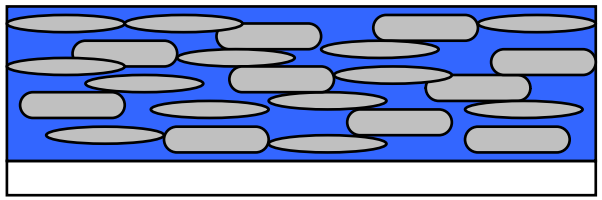
Low temperature process (typically< 150 ° C)

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

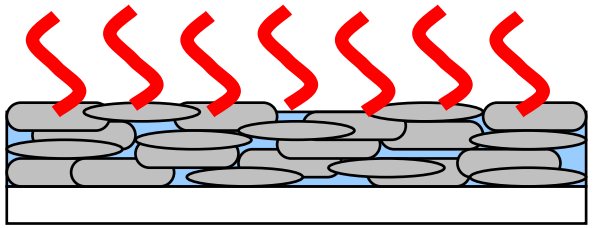
Mature robust technology in use for >30 years

“Thermoplastic” Polymer Thick Film Conductors

Wet Print



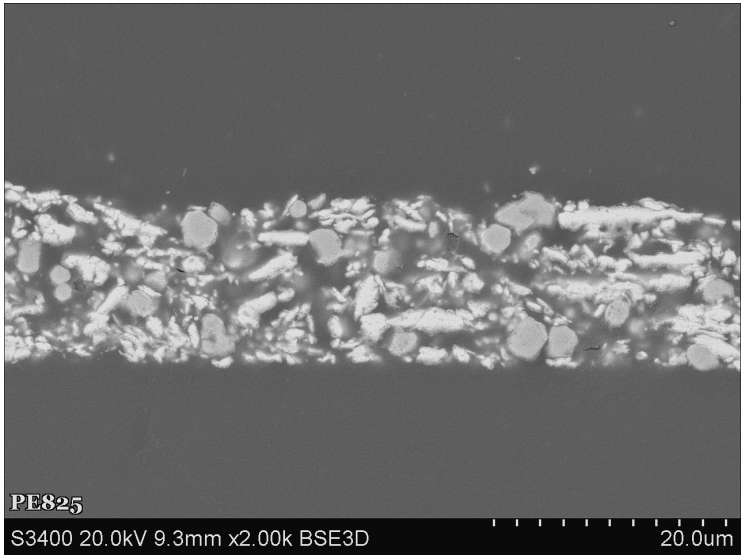
Solvent Removal



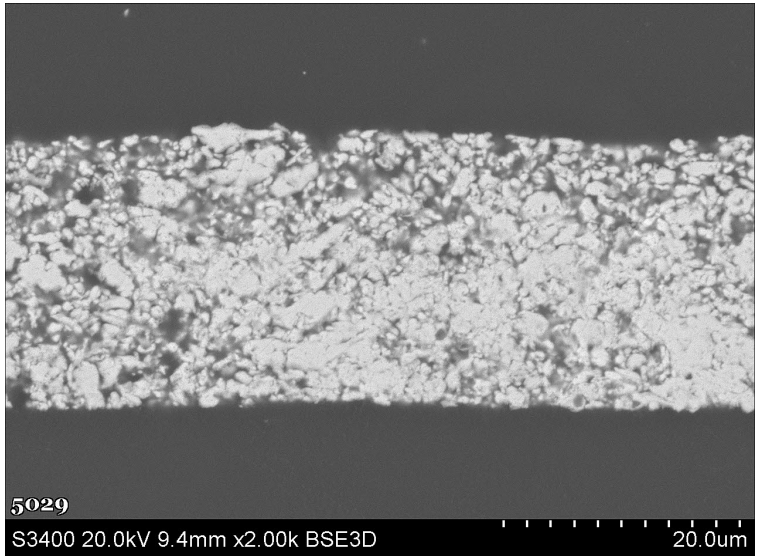
- Conductive particles pack together as ink dries, forming electrical pathways
- Conductive flake/particle ratio balanced for best conductivity at lowest cost
- Best overall balance of electrical & physical performance and printability
- Formulated with solvents that balance screen life with drying efficiency
- 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, Ag AgCl, etc)**
  - Customized for application
  - Wide range of properties

Conductor Choices

Heat Map Showing typical trade-offs

Type	Resistivity mΩ/□/mil	Resistance mΩ/□	Variety of Material Choices	Hardness/ Adhesion	Cost $/gram
Silver					
Copper					
Carbon					
Silver Coated Cu					
Nano Silver					

Critical Parameters for Conductors

Particle Morphology Critical

Flake vs. Spherical Particle

Surfactant Coating on Precipitated Particles

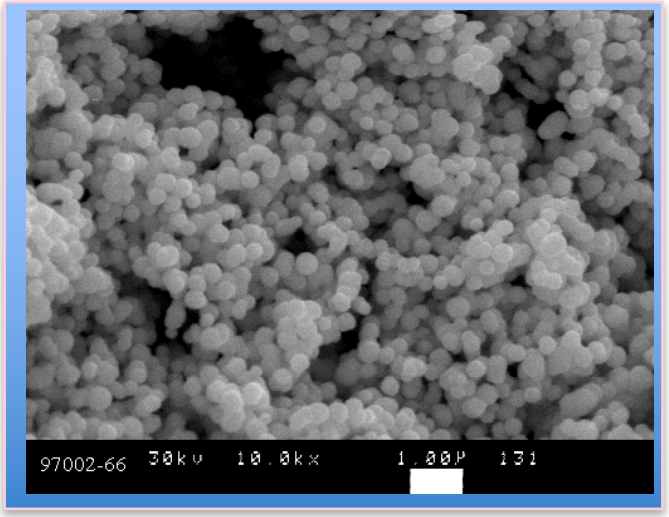
Interaction with Resin!

Maximize Particle Packing Density

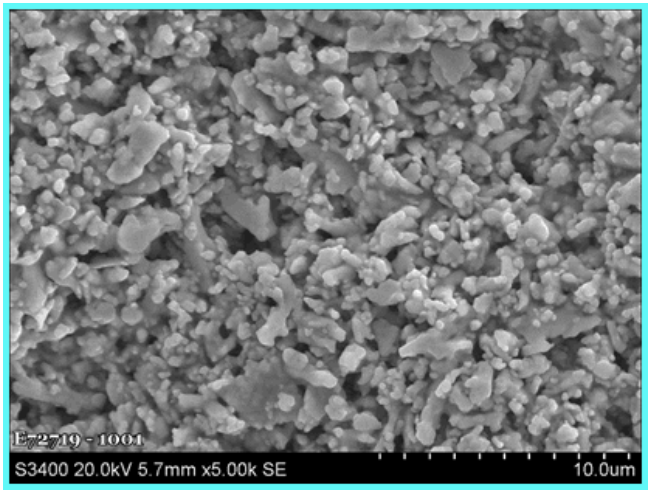
PSD (1-15 microns)

