FlexTech Alliance
for Displays & Flexible, Printed Electronics

Advances in Printed Electronic Materials that Meet Cost and Performance Needs

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Agenda

- DuPont & Printed Electronics
- Applications & Materials Enable Lower Cost
- Trends & Challenges
- New, Differentiated Material & Process Solutions
- Summary

DuPont 2012 Segment Sales

$3.4B
Nutrition & Health

$10.4B
Agriculture

$1.2B
Industrial Biosciences

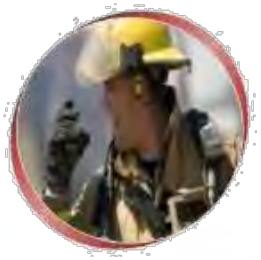
$2.7B
Electronics & Communications

$34.8B*

$6.4B
Performance Materials

$7.2B
Performance Chemicals

$3.8B
Safety & Protection



* Total company sales exclude transfers.

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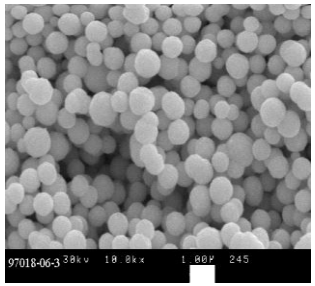
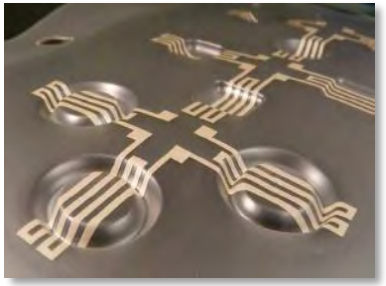
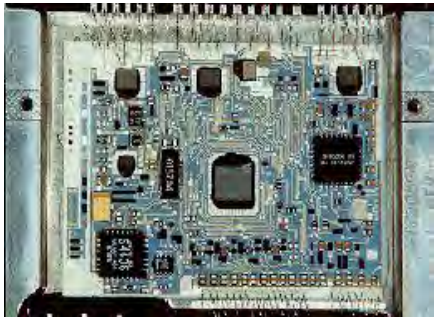
Microcircuit Materials Business Over 40 Years







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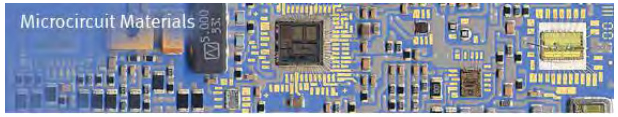
Traditional Printed Electronics at DuPont

Materials (>95% Screen Print)

- Conductors: Silver, Gold, Copper, Alloys
- Dielectrics – Multilayer, Cross-over, Encapsulant
- Resistors – Carbon, Ruthenium
- Specialty – PTC, Phosphor, ITO

Applications / Substrates

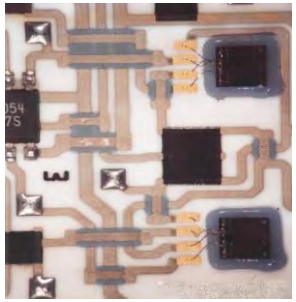
- Membrane Switch, EL / PET Film
- Rear Window Defogger / Glass
- Hybrid Microelectronics / Alumina
- Photovoltaic / Silicon
- Thin Film PV / Foil



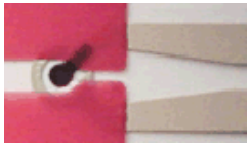
Thick Film Multilayer Hybrid

Battery Tester

Chip Resistors

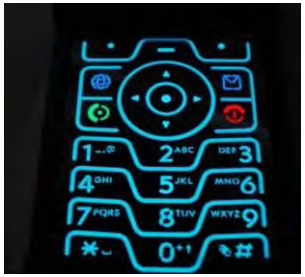


"Hybrid IC" on Alumina



Bio Test Strip

RFID Antenna



EL Lamps/Backlight

Membrane Touch Switch

Photovoltaic Si Cells

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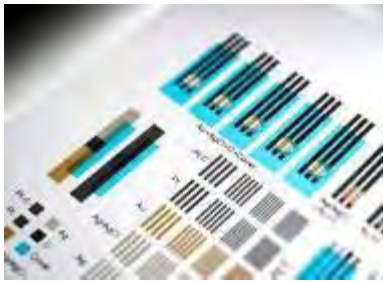

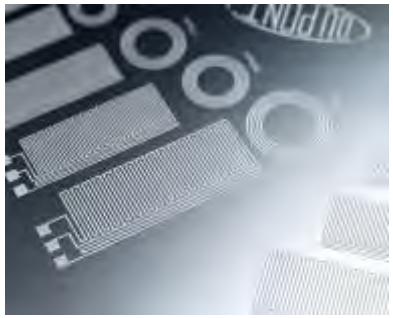

Current Products & Applications

- **Flexible TF Photovoltaics**
  Ag grid and bus bar
- **Biomedical sensors**
  Au, Ag/AgCl, carbon electrodes
- **Interconnects and membrane switches**
  Ag, C, dielectric
- **Electroluminescent lamps**
  Ag, phosphor, dielectric, carbon
- **RFID**
  Ag antenna
- **Displays, OLEDs, touch screens**
  Ag and C grid lines and connectors

R&D

- Ink-jet inks
- Nano-Ag powders and inks
- Transparent conductors

Core Competencies

- Fine powder production
- Polymer chemistry
- Dispersion techniques
- Imaging techniques
- Rheology
- Coating and Casting

