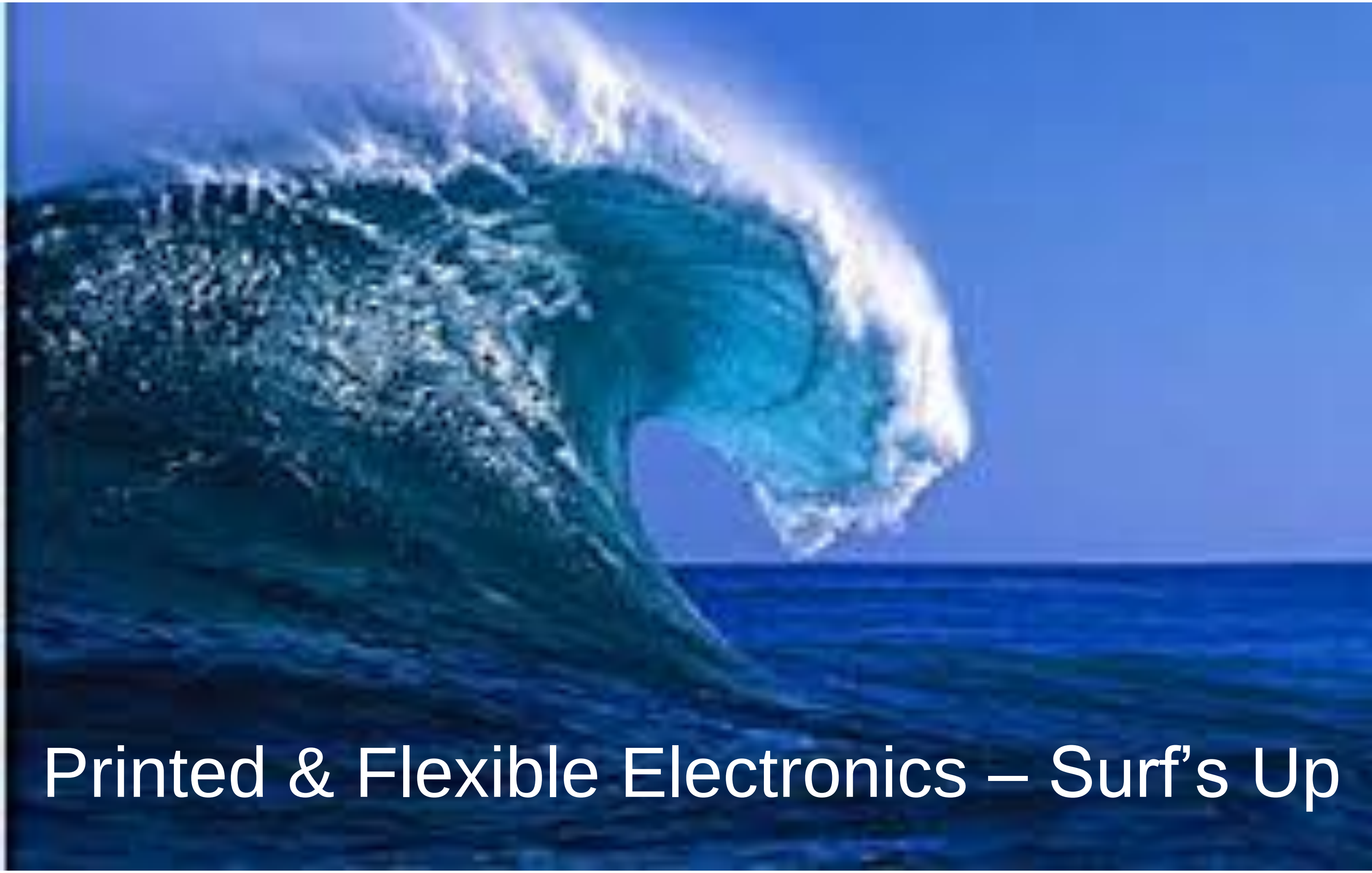


Printed & Flexible Electronics – Surf’s Up

Daniel Gamota – Jabil, Inc.