Powder Morphology

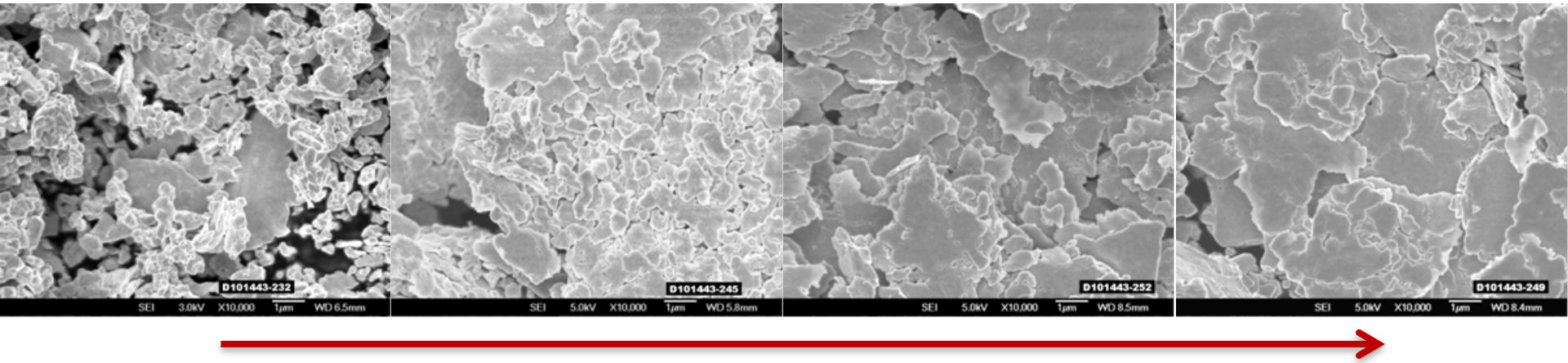
Spherical Silver



Flake Silver



Flaking Progression



- 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 ➪ **110-140° C**
- **Thermoset**
  - Reacts during curing to form a rigid structure which cannot be changed with further heating
  - Rigid, more stable
  - High temperature curing ➪**160-200 ° 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

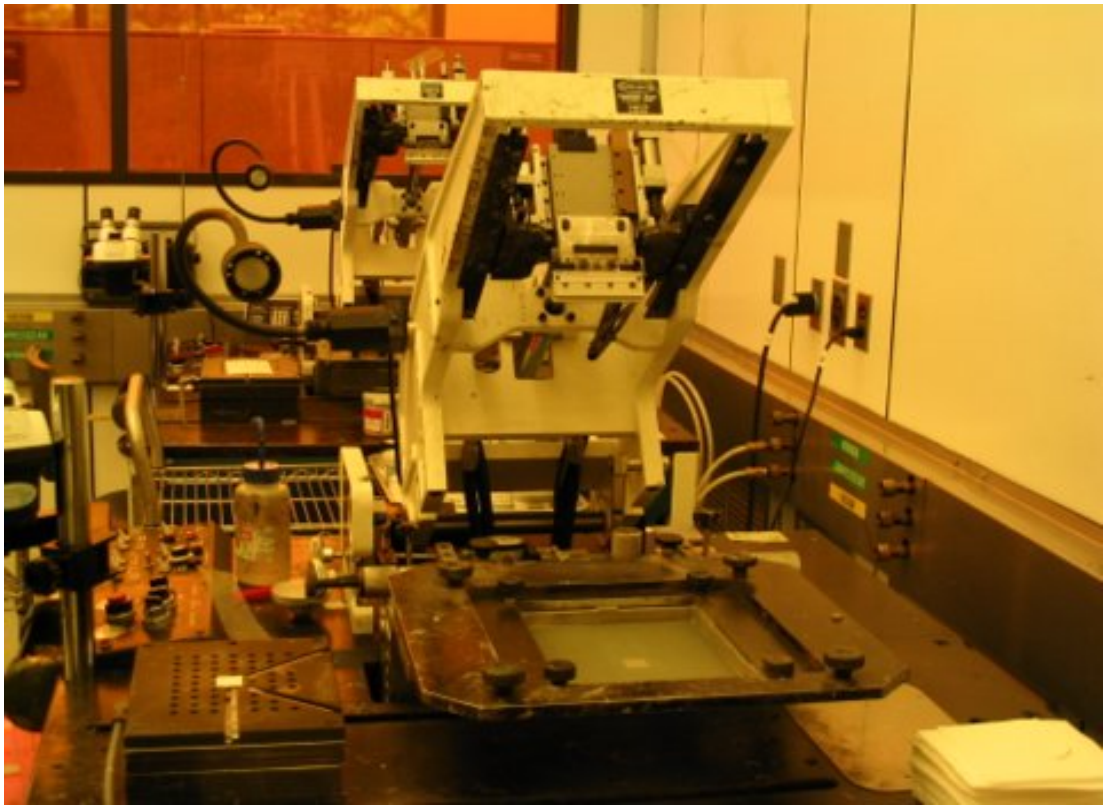
- Many types
  - Glycol ethers, esters, alcohols
- Solubility
  - Must dissolve resin effectively
- Volatility
  - Balance between processing/screen life
- Environmental
  - Low odor
  - Non harmful
  - Low flammability

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

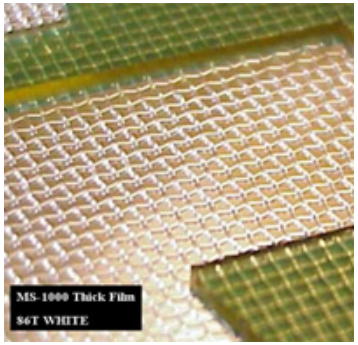
ASTM (Printed Electronics) & **IPC** (Printed Electronics)

- **Cross HatchTape Test Adhesion**
- **Pencil Hardness**
- **Crease Test (180º blend)**
- **Flex Testing (bending around mandrel)**
- **Silver Migration Resistance**
- **Resistance**

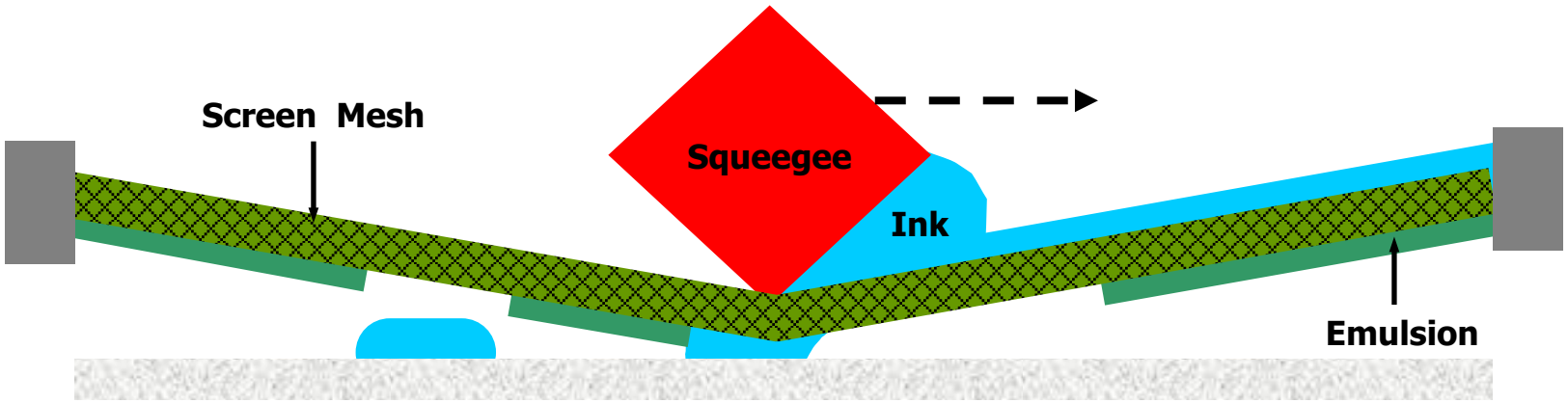
Technology of Screen Printing

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**

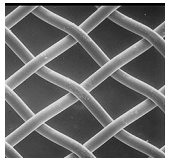


Screen Printing Diagram

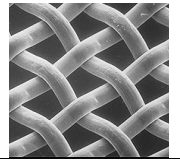


- Squeegee moves ink across & through screen mesh
- Emulsion defines & gaskets printed pattern
- Mesh count, wire diameter, & emulsion affect deposit

