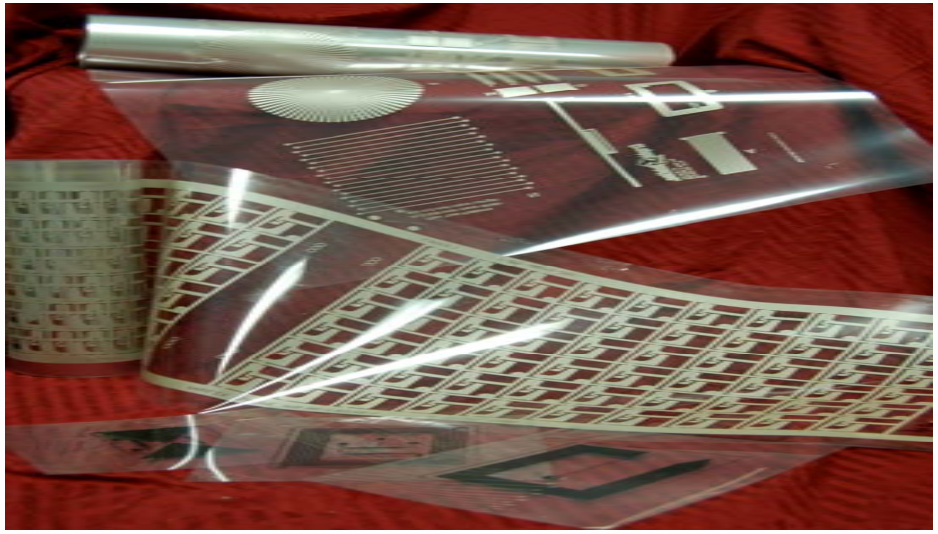
APEX EXPO 2012 IPC

Printed Electronics - Performance Requirements for Flexible Substrates



Neil Bolding
Manager, Quality & Technical

MacDermid Autotype Inc.

MacDermid Autotype

Presentation Expectations

- **Will**
  - Define Printed Electronics
  - Provide general market information & Applications
  - Provide performance information on a wide variety of thermoplastic films
  - Provide processing considerations for current PE applications
  - Provide incite into future product developments
- **Will Not**
  - Provide specific substrate processing or ink recommendations per PE application
  - Provide information on paper or foils

Printed Electronics

- Is a set of printing methods used to create electronic circuits, sensors, devices, and various electronics products.
- Is emerging as a technology that can replace traditional photolithography process, which requires costly material, very complex process, and expensive equipment in manufacturing of simple circuits and electronic components.
- Enables direct patterning of desired materials on the desired location without a complex process.

Displaybank Feb. 2012

The Technology

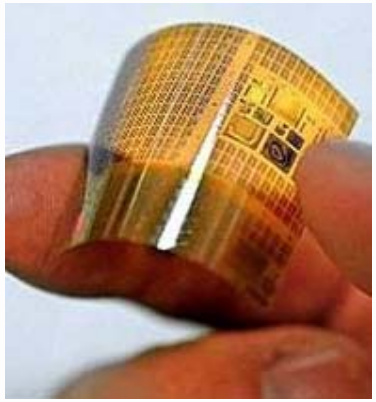
- **PE is the application of conductive, semiconductive, and dielectric materials onto various substrates in order to form electrically functional devices.**

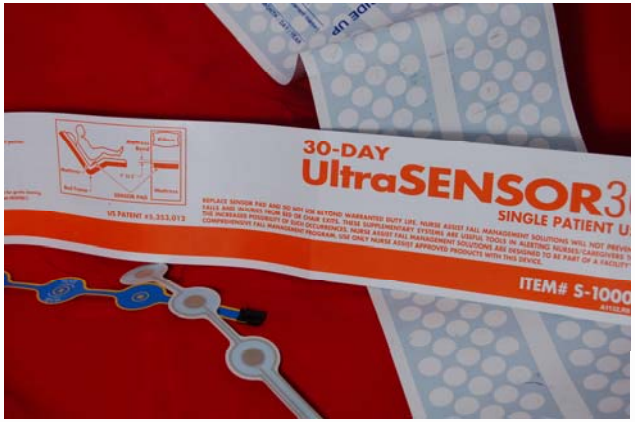
- **Printing Technologies**
  Screen, flexographic, gravure,
  Offset and ink jet

The Technology

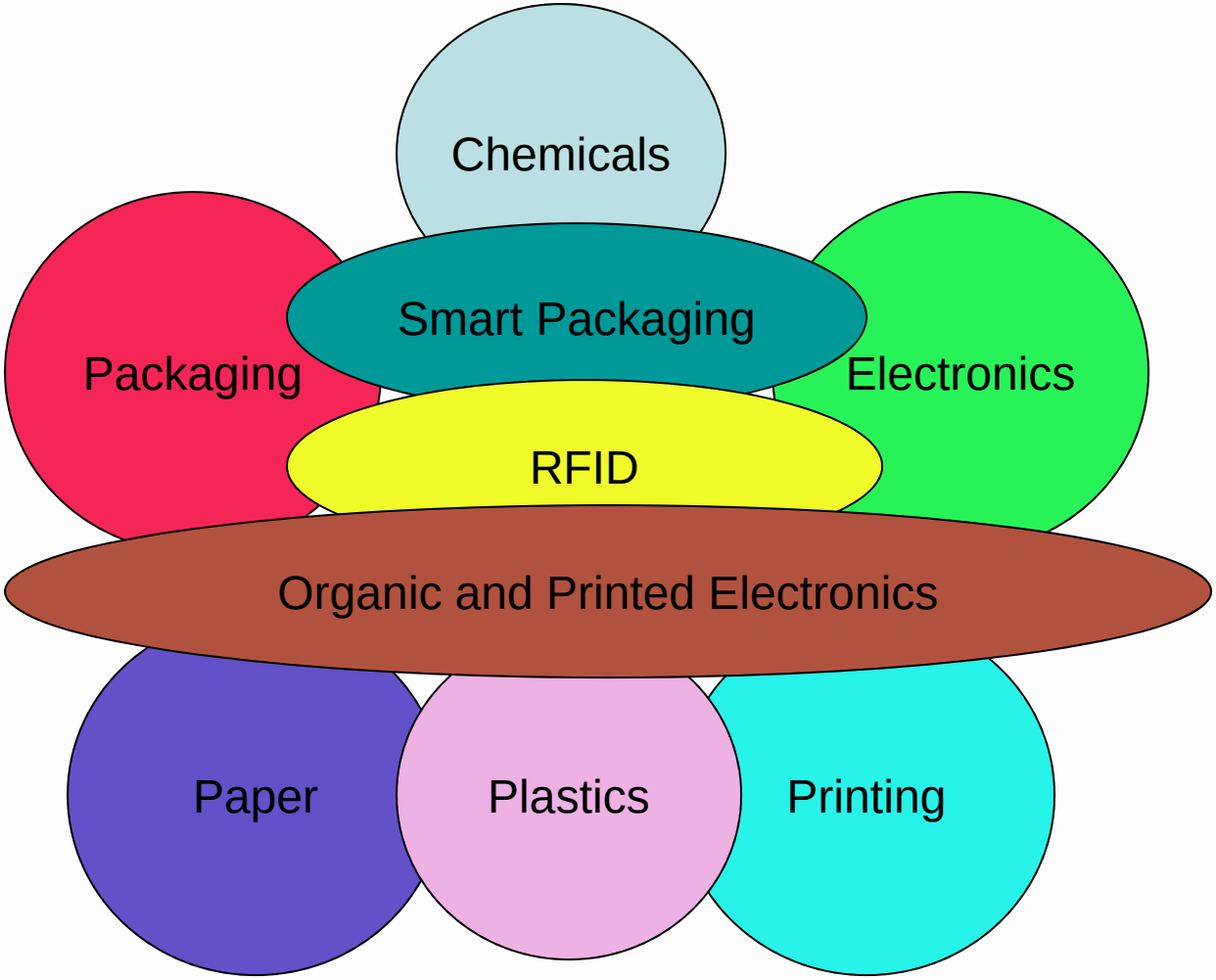
- **Substrates vary widely. Mostly flexible plastics and papers**

- **Current Products in Volume**
  - **Membrane Switches**
  - **Key pads**
  - **Diagnostic strips**
  - **EL**
  - **OLED**
  - **RFID**
  - **Sensors**
  - **Fabrics**

