Functional Inks for IME and High Temperature Applications

Hee Hyun Lee
DuPont MCM

TechConnect World 2022
June 13
AGENDA

DuPont Functional Inks for Flexible Electronics
In-Mold Electronics (IME) for 3D Electronics
New Generation IME Inks
Polyimide Inks for High Temperature Applications
DuPont MCM’s Functional Ink Technology Across the Spectrum of Plastic Substrate with Temperatures

PE827/828 Inks for Low Temperature Printed Electronics

ME-series Inks In-Mold Electronics Materials

HT-series Inks for High Temperature Electronics

PE-series Inks Stretchable Electronics Materials

Low Temperature

High Temperature

Representative Polymeric Substrate for Flexible Electronics

Copyright © 2022 DuPont. All rights reserved.
Screen Printing

• Functional pastes are screen printed to form a desired electronic pattern on a substrate of choice, with/without graphic inks.
• The pastes are dried to remove the solvents
• Multilayers are fabricated by repeating the print/dry steps

Drying

A critical processing parameter
It’s important to ensure complete solvent removal

▪ Temperature < 120°C for PC (best 110°C to 120°C)
▪ Time – Dependent on drier efficiency
▪ Air – Good airflow is essential
During the drying step, solvent is removed & the conductive particles pack together forming electrical pathways.

Choice of particle morphology is important
- Flake is preferred (better conductivity & ↓ Ag loading)

Copyright © 2022 DuPont. All rights reserved.
In-Mold Electronics (IME) for 3D Structured Electronics

IME is a printed electronic circuit, on a polymeric film, which will have undergone a thermoforming and injection molding process to form a 3D-functional device (typically used with Capacitive Touch Technology)

Enabling Ink Technology

Stretchable inks (without cracks) which can withstand the high temperature processes / Choice of resin chemistry and particle morphology are very important to achieve stretchability and high temperature resistance

Conventional Ag

ME604
In-Mold Electronics in 3 steps

This technology is a natural fit with existing processes

Considered an *extension / addition* to IMD/FIM (Film Insert Molding) - base technology from the 1990’s

Essentially combines film, graphics and electronics to form a 3D functional fully integrated electronic device with components.
Example of The Value IME Brings

Overhead Control Panel Comparison

64 parts
45mm part thickness
650g weight

1 molded part + small PCBA
3mm part thickness (-90%)
200g weight (-70%)

Up To 70% Lighter
Mechanical buttons and wires elimination, IME part can be as slim as 2mm thick!

New Design Freedom
Enable 3D modern Smart Surfaces design with continuous surface

Up To 40% Assembly Time Reduction
Switches and LED embedded in structure significantly reduced parts for assembly

Highly Touch Sensitive
Capacitive switches are printed directly on device film to minimize signal travel distance

Durability
Injection molded part protects components from vibration / environment

Up To 30% Less Cost
Simpler and more efficient production
DuPont IME Suite of Pastes

**Silver conductors**
- ME604 - 35 mΩ/□/mil formable, General purpose
- ME614 - 30 mΩ/□/mil formable, Laser patternable
- ME102 - 14 mΩ/□/mil RFID

**Conductive Adhesive**
- ME902 - 1200 g-force, flexible

**Transparent conductor**
- ME802 - 500 Ω/□, 90%+ VLT

**Crossover Dielectric**
- ME778, ME779 – BDV > 2.5 kV, white

**Protection Encapsulant**
- ME772 - Clear, formable over-print
- ME780 - Clear, formable with UV protection

**Carbon conductor**
- ME201 - 500 mΩ/□/mil stretchable
## Meet Our New Conductor Ink Family Members

<table>
<thead>
<tr>
<th>Gen3 Products</th>
<th>What are the improvements?</th>
<th>Benefit to customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor (ME604)</td>
<td>• Higher conductivity&lt;br&gt;• Higher thermoformability</td>
<td>✓ enhanced design freedom&lt;br&gt;✓ higher productivity</td>
</tr>
<tr>
<td>Conductor (ME614)</td>
<td>• Higher conductivity&lt;br&gt;• Higher thermoformability&lt;br&gt;• Laser patternable</td>
<td>✓ enhanced design freedom&lt;br&gt;✓ higher productivity&lt;br&gt;✓ enabling fine line technology (30µm l/s)</td>
</tr>
<tr>
<td>Conductor (ME102)</td>
<td>• Highest conductivity</td>
<td>✓ enhanced design flexibility&lt;br&gt;✓ extension of potential applications (RFID Antennas)</td>
</tr>
</tbody>
</table>
Stretch Comparison: ME604 (Gen3) vs. ME602 (Gen2)

**1mm wide line**

**0.5mm wide line**

**0.25mm wide line**

- **ME602**
- **ME604**

Thermoformed Part for Stretching Test

Morphology at Highly Stretched Track#12

- Cracking visible
- Dense appearance

Copyright © 2022 DuPont. All rights reserved.
ME614(Gen3): Fine Line Patternable Conductor