Fine Mesh



Coarse Mesh



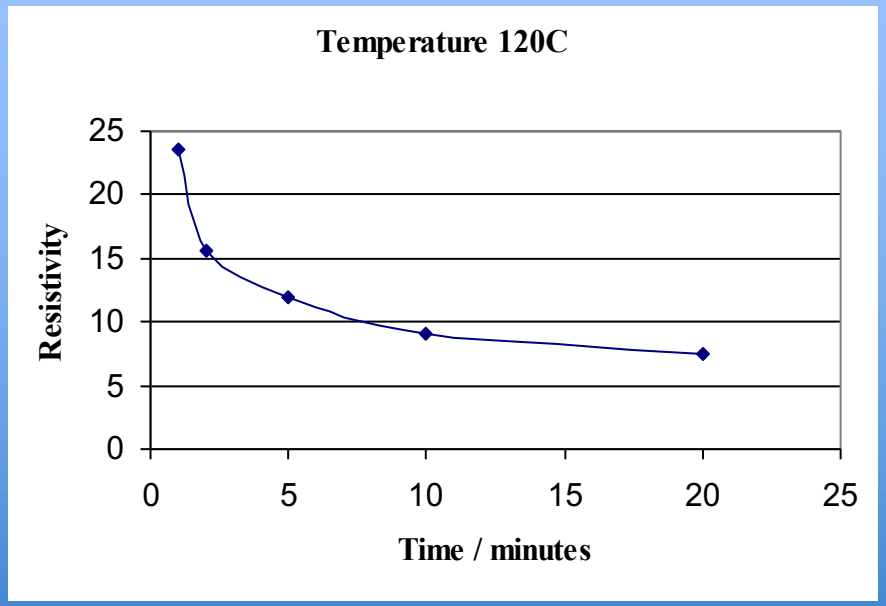
Processing Polymer Thick Film Composition