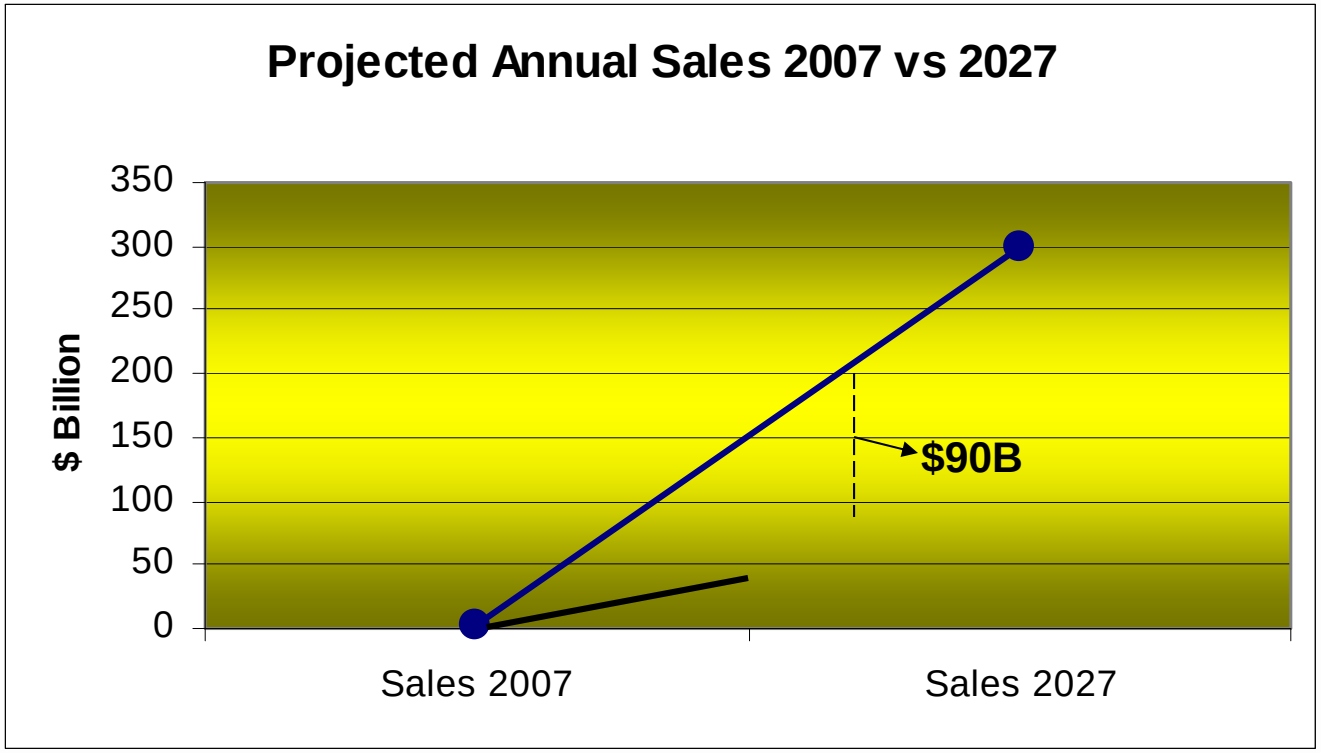




Industry Convergence



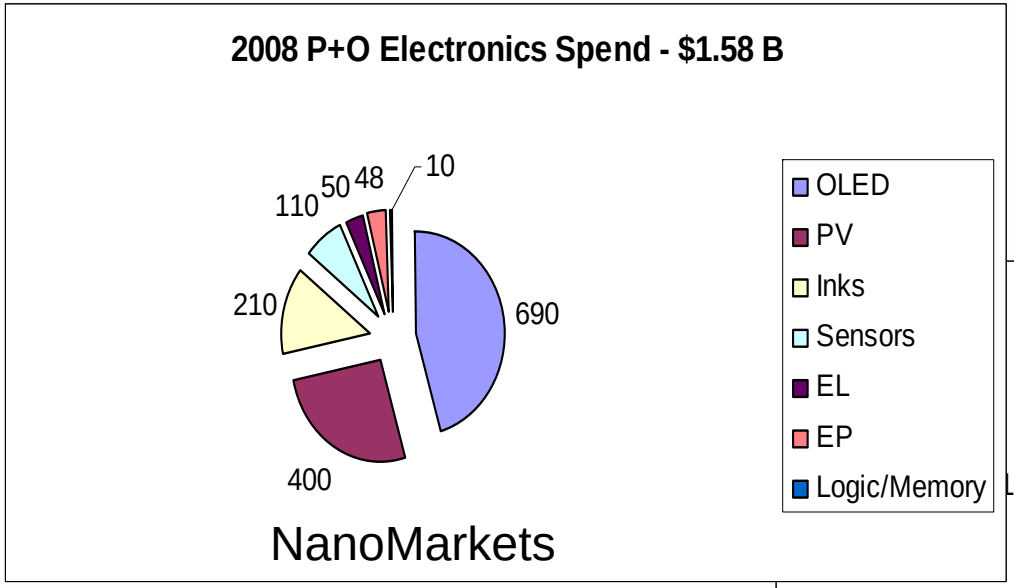
Market Trends



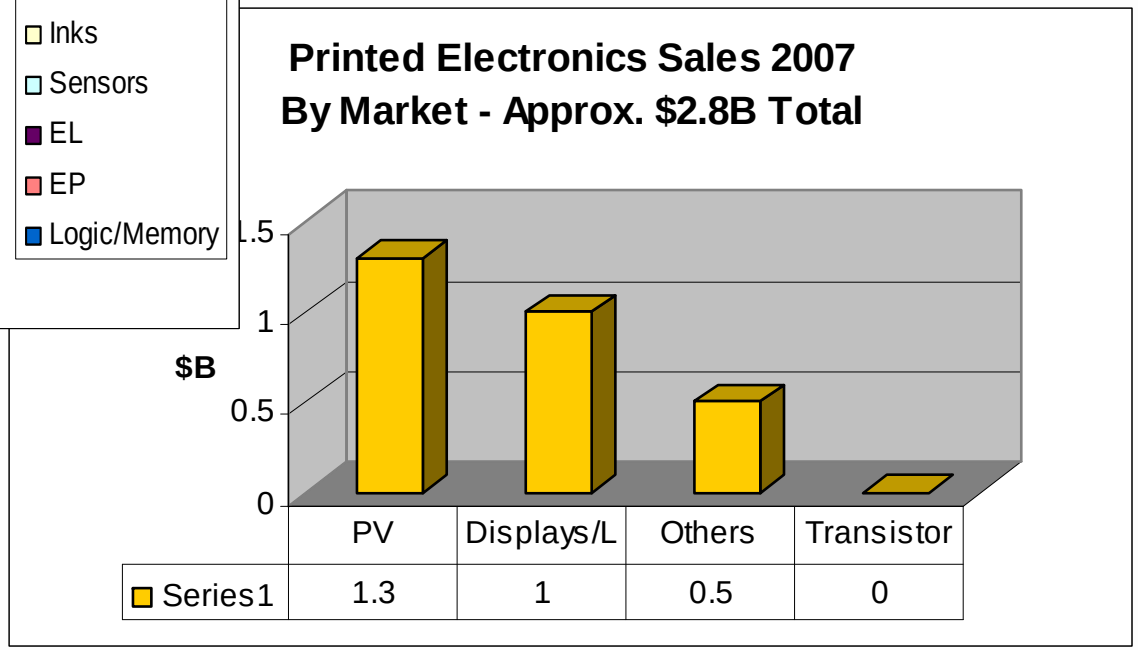
- IDTechEx projection - $300B 2027
-NanoMarkets projection - $30B 2015

- OLED, PV, Logic/Memory will be 80+% of market through 2017
- 400M m2 manufacturing by 2014 represents $40B

Market Trends - Recent



NanoMarkets



IDTechEx

Various PE Market Niches

Batteries
- lithium
- manganese dioxide zinc

Displays
- electrochromic
- electroluminescent
- electrophoretic
- OLED
- thermochromic