Deposition

- Flat Screen
- Rotary screen
- Flexography
- Dip
- Spray

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Courtesy of Ascent

Flex TF PV

Displays

Touch Screens

Courtesy of Holst Centre

OLEDS

Courtesy of Power Paper

Printed Batteries

Flexible Displays

Courtesy of Holst Centre

Smart Packaging

Courtesy of Storaenso

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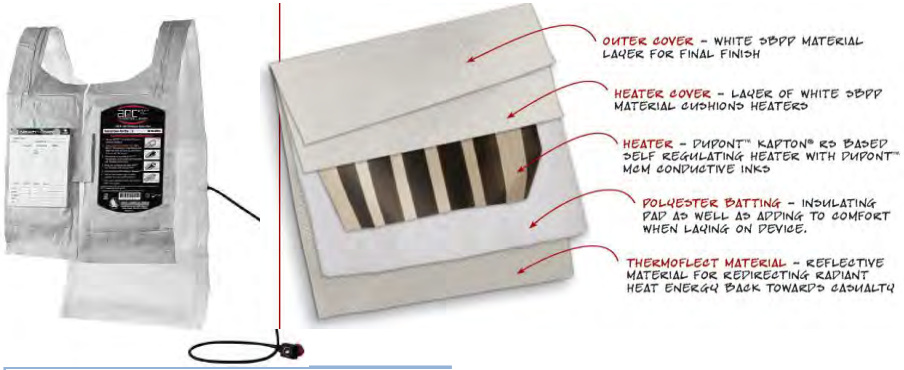
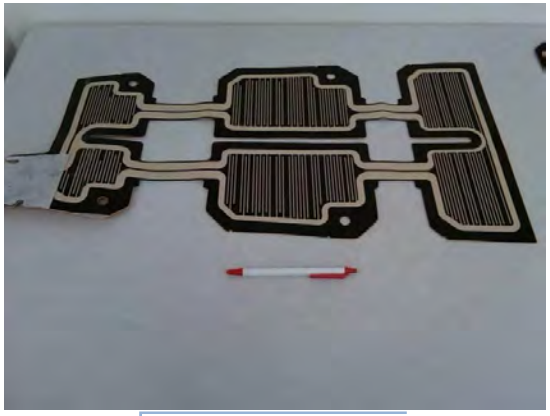
Current Focus Area

Technology Leadership & New Product/Application Development with Superior Functionality and Lower Total Cost to Customers

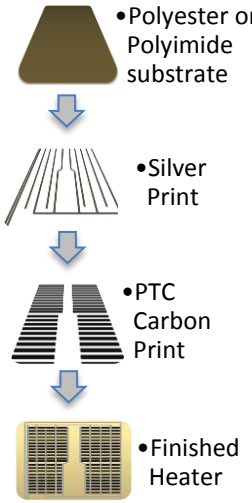
Screen Printed, Self Limiting Heaters



North American Rescue Hypothermia Prevention Vests



Seat Heater WET Automotive



Enabling Ink Materials

- ***NEW, Robust PTC Carbon Inks!***
  - **Heats, but is Self Limiting (fails cold)**
  - **New Formulations Replace 7282**
  - **Improved Temperature Stability**
  - **No Pre-Conditioning**
  - **Improved Compatibility w/Adhesives**
- ***NEW, High Conductivity Silver Inks!***
  - **Low Enough R for Single Print**
  - **Excellent Crease Resistance/Flexibility**

PTC Self Limiting Auto Seat Heaters

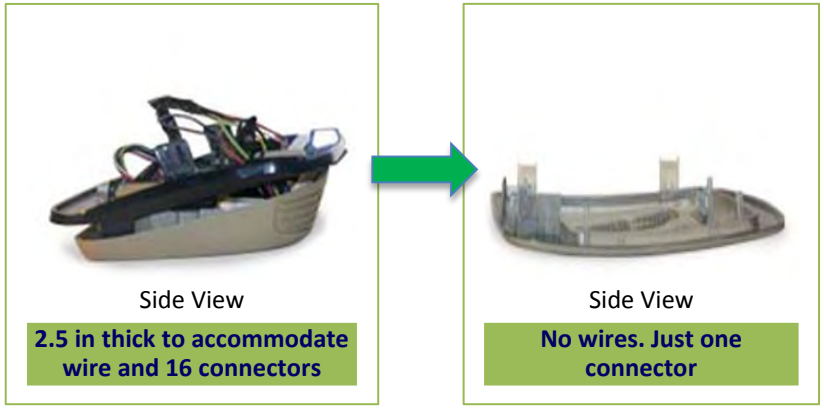
- **Address Liability Concerns**
- **Eliminate Controller and Temperature sensors, providing ~35% savings* vs. Incumbent Heated Wire Technology**
- **Lowest Energy Consumption technology**

**** Estimate***

Silver Conductors for 3D Thermoforming In-Mold Electronics

Standard Ag Ink Reference

New, Stretchable/Flexible Ag Ink !