Laser Structured ME614 on PET substrate
Gen 2 Crossover Dielectric

Product name: **ME778 and ME779** *(white color)*

Prevent Electrical Shorting between Top and Bottom conductor lines
Reduced Pinhole In Crossover Dielectric

Feature 1
*Improved polycarbonate substrate compatible with fewer pinholes (close to pinhole-free)*
Improved Crossover Reliability

Features 2

*Improved crossover thermoformability = Improve reliability*

<table>
<thead>
<tr>
<th>Cone line</th>
<th>Gen 1</th>
<th>Gen 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.7</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>6.2</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>7.0</td>
<td>3.7</td>
</tr>
<tr>
<td>6</td>
<td>7.9</td>
<td>4.7</td>
</tr>
<tr>
<td>7</td>
<td>9.8</td>
<td>5.3</td>
</tr>
<tr>
<td>8</td>
<td>10.8</td>
<td>6.5</td>
</tr>
<tr>
<td>9</td>
<td>12.9</td>
<td>7.2</td>
</tr>
<tr>
<td>10</td>
<td>15.3</td>
<td>8.9</td>
</tr>
<tr>
<td>11</td>
<td>17.6</td>
<td>10.4</td>
</tr>
<tr>
<td>12</td>
<td>19.7</td>
<td>12.9</td>
</tr>
<tr>
<td>13</td>
<td>21.2</td>
<td>16.4</td>
</tr>
<tr>
<td>14</td>
<td>22.0</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Build structure

- Top conductor
- x-over dielectric
- x-over dielectric
- x-over dielectric
- Bottom conductor
- PC substrate

Source: Holst Centre
Reduced Print Layers of Crossover Required

Crossover Effectiveness

![Bar chart showing crossover effectiveness for Gen2 and Gen1 products with different numbers of layers.]

Summary
- Excellent printability with minimal pin-holing
- High dielectric insulation properties with 2 - 3 printed layers
- High elongation with minimal / no cracking after thermoforming

Total number of parts, N= 50

Copyright © 2022 DuPont. All rights reserved.
ECA: Electrically Conductive Adhesive

Product name: ME902

Feature: Balanced Adhesion and Flexibility to incorporate components (ex: LEDs) during Thermoforming
LED Placed On Flat Film Before Thermoforming
Design Targets For New ECA

<table>
<thead>
<tr>
<th>Competition (Epoxy system)</th>
<th>DuPont ECA design target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td></td>
</tr>
<tr>
<td>Adhesion (2 kg)</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td></td>
</tr>
</tbody>
</table>

| Conductivity | | |
| Adhesion (1 kg)* | | |
| Flexibility | | |

* 1206 LED package Dimensions are 3.2x1.6mm. Surface area of 5mm²

Lack of Flexibility could result in cracking / delamination
- During general handling
- During thermoforming
- Under vibration during use
**Flexibility Test Result**

Flexibility test with LED lit up (N= 30) with 1” PVC pipe

**Product Benefits**
- One-part electrically conductive adhesive
- Provides good adhesion and flexibility
- Improved stretchability during thermoforming; survives over-molding
- Application via stencil-printing or syringe dispense

**Column (left to right):** Flat Flex Once 15 minutes 60 minutes

**ME902 (Gen2)**

**ME901 (Gen1)**

**Non-DuPont commercial conductive glue (Epoxy type)**

Green = LED Lit
Red = Fail to light up

Copyright © 2022 DuPont. All rights reserved.
Summary / Conclusions

• DuPont MCM has developed a family of stretchable, thermoformable, functional inks enabling circuitry to be embedded and integrated into 3D structures

• New IME inks have been introduced, providing improved performance (conductivity, dielectric strength and stretchability)

• IME technology provides the possibility to create novel & innovative solutions in Flexible Electronics
High Temperature Applicable Functional Inks

PE827/828 Inks for Low Temperature Printed Electronics

ME-series Inks In-Mold Electronics Materials

HT-series Inks for High Temperature Electronics
Vehicle contains Polyimide resin

PE-series Inks Stretchable Electronics Materials

Copyright © 2022 DuPont. All rights reserved.
# Major Improvement vs. Previous Products

<table>
<thead>
<tr>
<th></th>
<th>Previous Products</th>
<th>New Products</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dielectric</strong></td>
<td>KA701 (Fluorinated PI binder)</td>
<td><strong>HT-702</strong> (F-free PI binder), To be launched in 2022</td>
<td>• Higher Thermal / Chemical Resistance</td>
</tr>
<tr>
<td>(Inorganic Filler)</td>
<td></td>
<td></td>
<td>• Higher Dielectric Strength</td>
</tr>
<tr>
<td><strong>Resistor</strong></td>
<td>7082M, 7102 (Non-PI binder)</td>
<td><strong>HT-602, HT-603</strong> (F-free PI binder), To be launched in 2022</td>
<td>• Higher Thermal / Chemical Resistance</td>
</tr>
<tr>
<td>(CB filler)</td>
<td></td>
<td></td>
<td>• Lower TCR</td>
</tr>
<tr>
<td><strong>Conductor</strong></td>
<td>KA801 (Fluorinated PI binder)</td>
<td><strong>HT-802</strong> (F-free PI binder), Commercialized</td>
<td>• Higher Thermal / Chemical Resistance</td>
</tr>
<tr>
<td>(Ag Flakes)</td>
<td></td>
<td></td>
<td>• Lower Resistivity</td>
</tr>
</tbody>
</table>