Fuel cells

Lighting
- EL
- OLED

Logic
- inorganic
- organic

Memory
- transistors

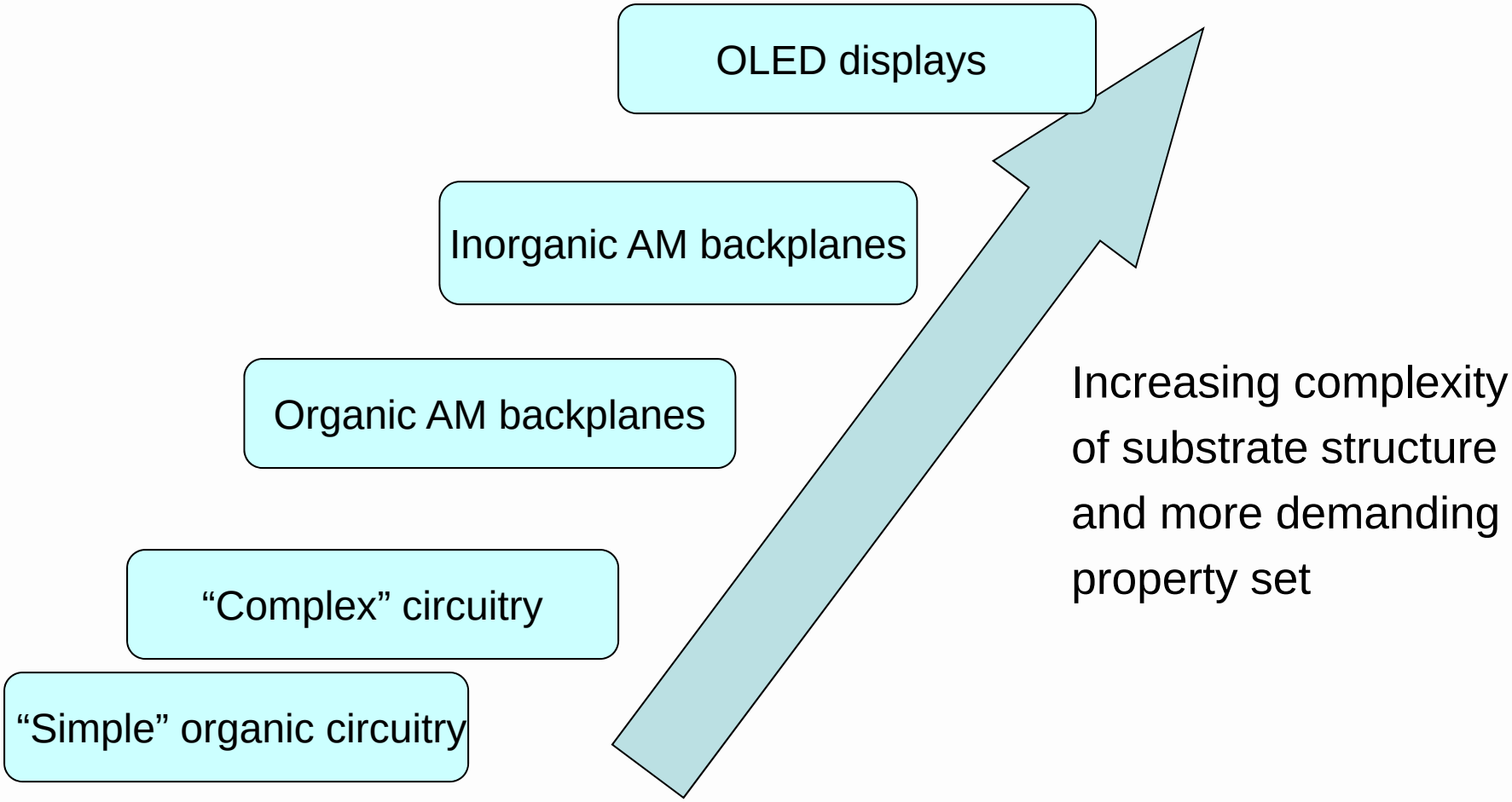
Photovoltaic
- CIGS
- DSSC
- organic
- printed silicon

RFID

Sensors

Touch Panels
- capacitive
- membrane
- resistive

Factors Influencing Substrate Choice -Property Set



Print Electronics is a Developing Industry Needing Companies Who Know….

- **Thermoplastic films**
- **Printing process, currently using conductive inks**
- **Electrical Engineering**
- **Electronic Design**

- **General lack of Material Capabilities & Print Understanding**

What Else is Needed?

- R2R process capability enhancements – Quality, Speed, etc.
- Collaborative environment in the industry to encourage partnering
- Government backed initiatives to grow plastic electronics in the US?

General Thermoplastic Characteristics

Characteristic	Amorphous Material	Semi Crystalline Material
Hardness / Softness	Soft over wide range of temperatures, easy to cut	Harder, more defined melting point, tougher to cut
Formability	Easy to form / thermoform, holds form well	Tougher to form, increased T helps, form will relax
Transparency	Excellent	Good at thin gauges
Solvent resistance	Generally poor	Generally excellent
Stress resistance	Easily prone to cracking and poor flex resistance	Good resistance and flex durability

Thermoplastic Features and Materials

Commodity	Amorphous	Semi Crystalline
Low - Cost Durability Strength	PETG – 80 PVC – 80 PMMA – 105	PP - <10 LDPE HDPE
Engineered		
Higher cost Improved resistance, strength, durability	PC – 150	PBT PET - 70
High Performance		
Highest cost Increased performance	PSO – 190 PEI – 215 PES – 225	PEN – 120 PTFE – 120 PEEK – 140
Imidized Excellent properties >400F		PI – 250 PAI – 275

Approx. Tg's ° C

Key Challenges – Transport & Performance

- Low Shrinkage
- Low Coefficient of Thermal Expansion
- Upper Temperature for Processing
- Clarity
- Rigidity
- Cleanliness
- Surface smoothness
- Barrier
- Solvent Resistance
- Moisture Resistance
- Flatness / Skew
- Conductive layers
- Commercial availability

Key Substrate Criteria

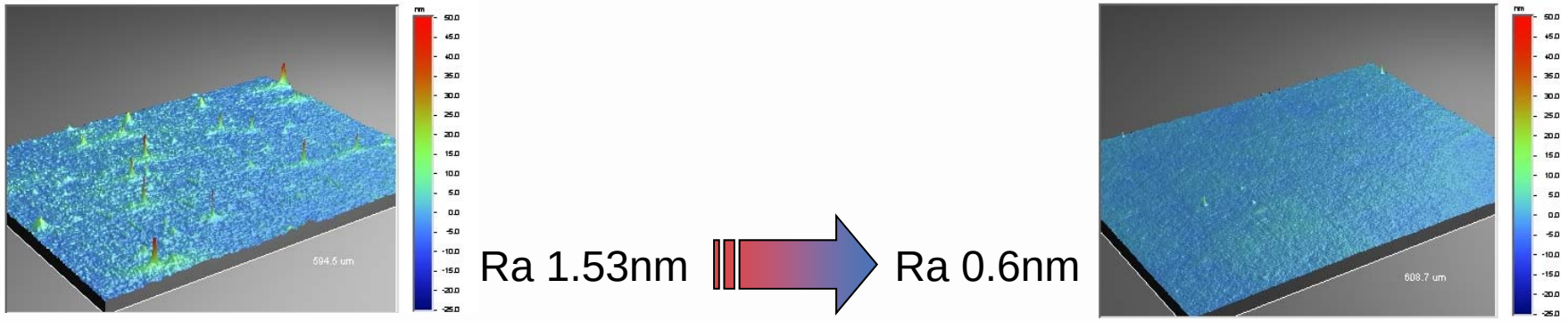
- Modulus, Strength, Rigidity
- Stability, 1 – 3 mil thickness
- Printability – solvent and UV systems
  Multi platform compatible – screen, flexo etc.
- Chemical Resistance
- Surface Profile – flatness, curvature, smoothness
- Roll to Roll processing
- Conversion capability – die cutting, laminating, metalizing, adhesive bondable, forming
- Environmental Compatibility - RoHS /Weee etc.
- Commercially available and supply consistency
- Cost

Film Surface Properties

Highly advanced Printed Electronics demand surface properties beyond typical plastic films