Drying / Curing

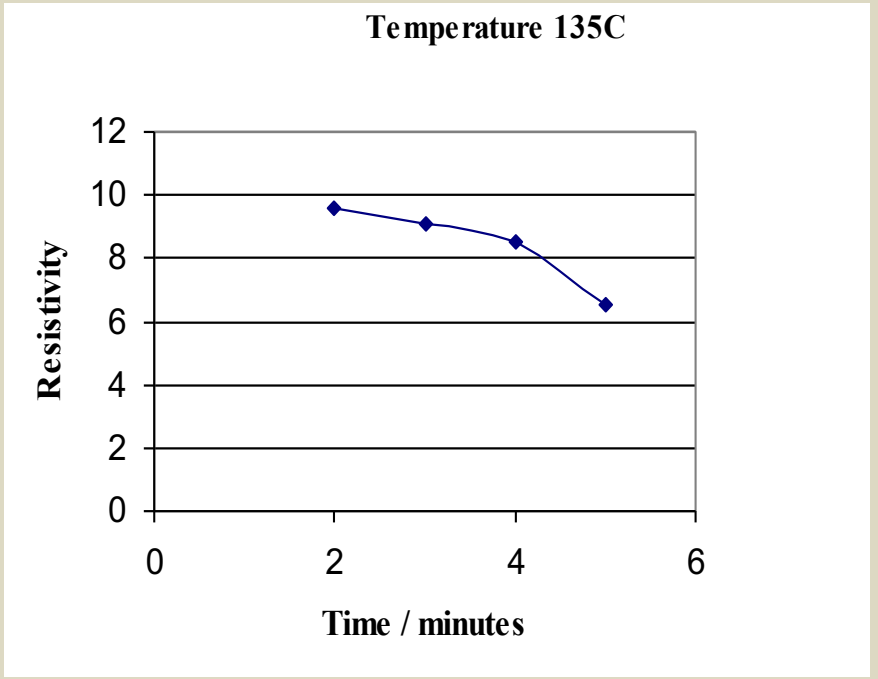
Electrical Properties

Effect of Curing Time/Temp on Resistivity

Box Oven



IR Oven



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

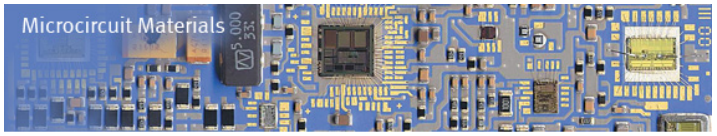
Applications / Substrates

Membrane Switch, EL / PET film

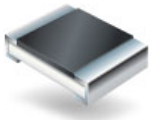
Rear Window Defogger / Glass

Hybrid Microelectronics / Alumina

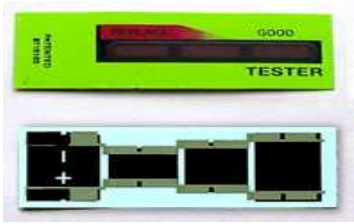
Photovoltaic / Silicon



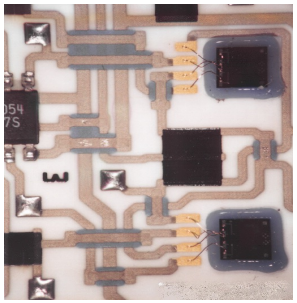
Thick Film Multilayer Hybrid



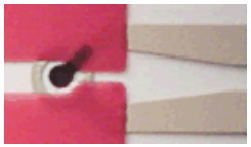
Chip Resistors



Battery Tester



"Hybrid IC" on Alumina



Bio Test Strip



RFID Antenna



EL Lamps/Backlight

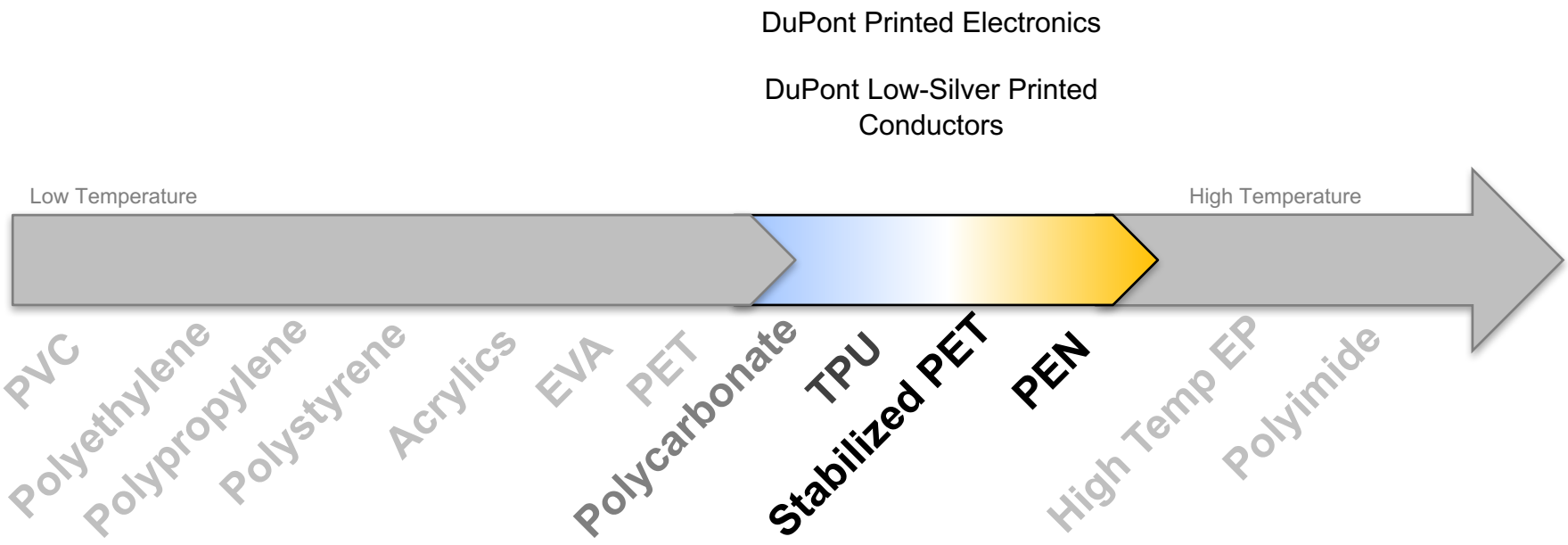


Membrane Touch Switch



Photovoltaic Si Cells

Primary Substrates for Printed Electronics - 2014



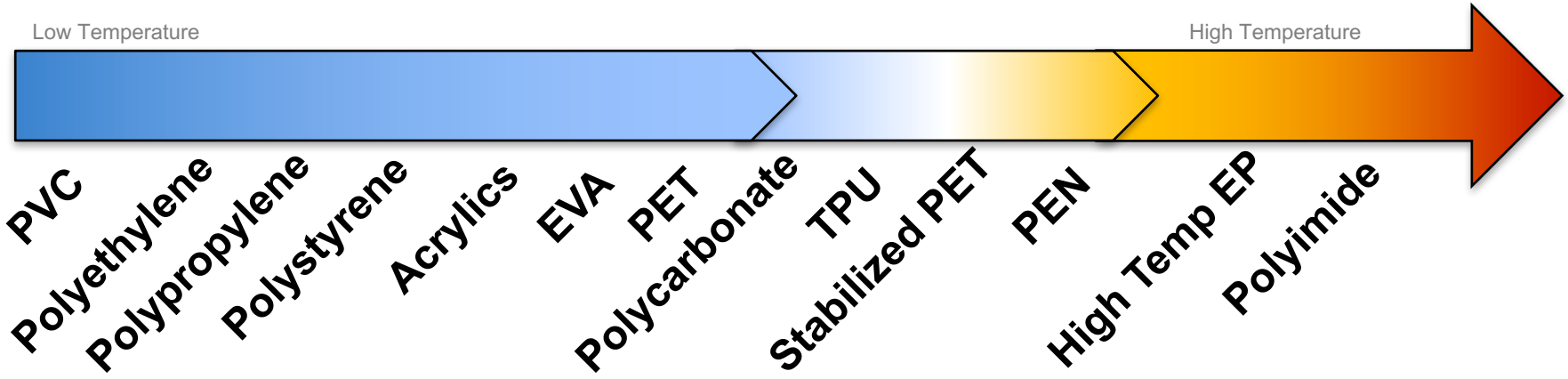
Transformations in Printed Electronics - 2016

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



Substrate Temperature Stability for Printed Electronics

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

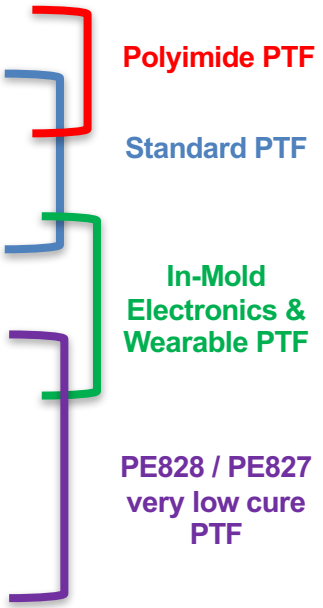
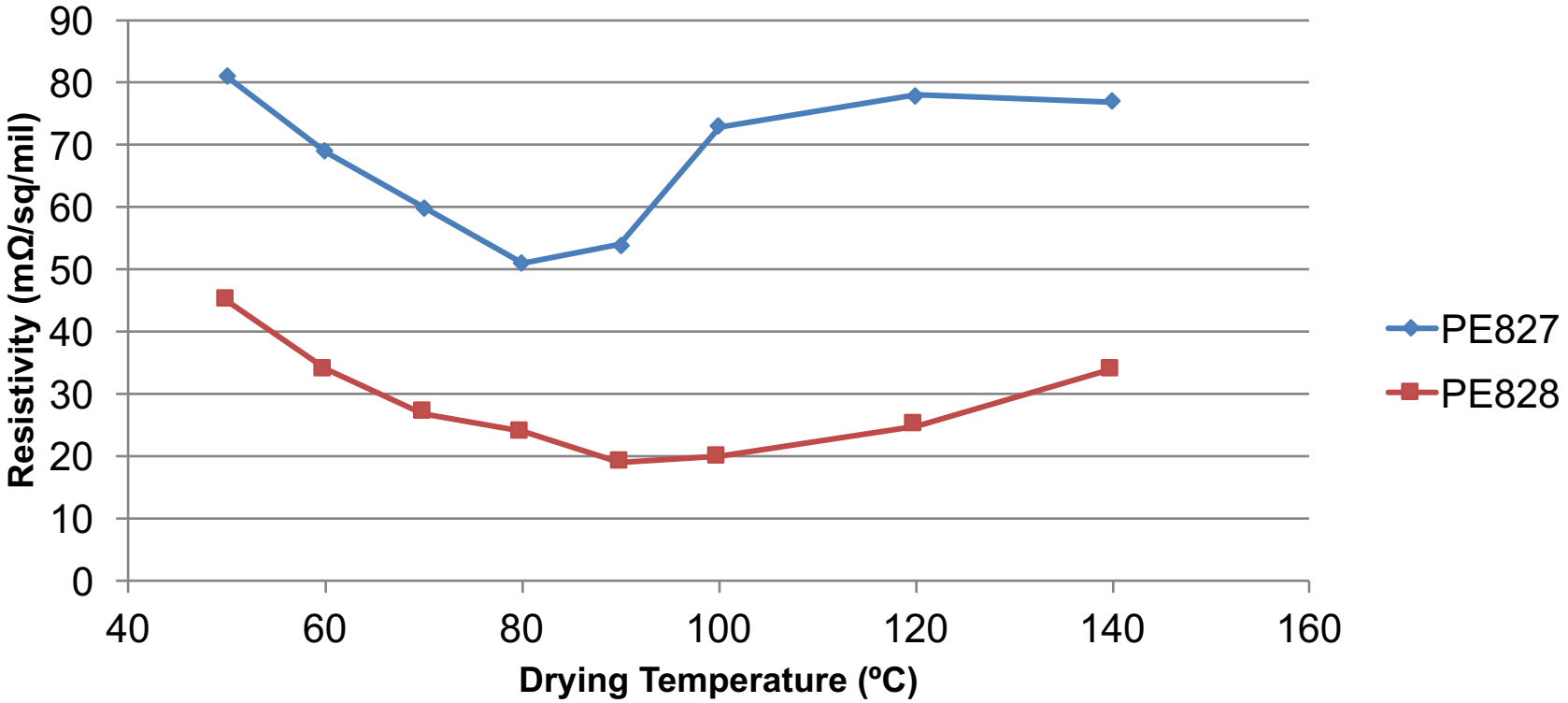