Courtesy of T-Ink

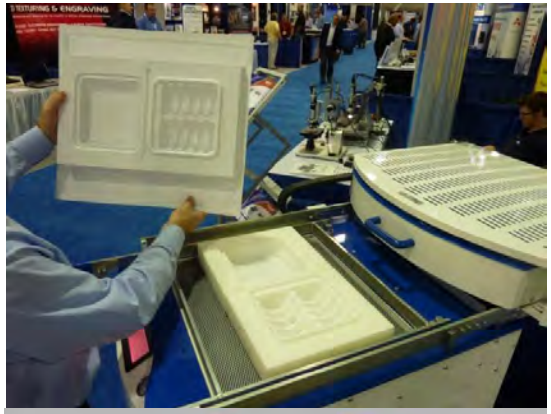
Enabling Ink Materials

- ***NEW, Ultra Flexible Silver Conductors***
  - **STRETCH >75%**
  - **Can withstand high temperature thermoform and In-Mold processing**
  - **Maintains Electrical Performance**
- ***NEW, Barrier & Insulating Dielectrics***
  - **Can withstand high temperature, thermoform and In-Mold processing**
  - **UV & Thermal Processing**

Automotive, Appliance, Medical, etc.

- **Capacitive Touch Design replaces Mechanical Switches for Simplicity, Reliability, Aesthetics**
- **Space & Weight Reduction, plus easier to assemble**

Thermoforming / In-Mold Electronics



Courtesy of Formech Inc.

Trends & Applications

- Eliminate electro-mechanical switches / knobs / etc.
- Reduced cost
- Reduced tooling and assembly costs
- Simpler supply chain
- Smaller, thinner, lighter
- More reliable
- Unlimited design options
- Drag and Drop design
- Quick turn prototyping

Prototyping Capability at DuPont 4th Qtr 2013

- Design Capabilities
- 20”x 20”x4” Printing & Thermoforming capability
- Multi-color UV, Thermoset, Hard-Coat Processing
- Injection Molding via DuPont Performance Polymers
- Polycarbonate, Polyolefin substrates & Others

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Trends in Materials Cost & Performance

Trend # 1

Impact of Precious Metals Price

***Unpredictable**, especially **Silver** since 2005*

Silver < $10/T.O. 1985 → 2005 with relatively low volatility;

Silver Peaked at $49/T.O. in 2011;

Silver is around $20/T.O. today but what about 2014? 2016?

How can users protect themselves against future cost spikes?

Solution # 1

Introduce New, Lower Cost Conductors

It isn't always that simple, however….

What is the Cost Target?

- ***>20% Reduction*** in Price ($/gr), and/or more ***Price Stability*** vs Ag cost?
- Other considerations such as Coverage (cm2/g); Screen Life?
- Additional capital equipment required for processing?

What is Acceptable Electrical Performance?

- Resistivity (mΩ/□/mil)--How efficiently does the ink utilize % Ag?
- Resistance (mΩ/□)--How thick do you have to print to get ***"Low Ohms"?***

Physical Performance?

- Adhesion, Crease Resistance, Line & Space Resolution
- Substrates other than PET film? (Coated Papers, Woven, Polyolefins)
- Long Term Aging Stability; Migration Resistance

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New ! (July 2013)

Lower Cost Thermal Cure Ag/Composite Conductors

Targeted Resistivity Ranges

- Allows designers to use inks with lower cost, based on track dimensions
- Each application has different conductivity requirements
- PE850, PE825 commercially available now
- Reduced-cost, higher resistivity versions under development
- ***Resistivity decade targets between 5 – 50 milliohms/sq/mil***

"Drop-In" Replacement in Most Cases

- No additional equipment required
- Use current printing/drying process
- Designed to meet ASTM specifications for generic MTS and Printed Electronics applications
- ***Conventional Solution for the Conventional Approach***

Trend # 2

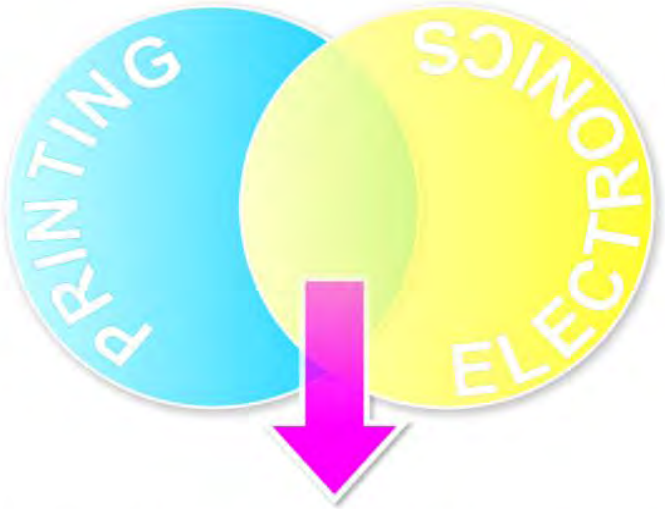
Convergence of Two Industries

Graphics Printing

- Visual Performance
- Roll-2-Roll Assets
- High Speed, Low Cost Printing

Electronics

- Functional Performance
- Precision Patterning
- Clean Rooms



Wide-spread, low-cost, lower-performance circuits with unconventional use *(at least in theory)*

Universities are Playing a Key Role

- Currently with Western Michigan (CAPE), Clemson (Sonoco), & Cal Poly State
- Long History of DuPont Collaboration with University Programs in Electronics

GOAL: Higher Speed, Lower Cost electronics

Solution #2

Develop Faster Curing Techniques

High Volume R2R Printing Requires Fast Drying

- **Highly Conductive Materials = Thicker Prints (solvent removal critical)**
- **Commercial Polymer Thick Film Inks have limitations**
- **Traditional drying equipment generally not sufficient**
  - Belt Oven: 120C for 2-6 minutes; Reel2Reel: 140C for 1 minute
  - Slow ramp-up of heat to substrate; limited airflow & turnover
  - Area of printed ink per impression too large
- **Other Issues for High Speed Printing Include:**
  - Limited # of Commercial Electronic Inks
  - Sample size too small to make cost-effective prototypes