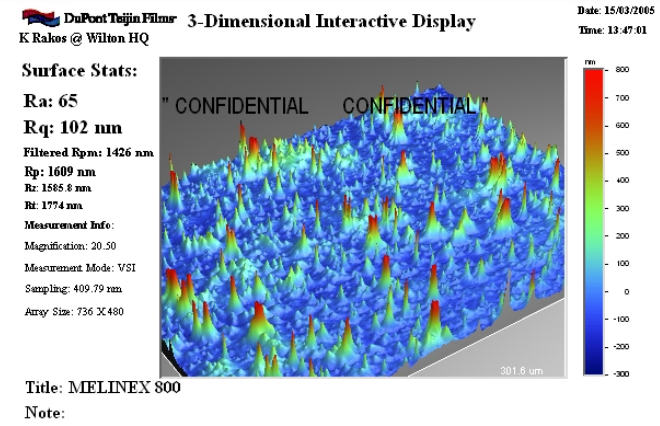
- **Planarizing Coatings**
  - **Give glass smooth surfaces, provide clean surfaces, and**
  - **Balance converting and end-user requirements**
    - **hardness, smoothness, stress/strain resistance**
    - **adhesion, solvent resistance, environmental resistance etc.**
- **Planarized PET and PEN are now commercial**
  - **Based on 5 mil stabilized PEN and 7 mil stabilized PET**

Courtesy DuPont Teijin Films

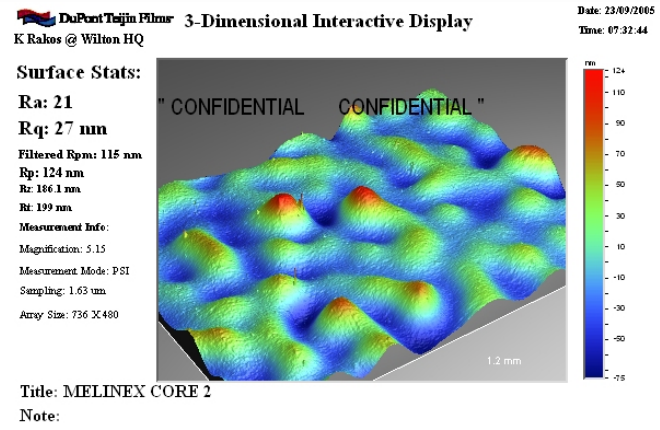


Surface Challenges

- Balancing cost of substrate and performance requirement
- Impact of Surface Profile ink deposit and continuity of deposit



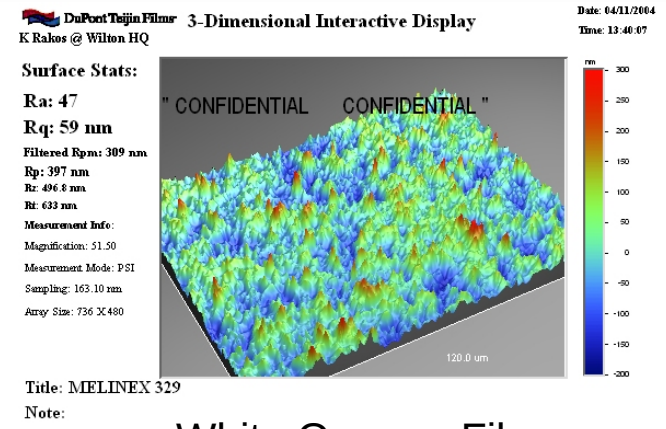
Standard Packaging Film



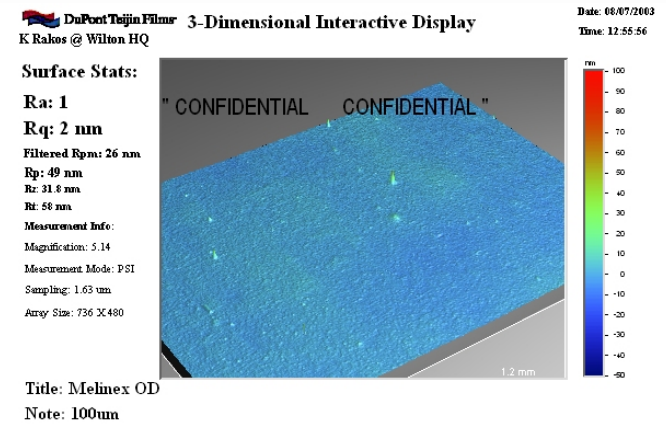
Laminating Film

Surface Challenges II

- Balancing cost of substrate and performance requirement
- Impact of Surface Profile ink deposit and continuity of deposit