Chart indicates maximum drying temperature of substrates for dimensional tolerances, NOT maximum operating temperature of the substrates or inks

New low-temperature inks are optimized to dry efficiently at 80ºC and can cure as low as 60ºC with good electrical performance

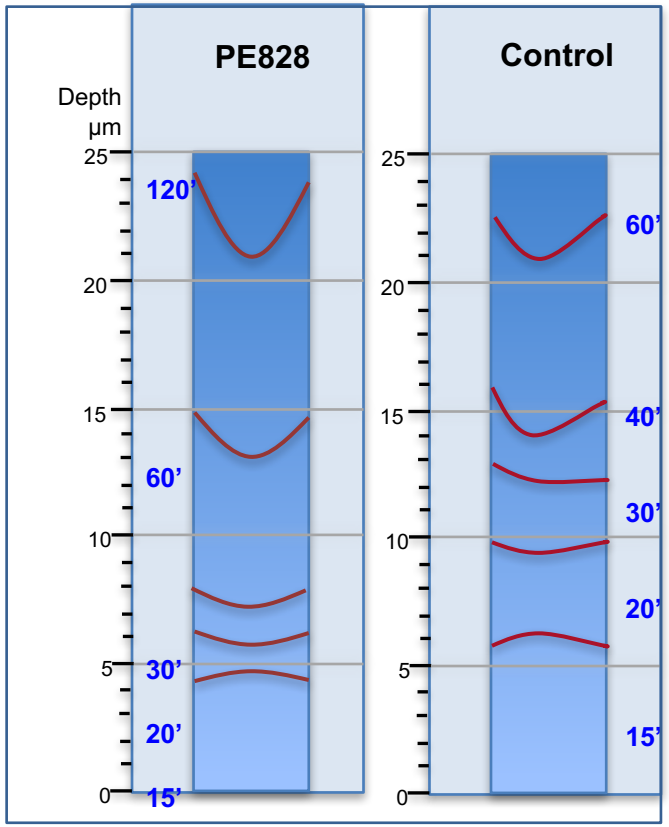


DuPont™ PE827 and PE828 do not dry rapidly on on the screens

However, at 60ºC, 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:

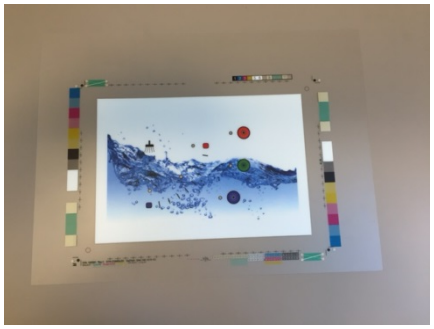
- Polycarbonate Substrate
- Printed Silver Conductors that are flexible
- Other printed materials