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Curing Techniques for Printed Electronics

Thermal

Traditional process--may require high temps for extended times

UV

Limited Mostly to Dielectrics; Inefficient for opaque conductors

Photonic

Pulsed light, rapid sintering of particles, rapid solvent evaporation

Other

- **Laser**
  Selective exposure by scanning with focused laser
- **Microwave**
  Rapid sintering, low penetration depths (~ 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

Photonic Curing/ Pulsed 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
- Convenient: noncontact process, ambient conditions
- Process variables are adjusted to accommodate ink and application (strobe energy, pulse length, # of pulses, web speed)
- ***New Focus on Photonic Curing of Base Metal Inks for High Speed Printing Applications***

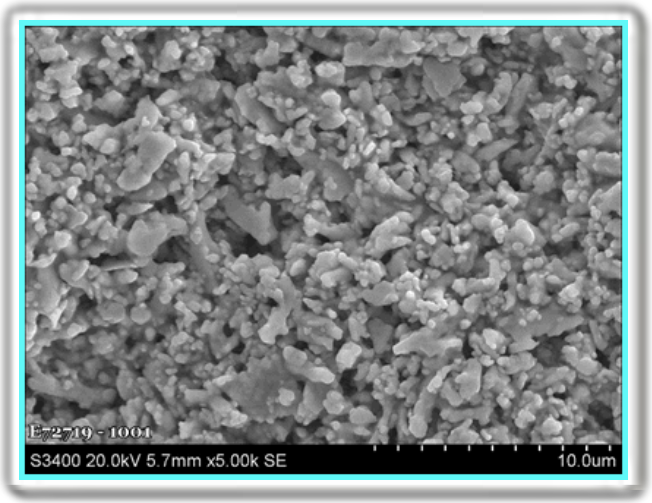
SINTERON 2000

PULSEFORGE® 3300

Commercial Units:

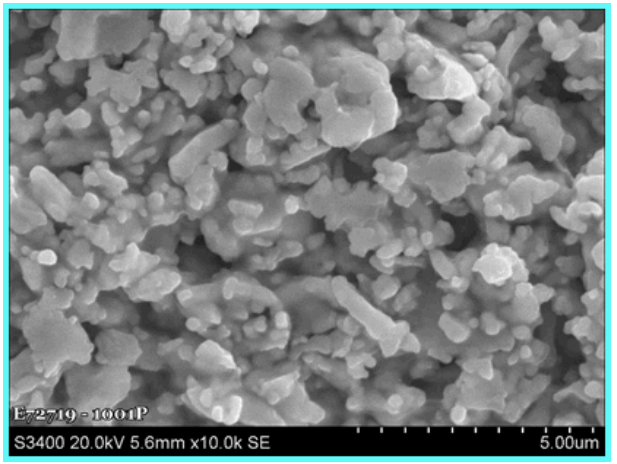
NovaCentrix PulseForge®
Xenon SINTERON™
Holst Center / Philips Aachen