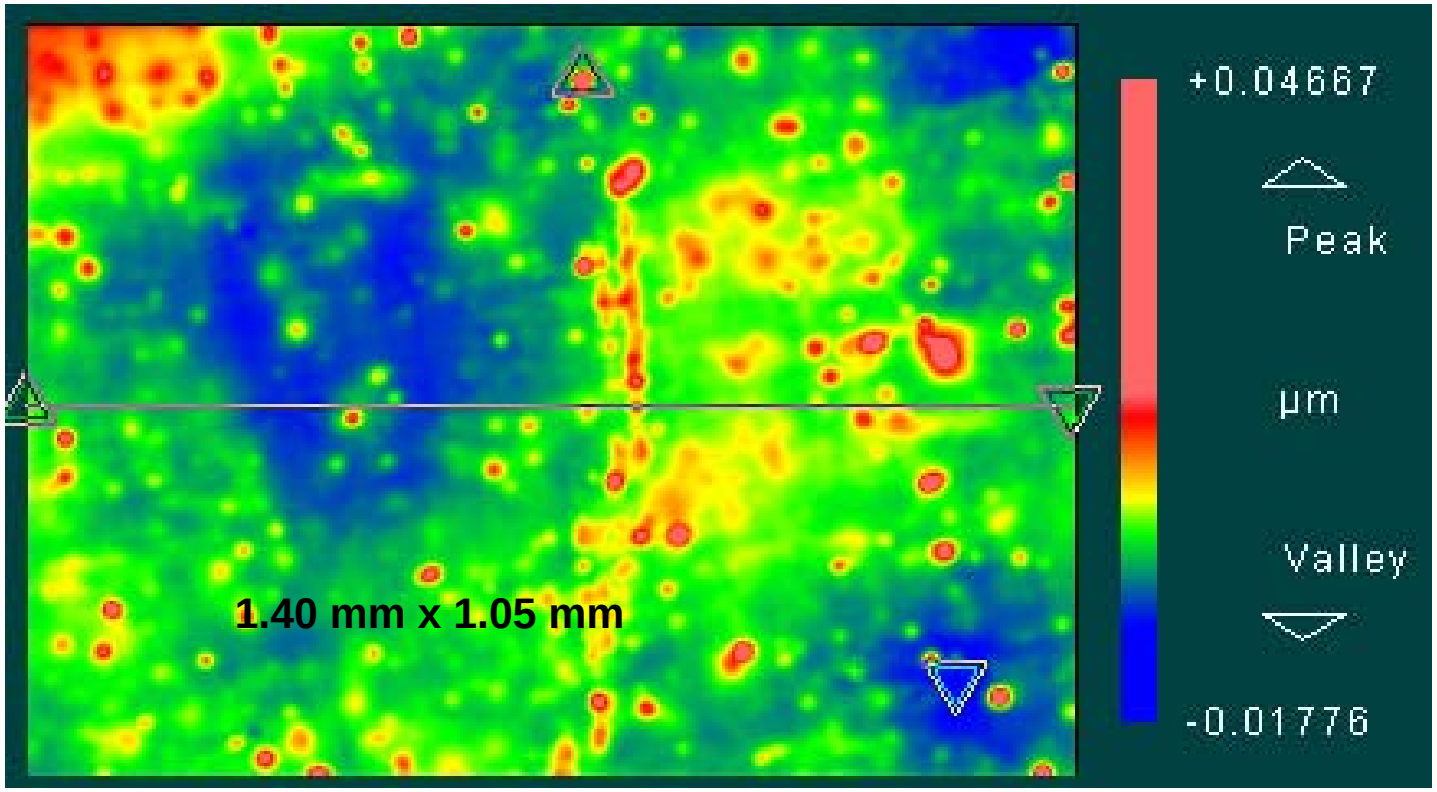


White Opaque Film



"Electronics" Grade Film

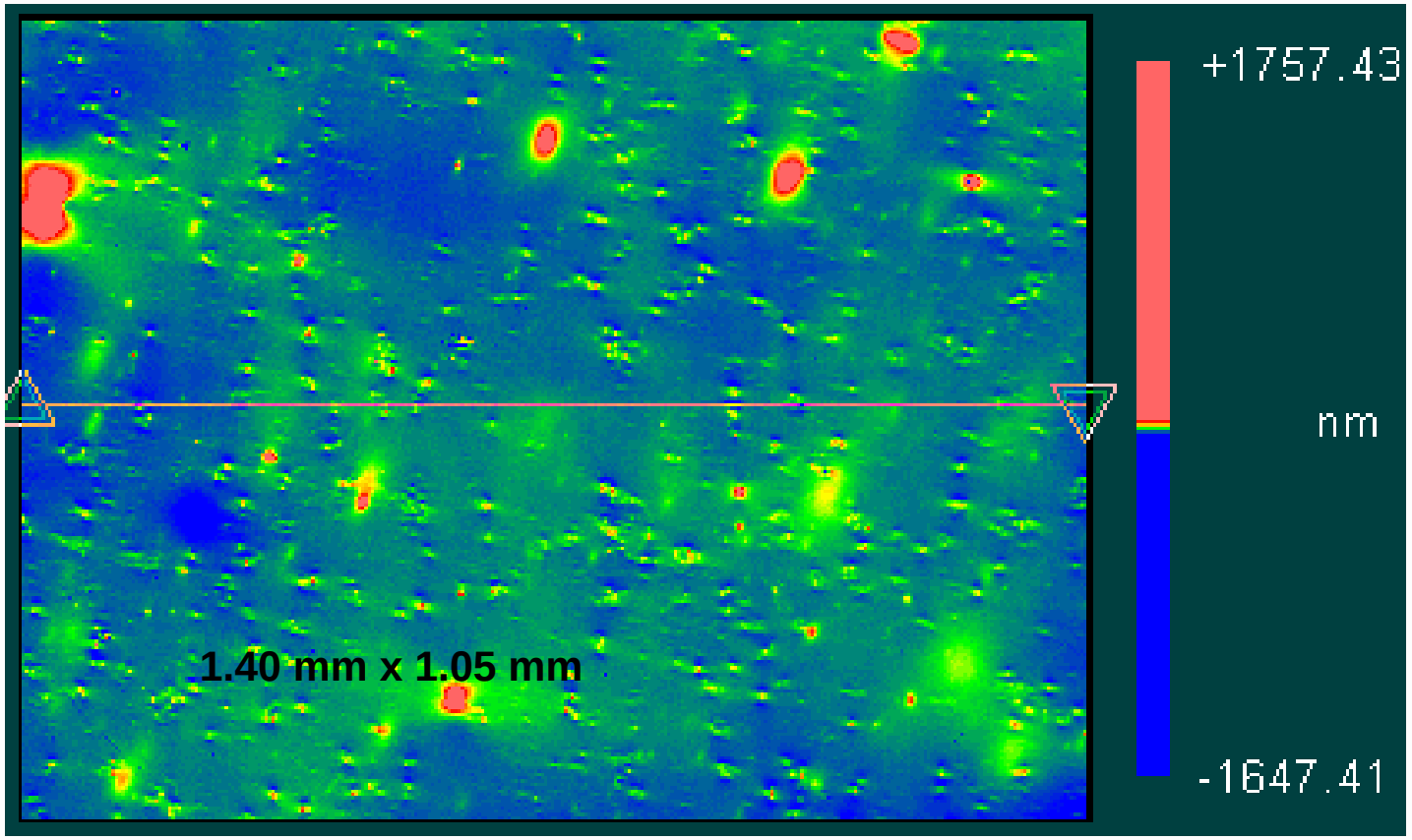
Typical HS PET



Autostat CT3

	PV (nm)	RMS (nm)	Ra (nm)	Rz (nm)
Average	62.9	112.6	5.3	4.0
St. Dev.	19.2	35.7	1.2	1.1

Impact of Handling Agents

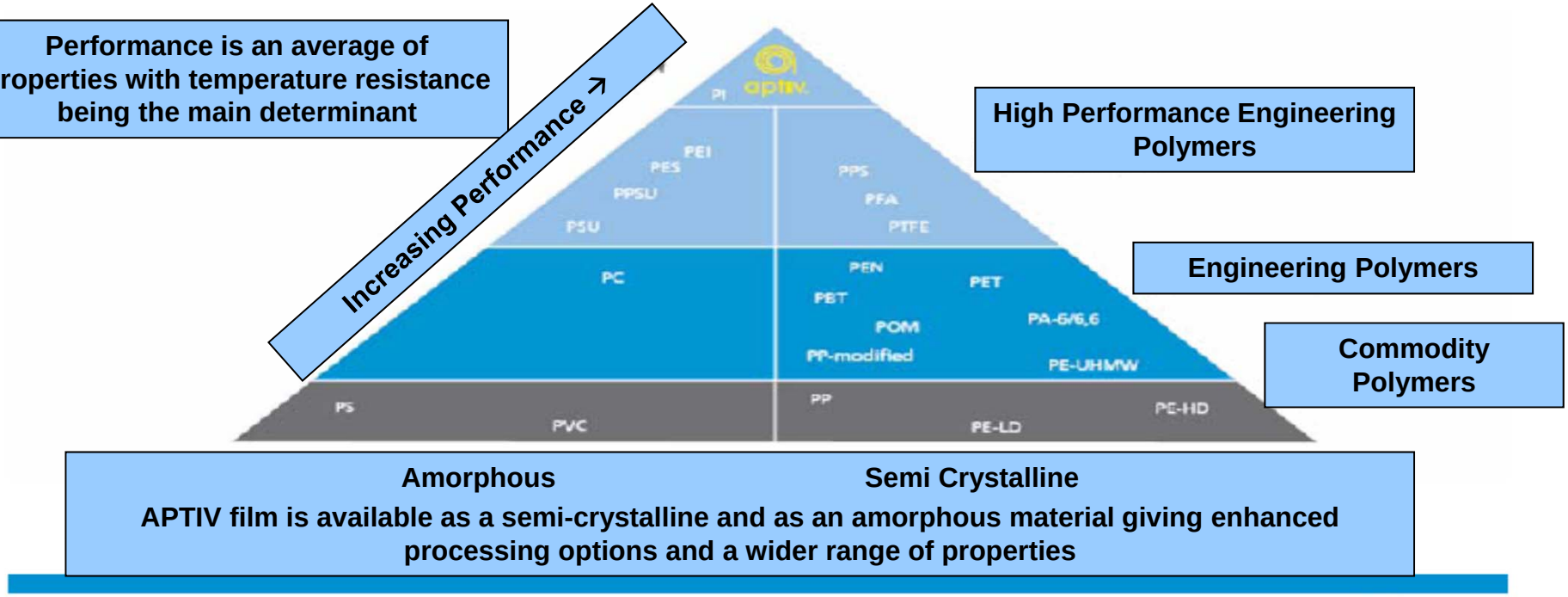


	PV (nm)	RMS (nm)	Ra (nm)	Rz (nm)
Average	2685.0	11.9	4.2	1292.0
St. Dev.	1561.0	5.8	0.4	854.0

Estar LS

Film Performance Pyramid

Performance is an average of properties with temperature resistance being the main determinant