Thermoformed

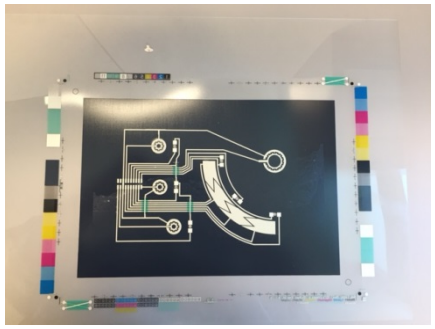


View “A” Side

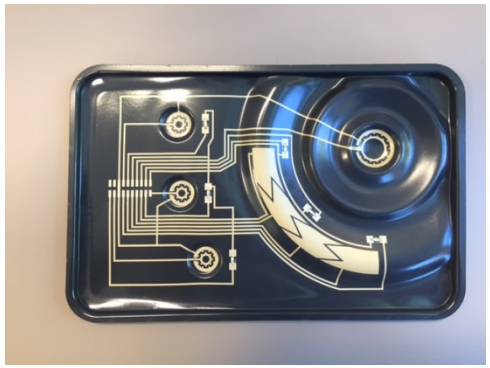
Flat Sheets



View “A” Side

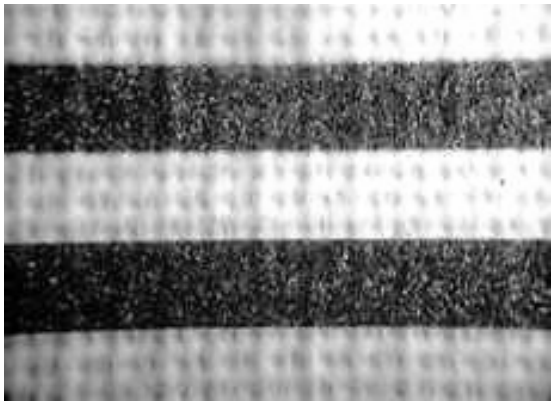


View “B” Side



View “B” Side

Wearable Electronics

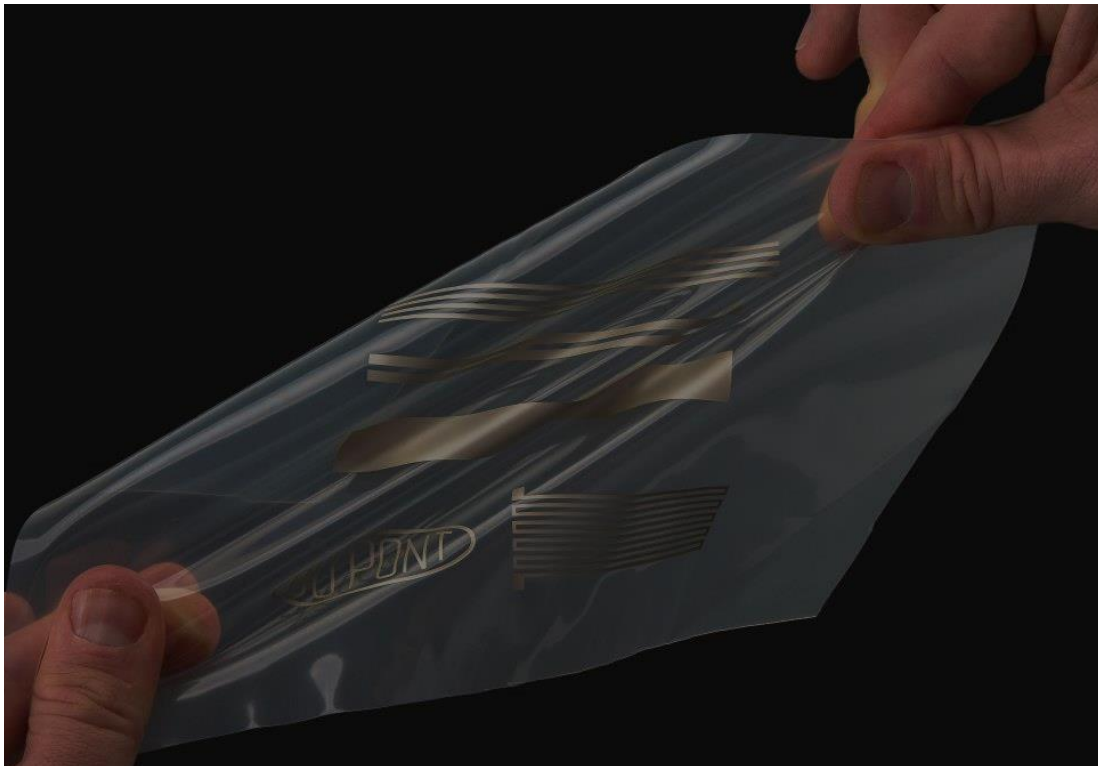






Printing on TPU

- Thin option providing exceptional comfort
- Rugged and washable



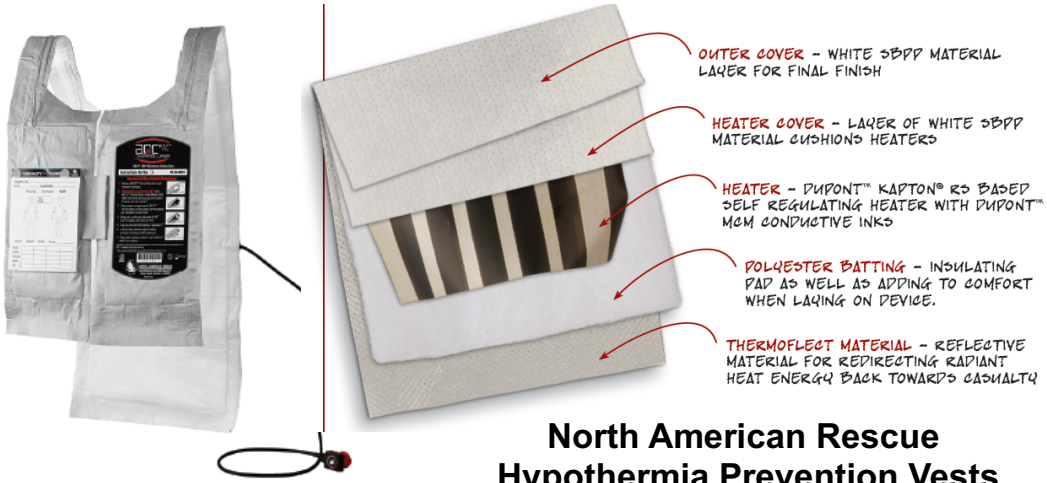
Copyright DuPont 2015

Emerging Printed Electronics

Printed Heaters that replace "wires"

Lower cost, improved safety

PTC Carbon and Low Resistivity Silver:



North American Rescue Hypothermia Prevention Vests

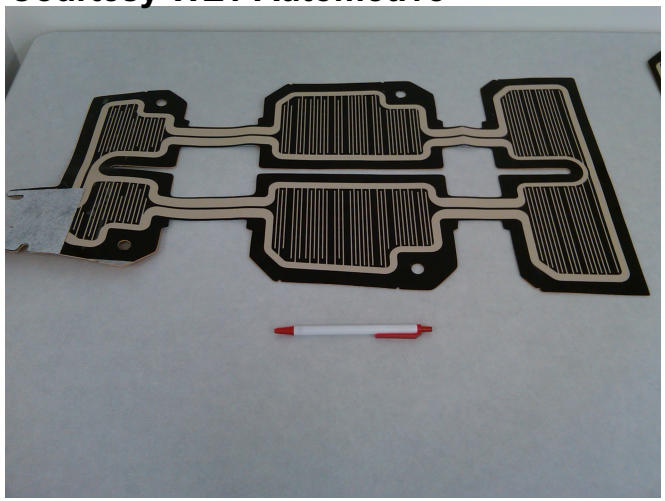
(Automotive)

Seat Heater Technology Comparison

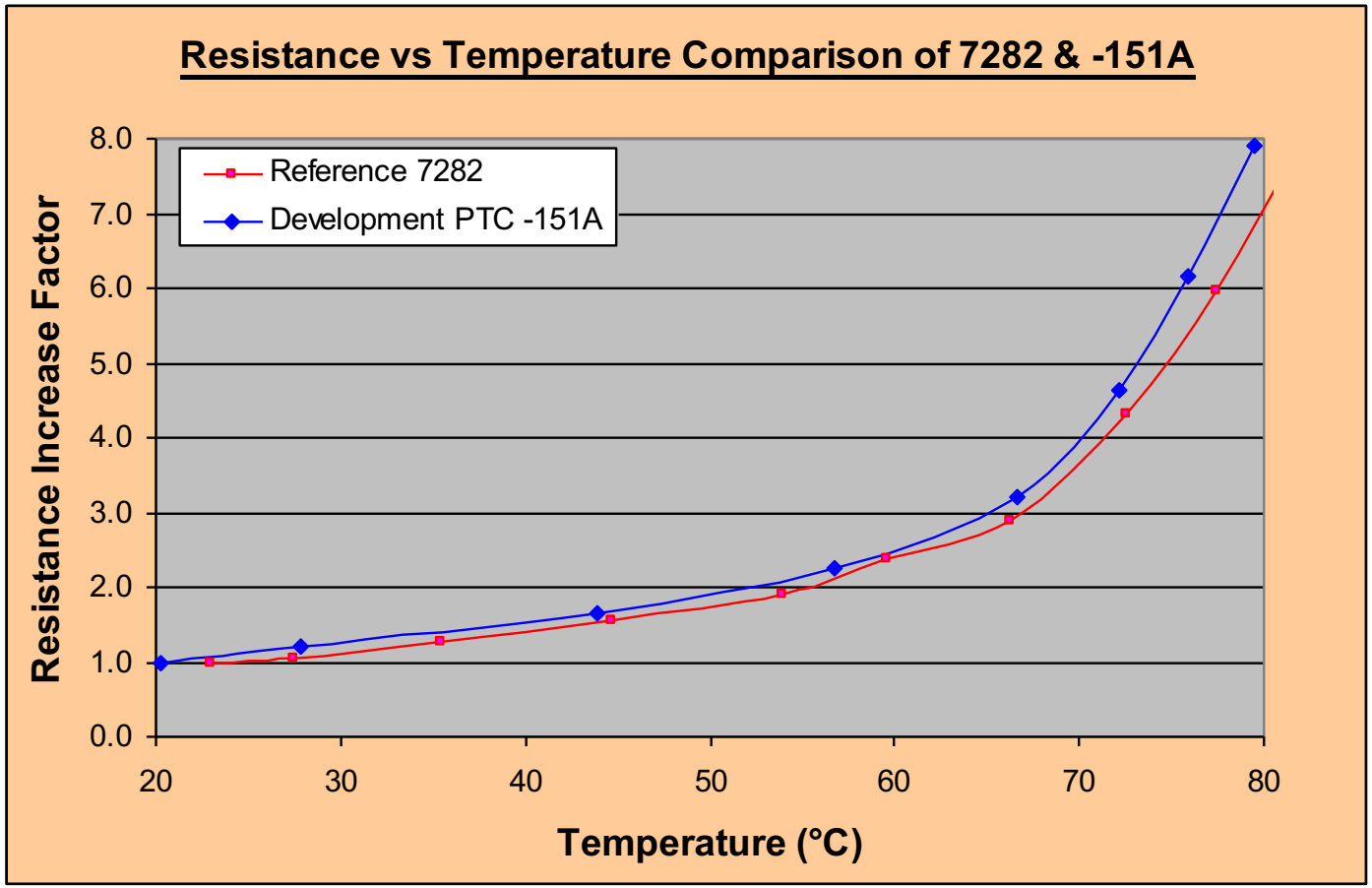
Category	ITW PTC Heater	Wire Type Heater	Carbon Type Heater
Self Regulation	Yes	Sensor Required	Sensor Required
Short Circuit Result	Self-Cauterizes	Burn Potential	Burn Potential
Fold Over Result	<5°C Increase	30°C Increase	15°C Increase
Conductor Temp	55°C	90°C	60°C
Current Draw	2.5A steady state	4.5A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