Low Cost Conductors
Before / After Photonic Curing

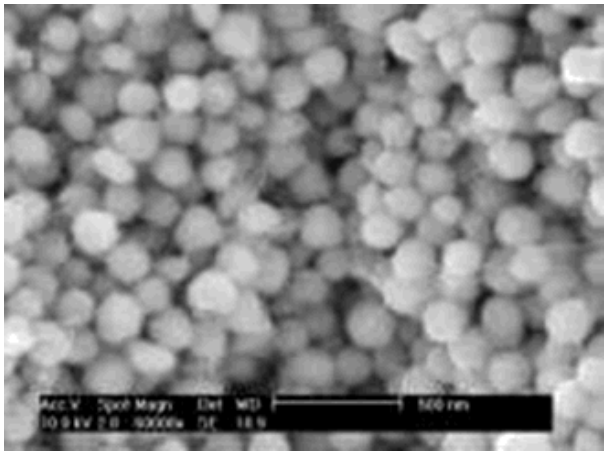


Thermal Cure 140C / 10min

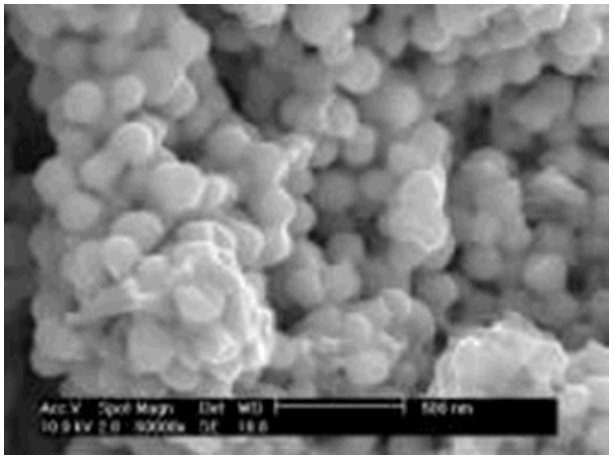
Ag Flake



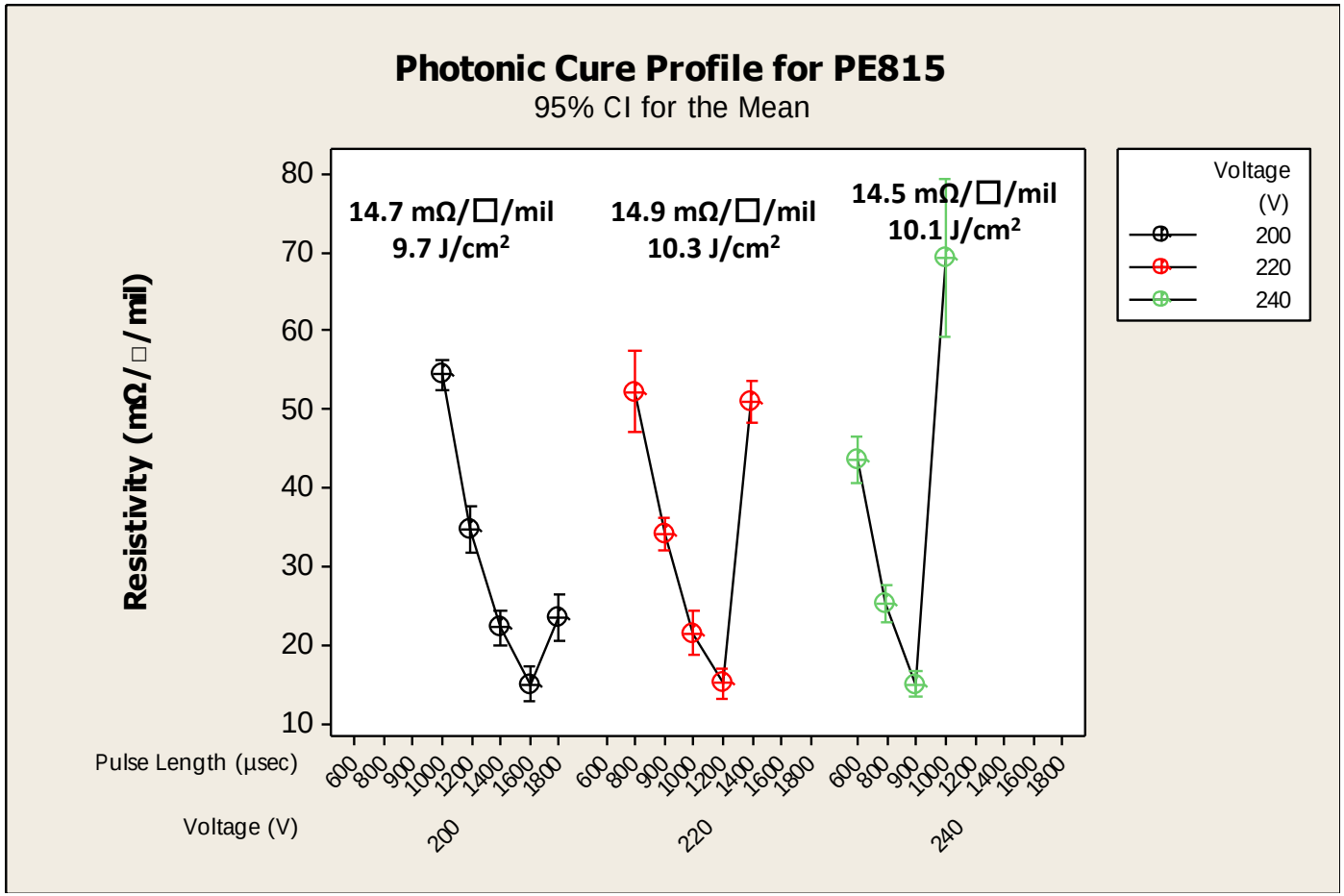
Photonic Cure



Ag Sphere



Photonic Curing Behavior for PE815



Minimum Resistivity achieved with several pulse voltage / pulse length combinations
Total exposure dose for each resistivity minimum is similar

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Lower Cost Conductors w/ Photonic Curing

		Resistivity (mOhms/sq/mil)	
Product ID	**Material**	**Oven (140C, 10 min)**	**Photonic Curing(*)**
5064H	**Silvers**	5	4
5025		12	9
PE850		**8**	**6**
7102	**Carbons**	28,400	28,000
7105		16,200	16,400
PE815	**Alloys &**	**90**	**12**
PE825	**Composites**	**20**	**20**
5524		40	35

- PE815 Designed for Photonic Curing / Lamination/ Hot Roll Calendering
- PE850, PE825 Designed for Thermal Cure only
- ***PE815, PE825, PE850 Available Now***
- Controlled Lab Testing with NovaCentrix PulseForge ® 3200
- Printed/dried on DuPont Teijin Films Melinex® ST505

The data above reflects results under a given experimental design and under controlled conditions, and should not be used to establish specification limits or used alone as the basis of design or appropriateness for use in a particular process or product configuration. The data provided herein shall not constitute a warranty of any kind.