High Performance Engineering Polymers

Engineering Polymers

Commodity Polymers

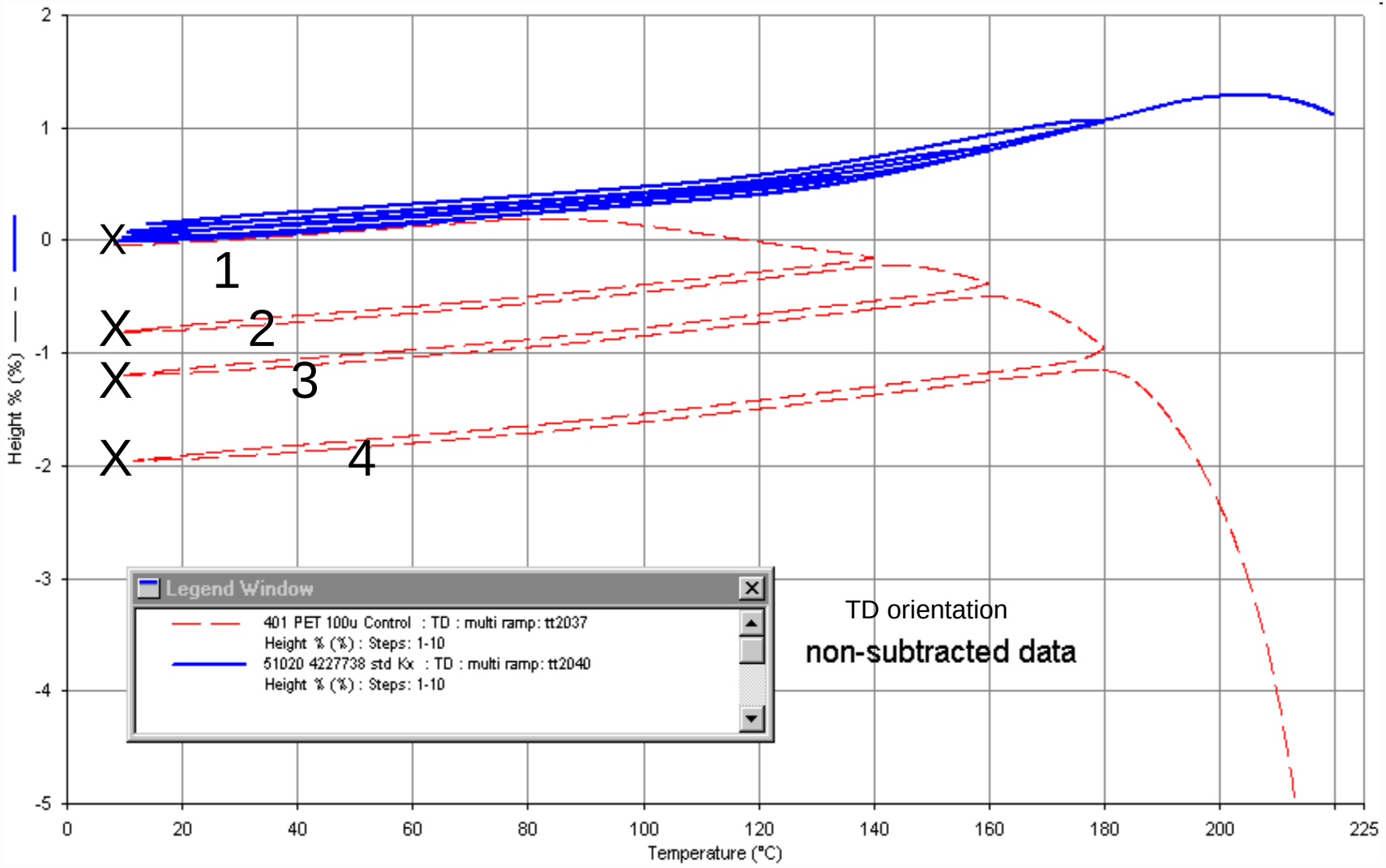
Amorphous **Semi Crystalline**

APTIV film is available as a semi-crystalline and as an amorphous material giving enhanced processing options and a wider range of properties

Heat Stabilized Substrates

- HS PET is dimensionally stable up to 150°C
  - For greater thermal stability
  - For greater modulus
- HS PEN is dimensionally stable between 180-220°C
- Specification temperatures of heat stabilization
- This largely dictates upper temperature for processing-film selection for printable electronics
  - Registration
  - Dimensional stability

Unstabilised PET vs. Heat Stabilised PEN



Film Market Trends

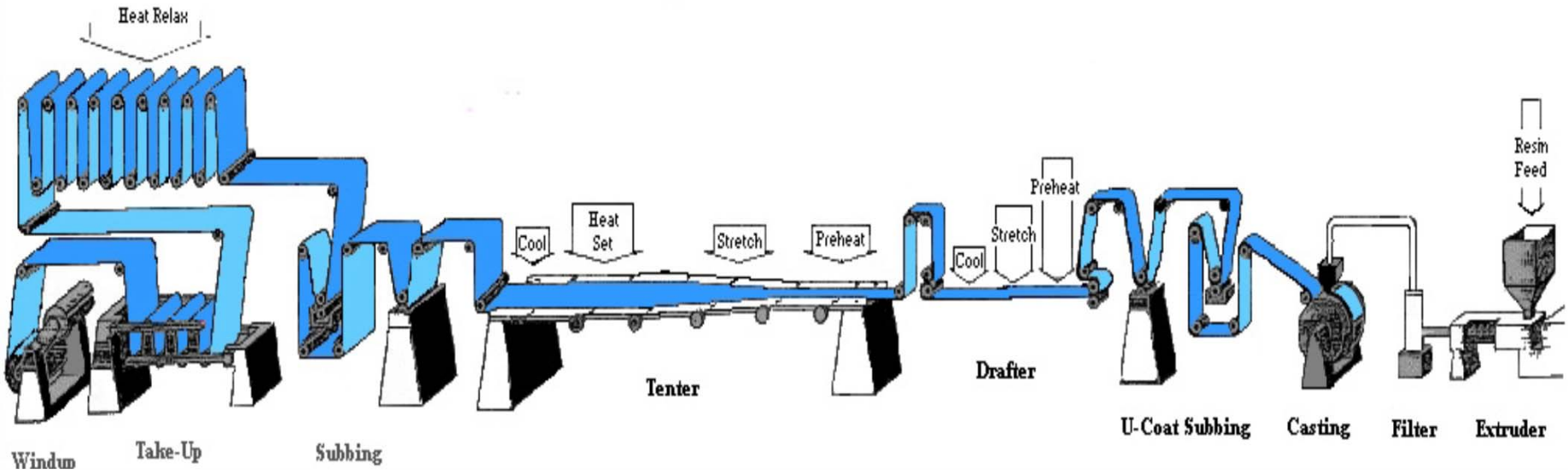
- **As the market evolves, customers and end-users are demanding**
  - **Reduced device thickness**
  - **Improved economics, productivity & quality**
  - **Enhanced flexibility, optics & film surface properties**
- **Thinner stabilized polyester films, target device thickness**
  - **Low scratch, high quality films designed for high-end electronics applications are needed**
  - **Dimensional stability equivalent to conventional thicker films**
  - **Haze below 1%, much of which is surface haze that can be reduced by coatings or optical adhesives in the final structure**
  - **Good handling, R2R printing and vacuum processing**
  - **Examples**

Key Features	Film Type	Adhesion Primer	Market Application
Crystal Clear (Haze <1%)	ST579	1-side general purpose adhesion promoting	ITO, Displays, Touch Screen
High Transparency, clean, smooth	ST580	1-side specialty adhesion promoting	Flexible Electronics
Crystal Clear, UV Same as above + UV protection	XST6582	1-side specialty adhesion promoting	Printed Electronics, organic semi conductors

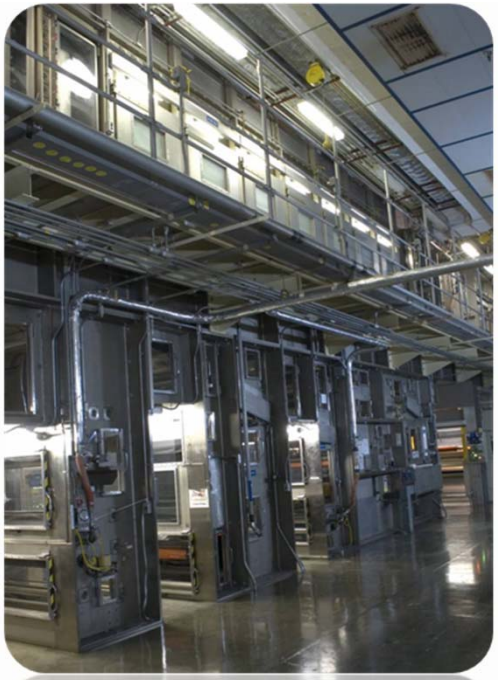
Film Market Trends

Improved economics, productivity & quality to meet market needs

- **Improved manufacturing capabilities**
  - **Clean room certification**
  - **Total web enclosure**
  - **In line Coating, scanners, stabilization**