Source: ITW

Courtesy WET Automotive

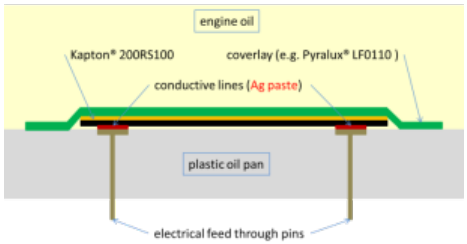


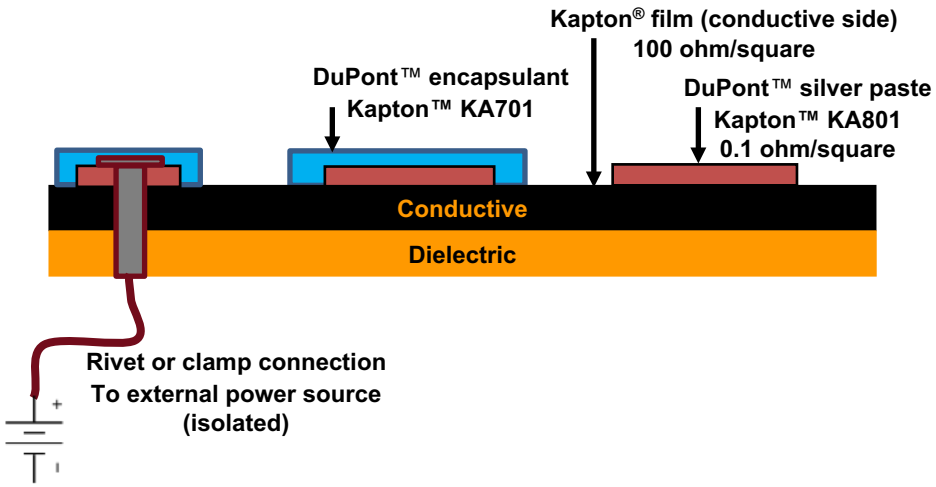
What is a PTC Carbon Resistor?



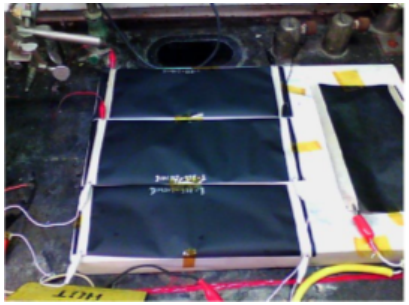
KA801 & Kapton® heaters demonstrations

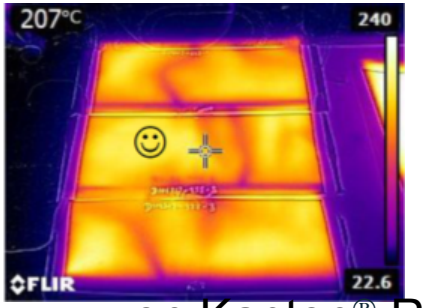




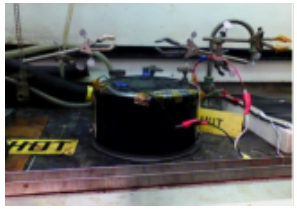


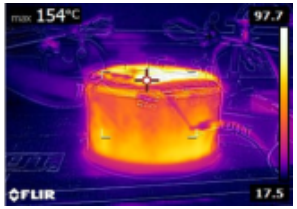
at ~207 ° C = ~405 F, held >1000 hours, cycled daily





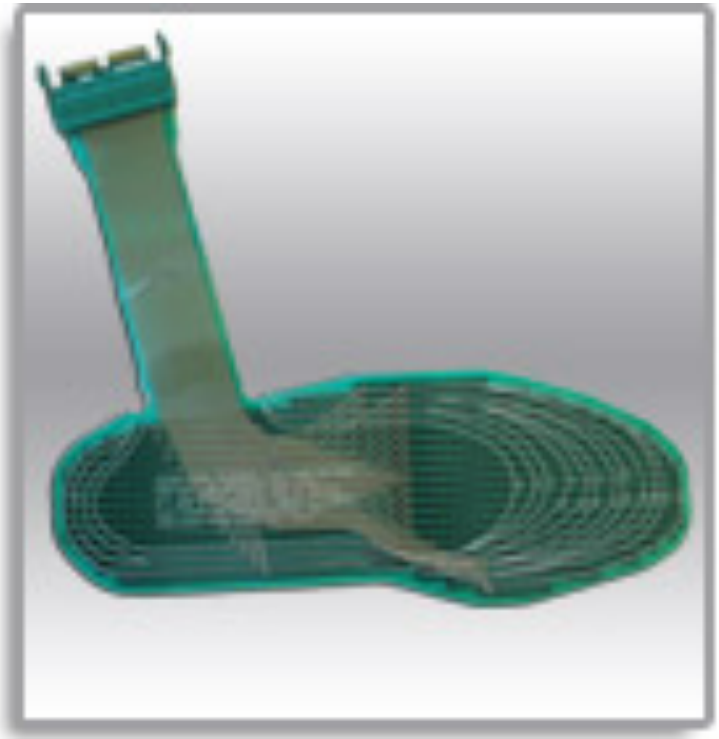
on Kapton® RS





Force Sensor: Carbon Conductor

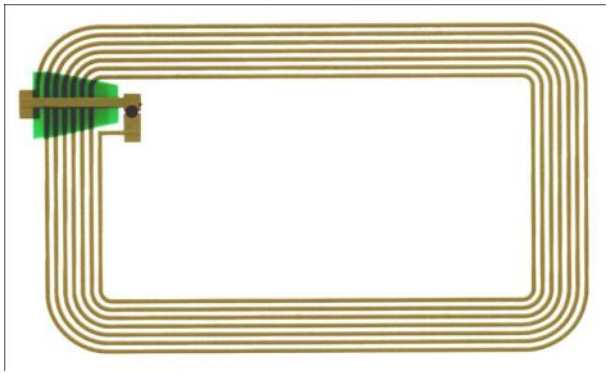
When Pressure is Applied the Resistance Decreases