Improved Performance Using Lamination / Hot Roll Calendering

Smart Card Production Unit
Courtesy Muhlbauer

Trends & Applications

- Contactless Smart Cards in Production since early 1990's
- Calendering used in paper & film manufacturing
- Desire to switch from high Ag-content to new Alloys
- Additive High-Speed Screen Printing vs Etched Foil
- In use with DuPont 5029 Ag; PE815 & New Alloy Inks*
- New, targeted resistivity inks under development
- Smart Card, RFID, MTS, Biomedical, Smart Packaging
- Uniaxial Lamination or Continuous Hot Roll Calendering*

**Patents Pending*

Prototyping Capability at DuPont

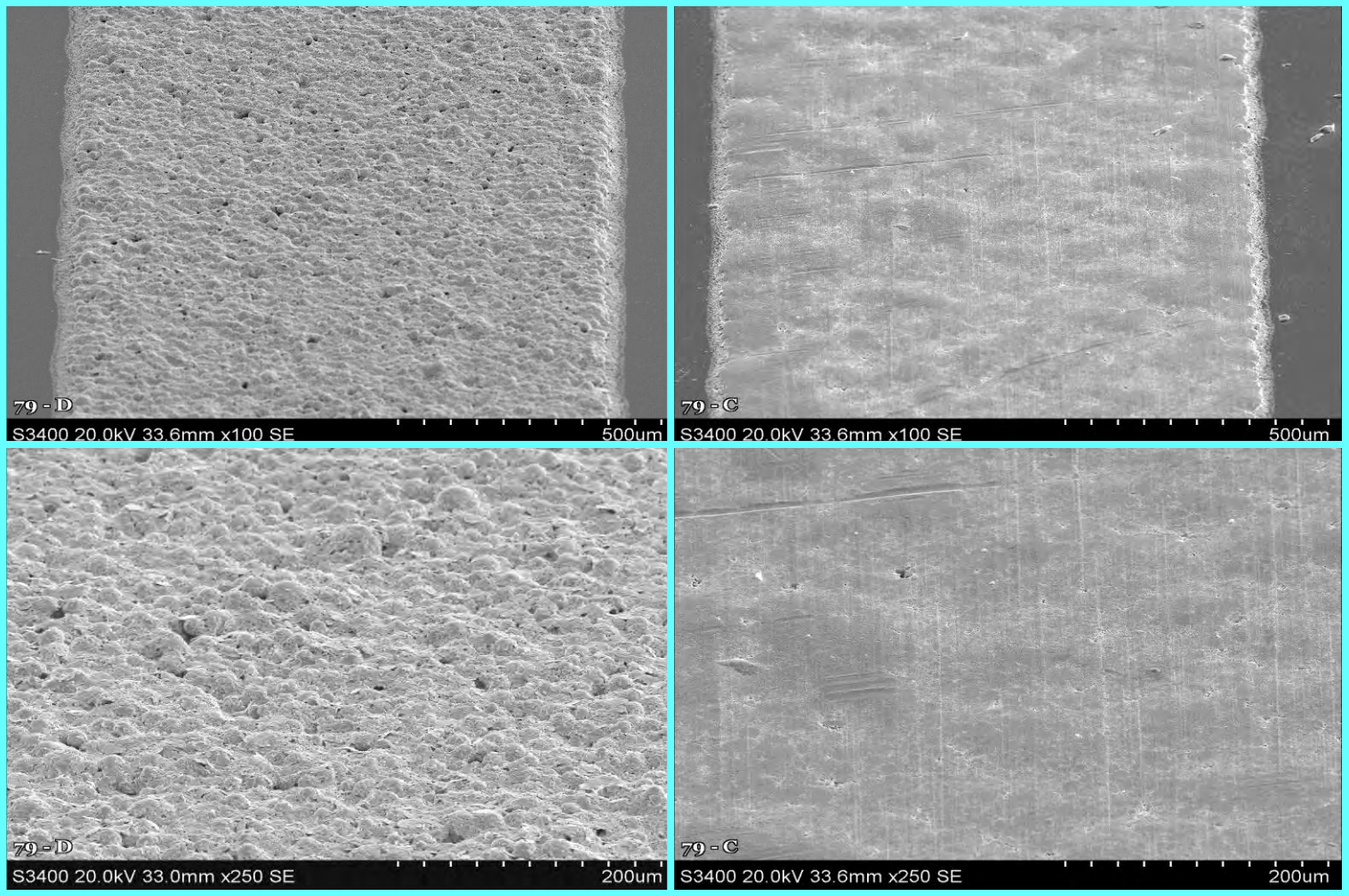
- Small scale Sheet or Roll Calendering up to 130C
- 18"x18" Uniaxial Lamination up to 130C
- New Printed Electronics Lab @ RTP 4th Qtr 2013