Improved Manufacturing Capabilities



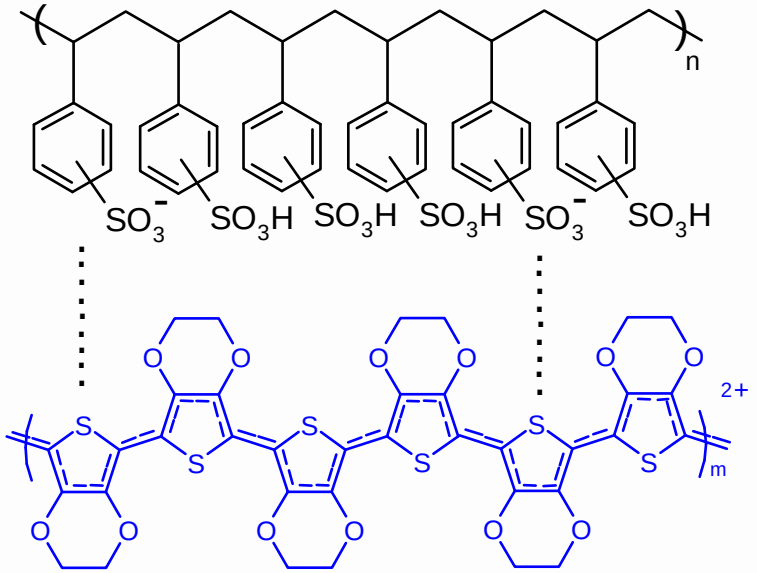
Courtesy of Kodak

PEDOT:PSS Conductive Coatings

- Waterborne dispersion of the polymer complex poly(3,4-ethylenedioxy-thiophene)/ polystyrene sulfonate
- Nano particle sized gel particles
- Forms a continuous film upon drying

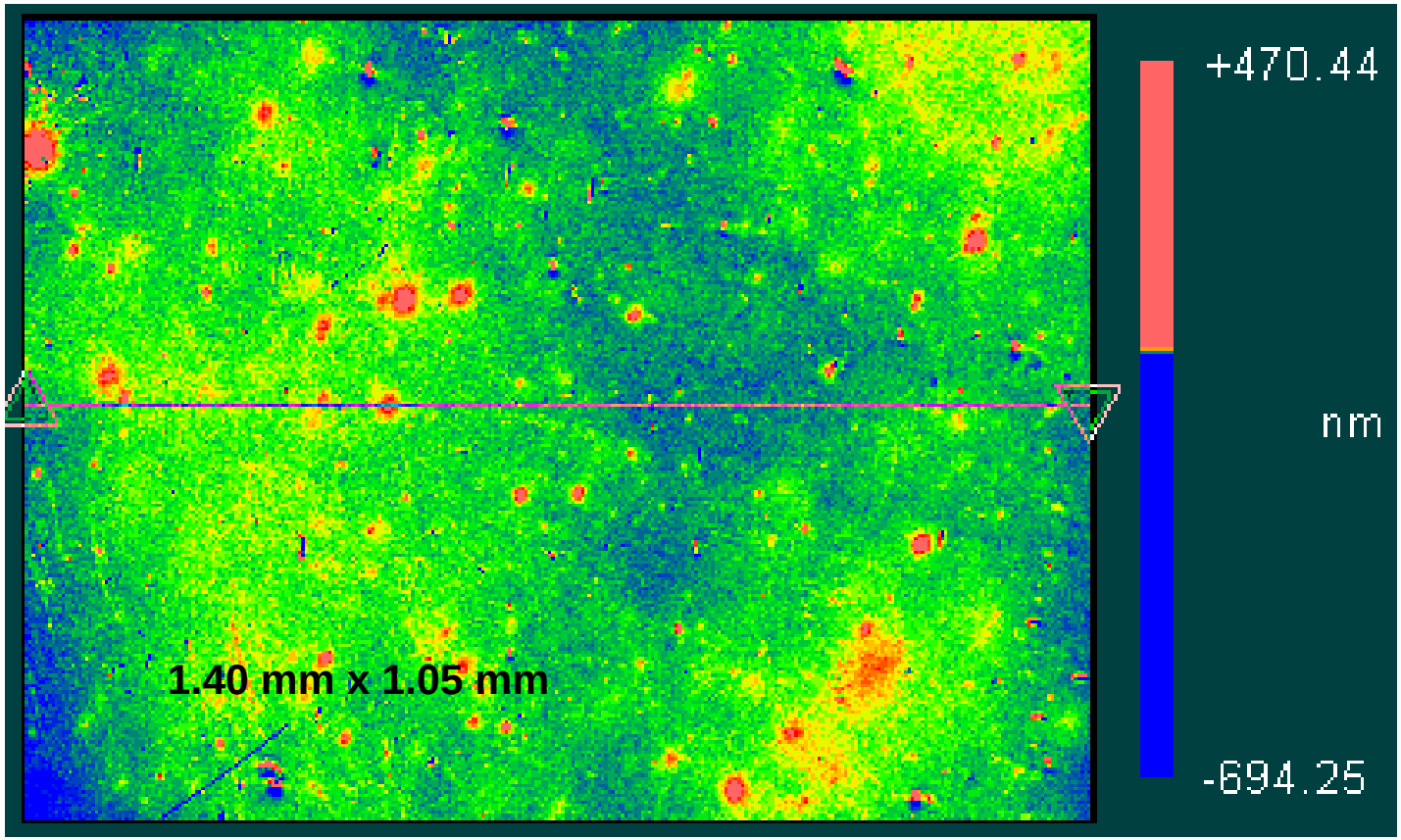
Main features

- Highly conductive
- Highly transparent
- Easy-to-use, printable
- Durable



Courtesy H.C. Starck

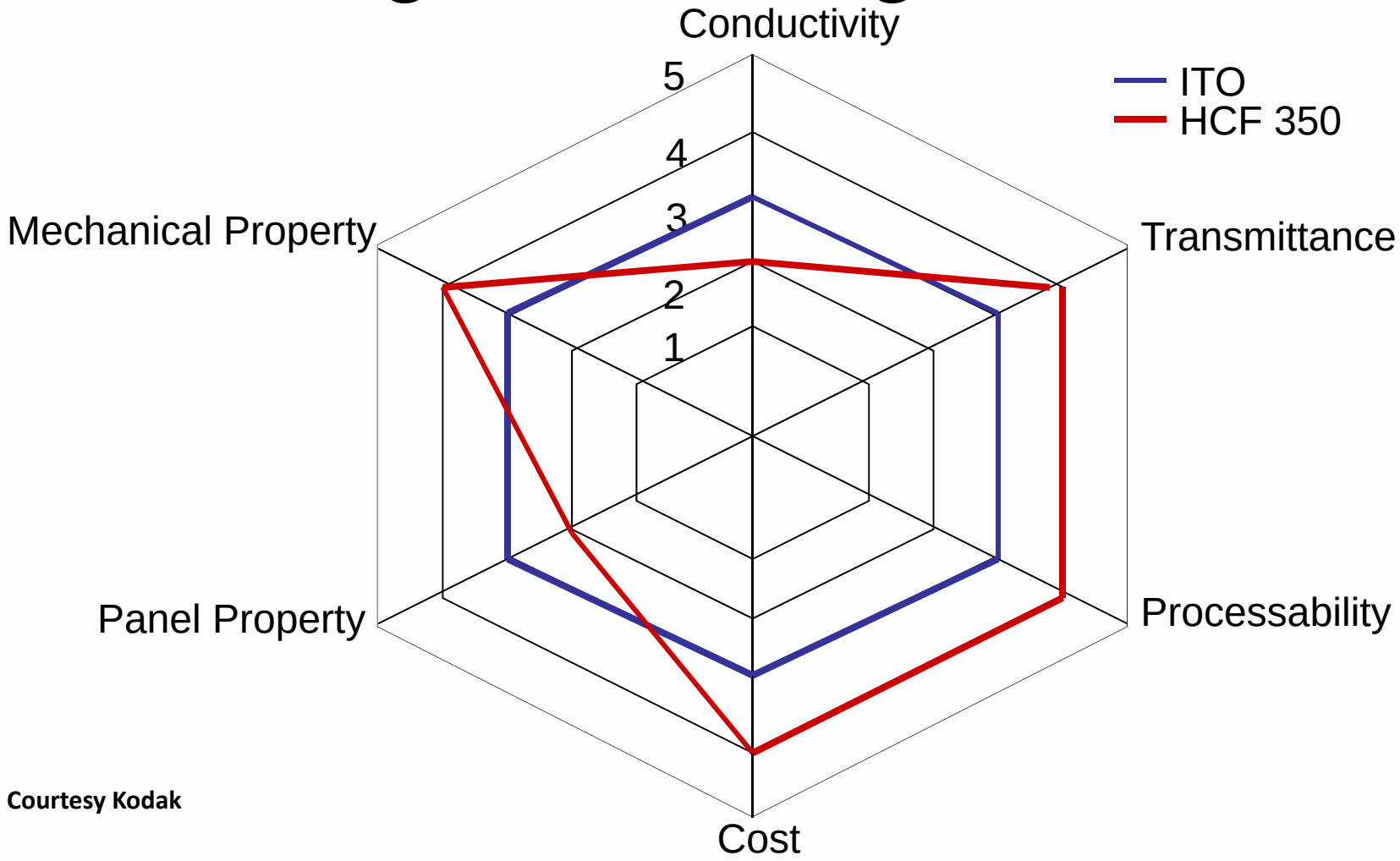
Organic Conductive Coating



	PV (nm)	RMS (nm)	Ra (nm)	Rz (nm)
Average	1319.3	4.2	1.9	638.6
St. Dev.	466.1	1.1	0.5	283.1