Lamination of Conductors to Lower Resistance

Smart Card Processing



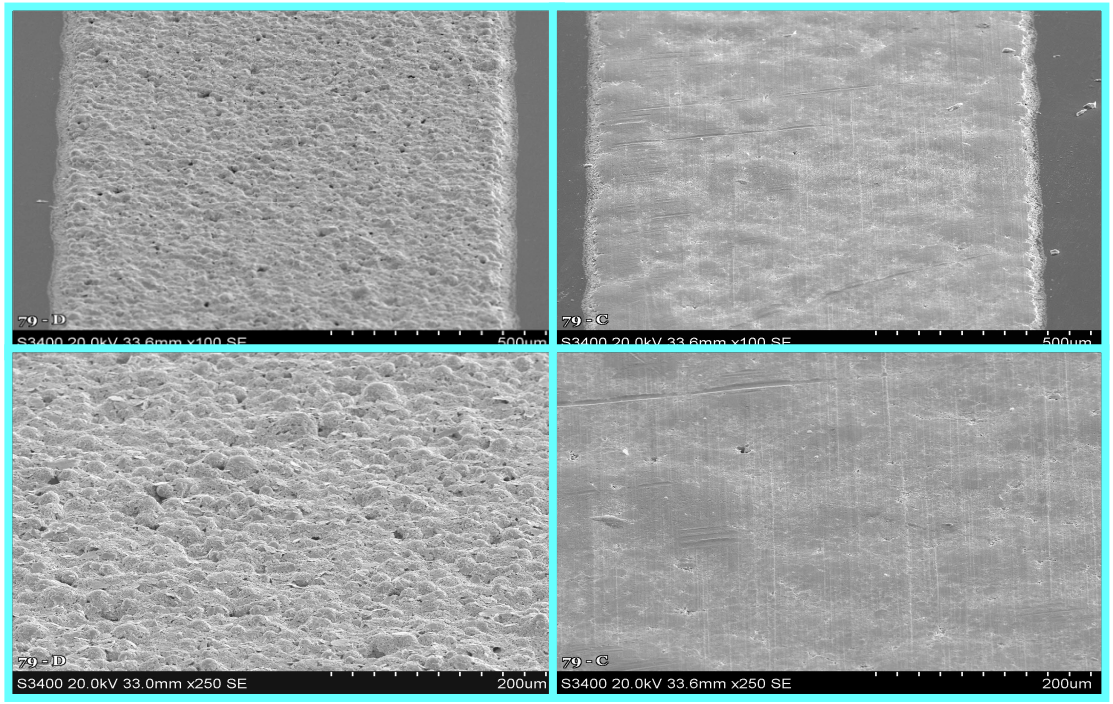








High Conductivity "Silver Alloy" for Smart Cards



PE815 Dried Print

Laminated / Hot Roll Calendered

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

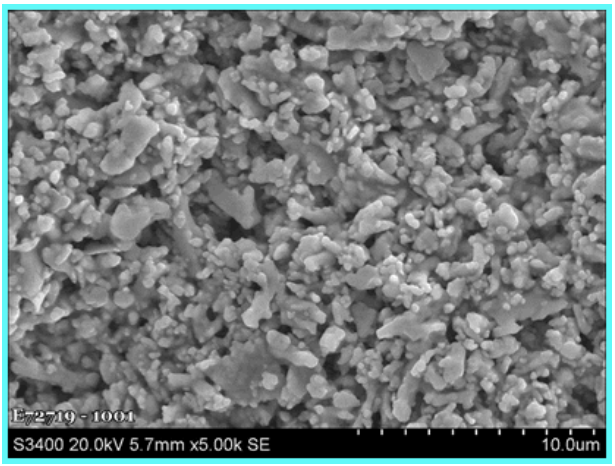


SINTERON 2000

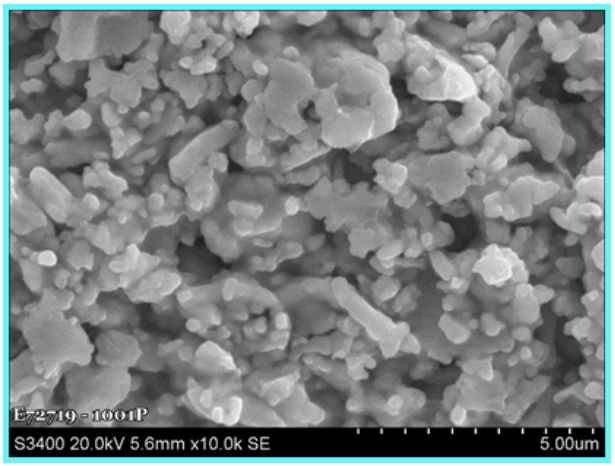


Pulseforge® 3300

Before / After Photonic Curing

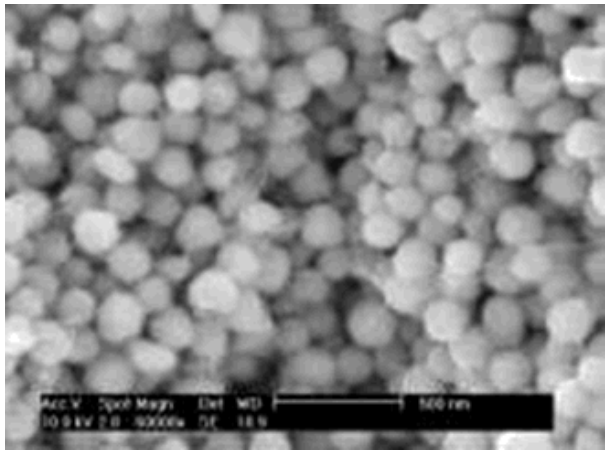


Ag Flake

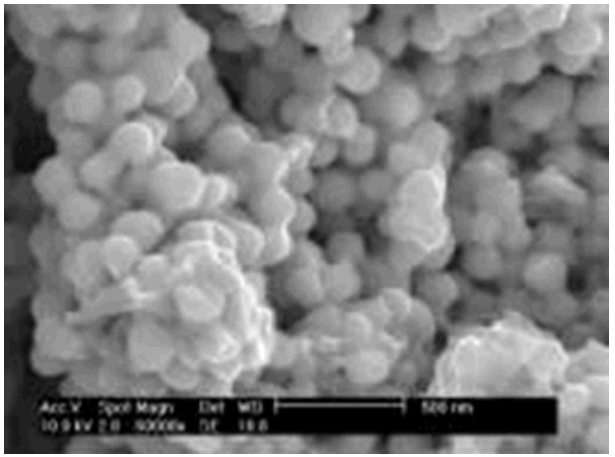


Thermal Cure 140C / 10min

Photonic Cure



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,

John Crumpton
DuPont Photovoltaic & Advanced Materials
14 Alexander Dr.
Research Triangle Park, NC 27709

The miracles of science™