Lab-Scale Calendering Unit
Courtesy Mathis AG

Lamination / Calendered Surface

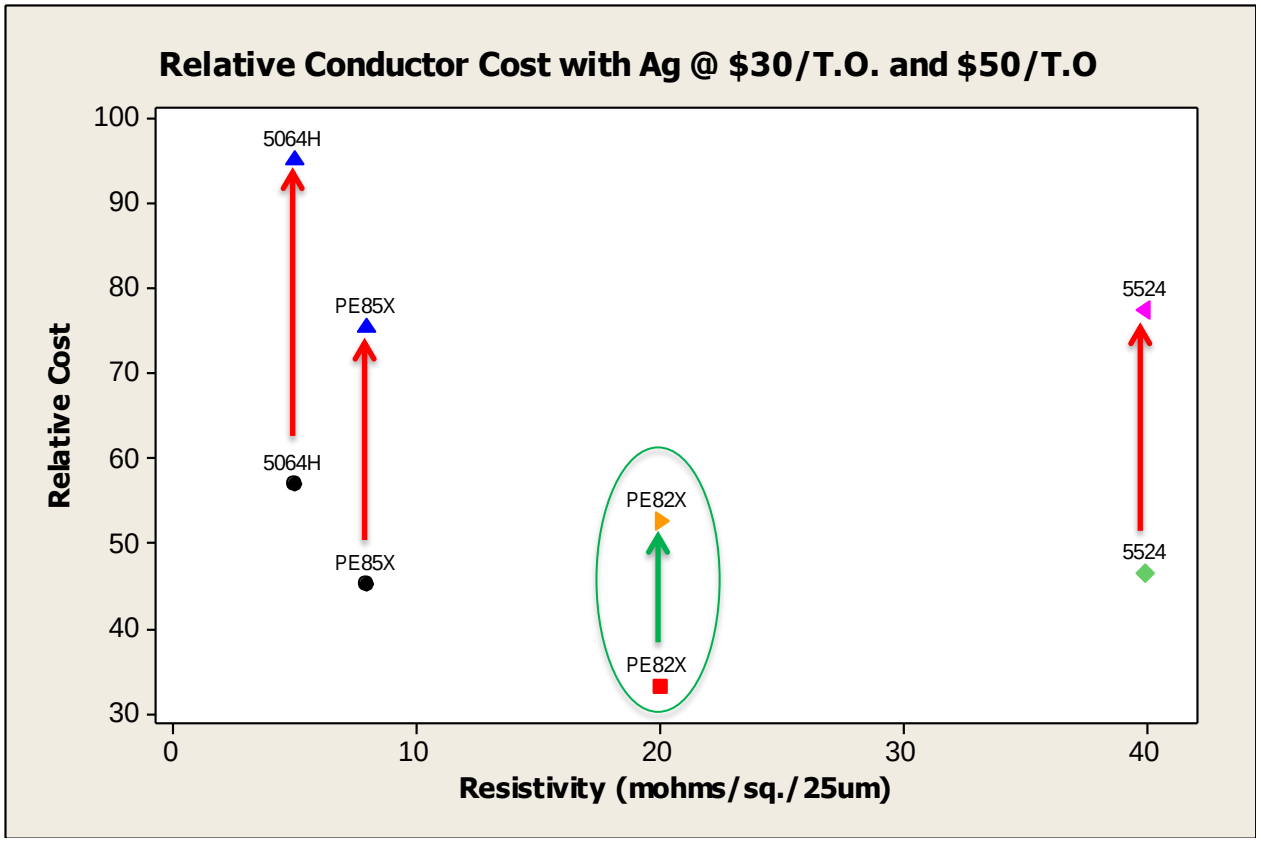
Dried Print

Laminated / Hot Roll Calendered



Conductor Costs – Thermal (140C) Cure

Protection against rising Silver Costs



PE850 (Silver)

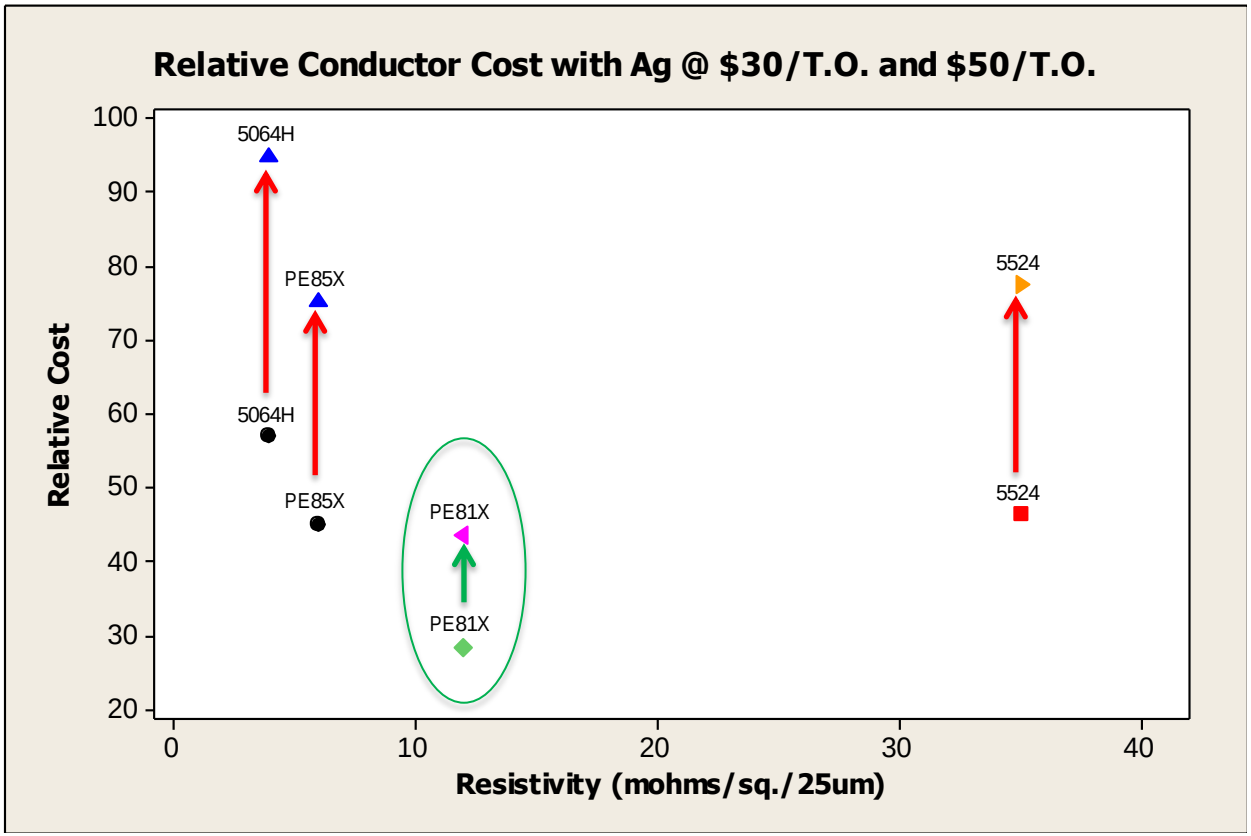
- ✓ Lower Ag content
- ✓ Low Resistivity
- ✓ High Coverage