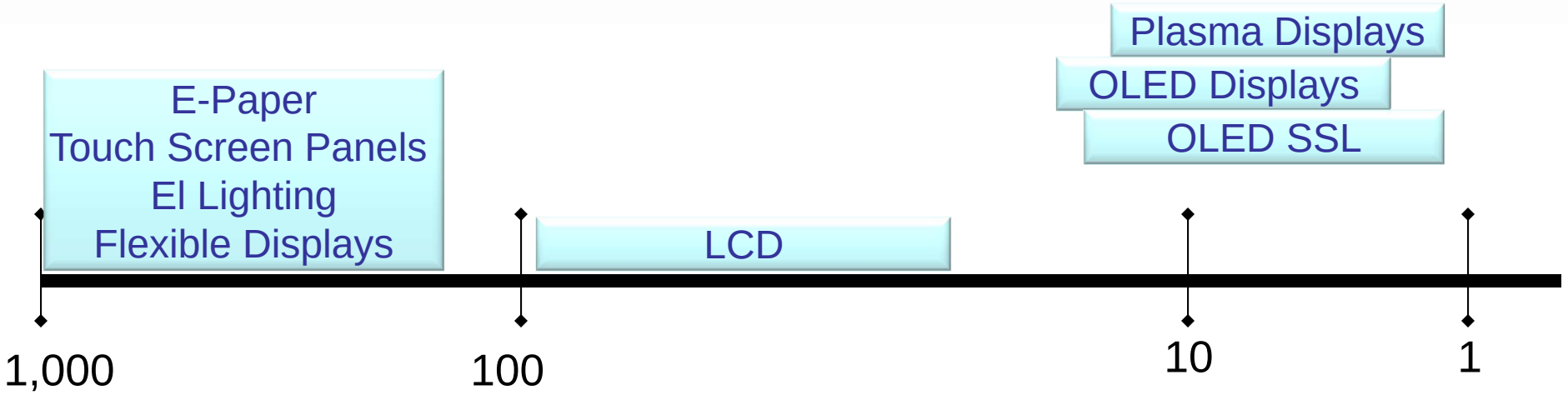
HCF-350

Organic Coating vs. ITO



Courtesy Kodak

SER Ranges for Electronic Displays



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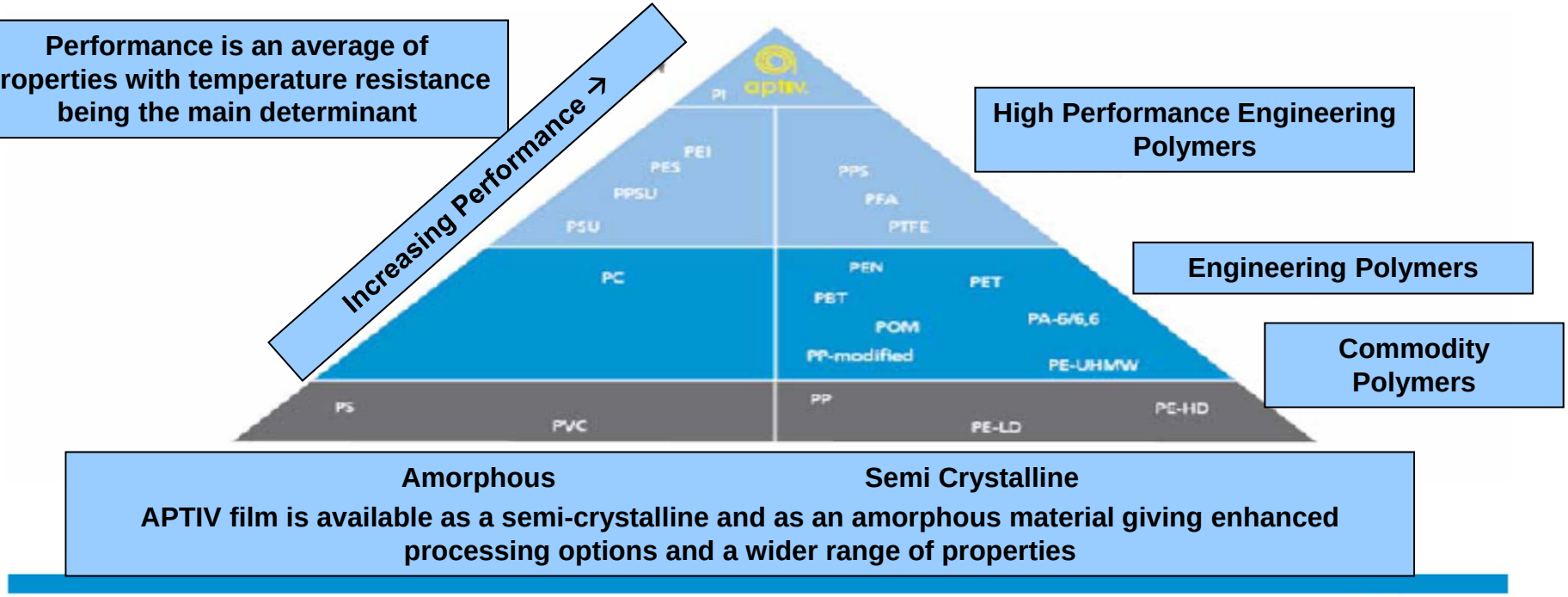
Performance is an average of properties with temperature resistance being the main determinant



High Performance Engineering Polymers

Engineering Polymers

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Peek Films - Comparison

	Mechanical Properties at 200 C	Moisture Absorption	Chemical Resistance	Abrasion Wear resistance	Radiation Resistance
Victrex Aptiv (Peek)	Very Good	Very Good	Very Good	Excellent	Excellent
Polyimide (PI)	Very Good	Fair	Poor	Good	Very Good
Polyetherimide (PEI)	Good	Fair	Fair	Fair	Good
Polytetrafluoroethylene (PTFE)	Poor	Excellent	Excellent	Poor	Poor

	Basic Character	Recycleable	Dielectic Properties	RTI Rating	Flammability
Victrex Aptiv (Peek)	Melt Processible	Yes	Very Good	220 C	Very Good
Polyimide (PI)	Thermoset	No	Very Good	200 C	Excellent
Polyetherimide (PEI)	Melt Processible	Yes	Very Good	180 C	Excellent
Polytetrafluoroethylene (PTFE)	Limited Melt Processible	Limited	Excellent	180 C	Excellent

Courtesy Victrex

Various PE Market Niches

Batteries
- lithium
- manganese dioxide zinc

Displays
- electrochromic
- electroluminescent
- electrophoretic
- OLED
- thermochromic

Fuel cells

Lighting
- EL
- OLED

Logic
- inorganic
- organic

Memory
- transistors

Photovoltaic
- CIGS
- DSSC
- organic
- printed silicon

RFID

Sensors

Touch Panels
- capacitive
- membrane
- resistive

Price Comparison Matrix

Substrate	Comparative Price
PET	1x
White PET	1.5x
HS PET	2.5x
HS White PET	3x
PEN	10x
HS PEN	20x
PI	25x
PEI	35x
PEEK	40x
Conductive Films	
ITO	28x
PEDOT	24x

Presentation Contributors

Grateful Thanks to:

- Conductive Compounds, Inc.
  - Don Banfield, Product Manager
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  - Michael Wobser, New Business Development Manager
- Toray Plastics
  - William Nelson, Business Development Manager
- Victrex
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