Fluorine Free PI binder allows higher Thermal/Chemical Resistance
HT-702 (Dielectric): Technical Features

- Good encapsulant and x-over dielectric (BDV > 0.5kV)
- Excellent thermal resistance up to 300°C (solder resistance)
- Excellent chemical resistance to common solvents
- Excellent adhesion to a variety of substrates
- Flexible
- No harmful off-gases (Halogen free)
## HT-702(Dielectric): High Temperature Resistance

<table>
<thead>
<tr>
<th></th>
<th>HT-702 (Gen 2)</th>
<th>KA701 (Gen 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss @ 300 °C</td>
<td>2.3%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Weight loss @ 495 °C</td>
<td>5.2%</td>
<td>16.1%</td>
</tr>
</tbody>
</table>

**TGA Analysis**
- Ramping up to 500°C, 10°C/min, Air

Much Improved Thermal Stability of HT-702 vs. KA701
# HT-702 (Dielectric): Applications

*High temperature resistant encapsulant to protect Cu circuit layers in PCB/FPC*

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Rigid Substrate</th>
<th>Flexible Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Solder Mask</td>
<td>Coverlay</td>
</tr>
<tr>
<td>Incumbent</td>
<td>LPI SM ink (Epoxy based)</td>
<td>Pyralux® PI + Adhesive layer</td>
</tr>
<tr>
<td></td>
<td>Photo-imaging process</td>
<td>Lamination, Laser opening</td>
</tr>
<tr>
<td>Limitation of Incumbent</td>
<td>Thermal resistance, Multiple steps</td>
<td>Multiple process steps</td>
</tr>
<tr>
<td>Values to customers</td>
<td>Additive printing (Fewer process steps), High thermal resistance</td>
<td></td>
</tr>
</tbody>
</table>

---

**Solder Mask**

*Solderedjoint - Solder mask - Wikipedia
FPC Coverlay (Cover Layer) | Flex PCB Manufacturer | MADPCB

Copyright © 2022 DuPont. All rights reserved.
HT-602, HT-603 (CB Resistors): Technical Features

- High thermal stability
- Stable Resistance against applied power and environmental temperatures
- Excellent adhesion to a variety of substrates
- Broad resistance (50~2500Ω/□) by blending two resistors and print thickness control
- May be blended with HT-802 conductor to get very low resistance (< 10 Ω/□)
- Excellent chemical resistance
- Flexible/Bendable

180deg bending over 1/4” diameter metal rod

Copyright © 2022 DuPont. All rights reserved.
HT-602, HT-603: CB Resistor Ink Printed on Kapton®

- Screen printed on Kapton film (5mil)
- Curing at 250°C for 1hr
- Thickness ~ 5μm

Broad range of Resistance (Ohm/sq) can be obtained by blending HT-602 and HT-603
HT Resistors: Short-time overload (STOL) test

Test procedure
Monitor resistance deviation (dR/R0) after applying short-time overload.
Chip resistor’s standard criteria is +/-1% at 2.5 times voltage.

Test condition
Test time: 5 sec
Voltage: Step increase until +/-1%
Sample size: 0.5 x 0.5 mm
Criteria: +/- 1% R change

Stable resistance up to 200W/cm²
HT Resistors: TCR (Resistance Change with Temperature)

$$TCR = \frac{(R2 - R1)}{R1(T2 - T1)}$$

Much lower Resistance change vs. Temperatures by using Polyimide resin

Copyright © 2022 DuPont. All rights reserved.
HT-802 (Conductor): Technical Features

- Highly conductive ($\leq 5\, \text{m}\Omega/\text{sq/mil}$)
- Screen printable, Nozzle dispensable
- High thermal stability; Temperature operation up to 300°C, 4000hrs, 350°C < 3hrs
- Good chemical stability (can be Ni plated, solvent resistance)
- Excellent adhesion to a variety of substrates including Kapton® films
- Flexible/Bendable
- Ideal for heater applications
- No harmful outgassing (passed NASA outgas test, ASTM E595)
Kapton® RS heater with HT-802 electrode

Highly Conductive, Flexible, Thermal Resistant HT-802: Ideal for Flexible Heater applications

Uniform heating > 230°C
Summary / Conclusions

• DuPont has developed a family of functional inks (Dielectric, Resistor and Conductor) for high temperature application using Polyimide resin

• New HT inks have been introduced, providing improved performance (Thermal stability, Chemical resistance)

• This technology provides the possibility to create novel & innovative solutions with additive printing technology on a variety of polymeric / Inorganic substrates
Thank you