PE825 (Composite)

- ✓ Lowest Cost
- ✓ Good Resistivity
- ✓ Lower $/TO Sensitivity

Conductor Costs – Photonic Cure / Lamination / Calendering

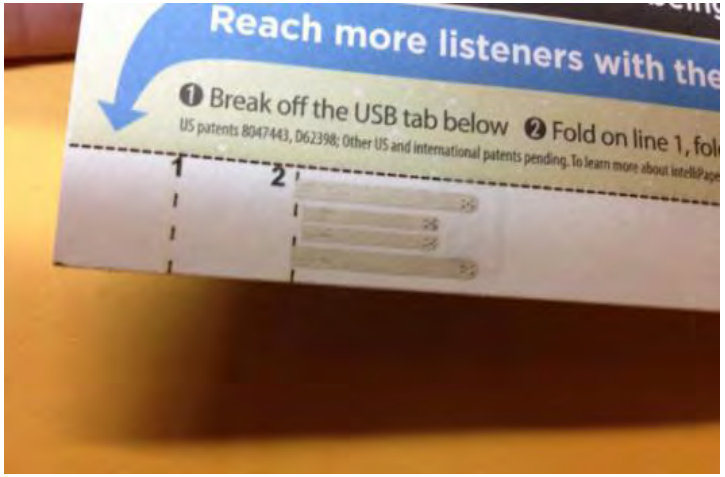
Protection against rising Silver Costs



PE815 (Alloy)

- ✓ Lowest Cost
- ✓ Good Resistivity
- ✓ Lower $/TO Sensitivity

Printed Electronics on Paper



Trends & Applications

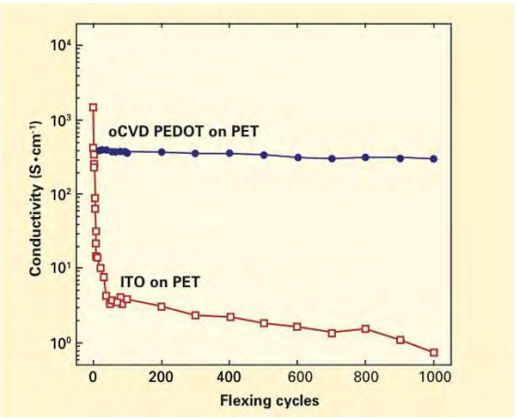
- RFID Labels for Inventory/Supply Chain
- Passports/IDs/Document Security
- I/C Connect to USB/Readers (IntelliPaper)
- Solvent or Water Based Flexo/Screen Print
- Electrical Performance vs Non-Permeable
- Number of New Substrate Technologies

Printed Solar Cells on Paper

PV Cells Screen Printed on Newspaper

MITei
MIT Energy Initiative

250 PV Cells = 50 Volts



Trends & Applications

- Low Cost PV need Low Cost Substrate & Inks
- Thin Film Electrode PEDOT vs High-Cost ITO
- High Speed Reel-2-Reel Printing for Volume
- Flexibility = Better Efficiency/Crease Performance
- Laminated w/ Plastic Film for Moisture Resistance

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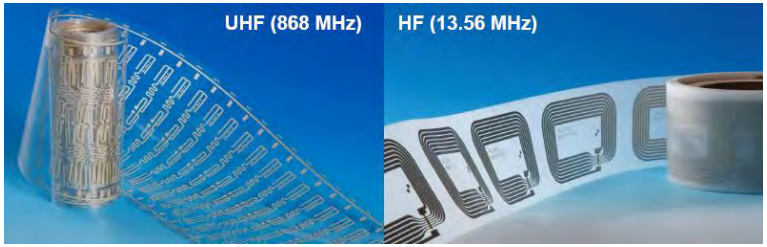
Printed Electronic Packaging

Packaging

- Diversification
- Logistics
- Traceability
- Sensing
- Medical

Advertising

- Diversification
- Interactivity
- Visual Impact



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Printed Electronics on Paper

T-Ink

Courtesy T-Ink

Hallmark Interactive

McDonald's Toy

Interactive Cereal Box

Kent Touch/LED Package

Summary

New Printed Functional Inks can Enable Lower Cost Solutions

- Enabled by advances in design, processing, and materials
- In-Mold Electronics & lower cost help drive innovation
- Alternative substrates to traditional PET film (Paper, etc.)
- ***Screen Printing is still the dominant printing technique***

Introduction of NEW Lower Cost Conductor Technology

- For traditional thermal curing & emerging photonic curing
- Can be used with lamination & hot roll calendering
- ***Provides protection against precious metal pricing***
- More new formulations & unique applications going forward

There are many Commercial / Developmental Material Options

- Application / Design Dependent
- ***Work with the Ink Materials Suppliers***

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Thank you

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