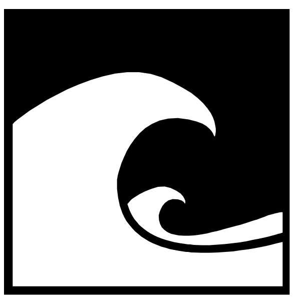
Presentation Outline

Printed & Flexible Electronics

- *Development Waves – 1st, 2nd, and 3rd*
- *Essentials*
- *Products and Applications*
- *Technology and Infrastructure Development*
- *Printed & Flexible Electronics Pipeline*
  - *Experts Only**

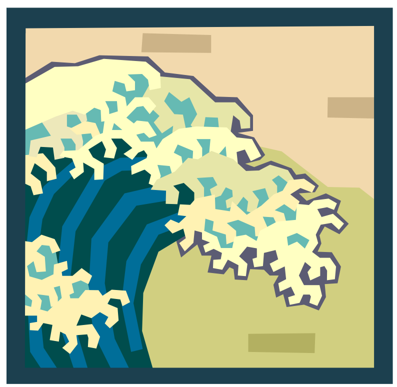
Printed & Flexible Electronics Development Waves

The 1st PE Wave:
RFID



2002

The 2nd PE Wave:
Flexible Displays



2007

The 3rd PE Wave:
Integration and Hybrid Architectures

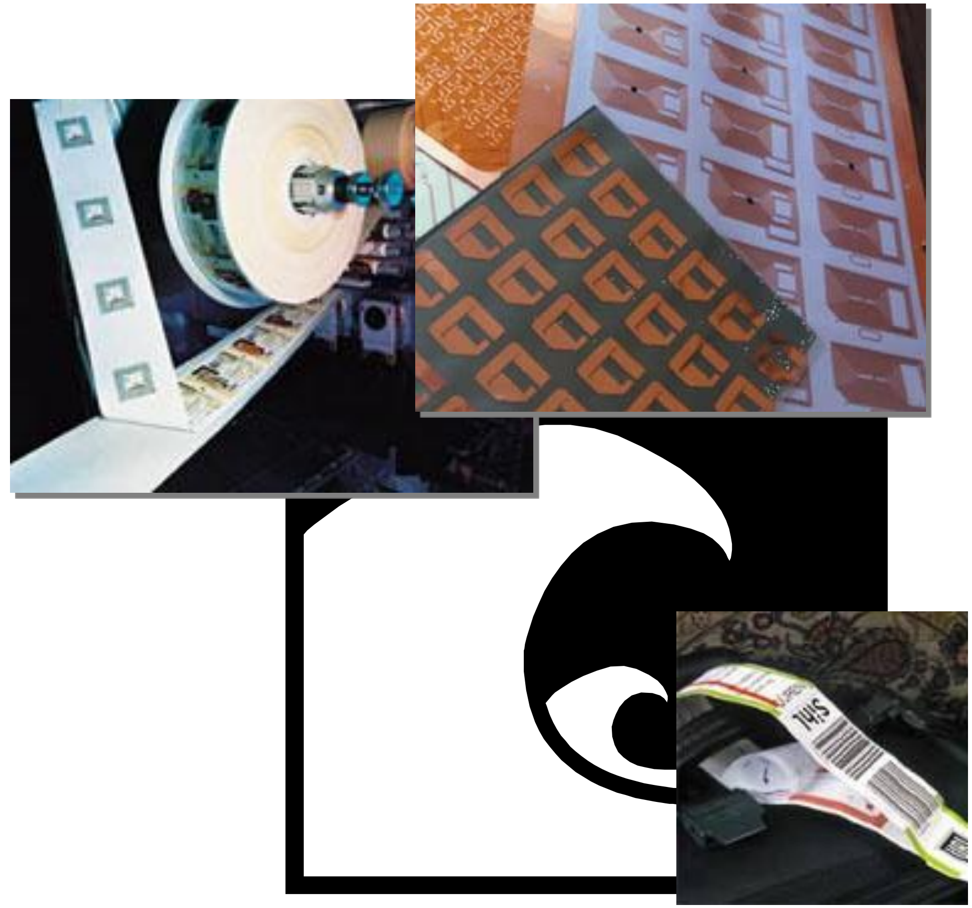
2012

Printed & Flexible Electronics technology can be discussed in terms of three waves with each wave representing a different period of technology exploration and growth.

1st PE Wave - RFID

Drivers

- RFID solution at a fraction of the cost; \$0.25 for Si RFIC versus \$0.01 for a PE-based RFIC.
- Low cost using non-vacuum, R2R printing manufacturing processes to fabricate the RFIC and minimal or no final assembly cost.



Result: Gnarly and Bail Out

- Electrical performance not adequate for circuitry to operate at frequencies mandated by EPC standards.
- Lack of robust CMOS system to facilitate shrinking of the circuit and enhance operating speeds.
- Demands placed on tight operating window and unable to achieve high yield of printed TFTs in manufacturing.
- Lack of a well-established supply chain to support PE.

1st PE Wave increased visibility and promoted the opportunities that could be realized.

2nd PE Wave – Flexible Displays

Drivers

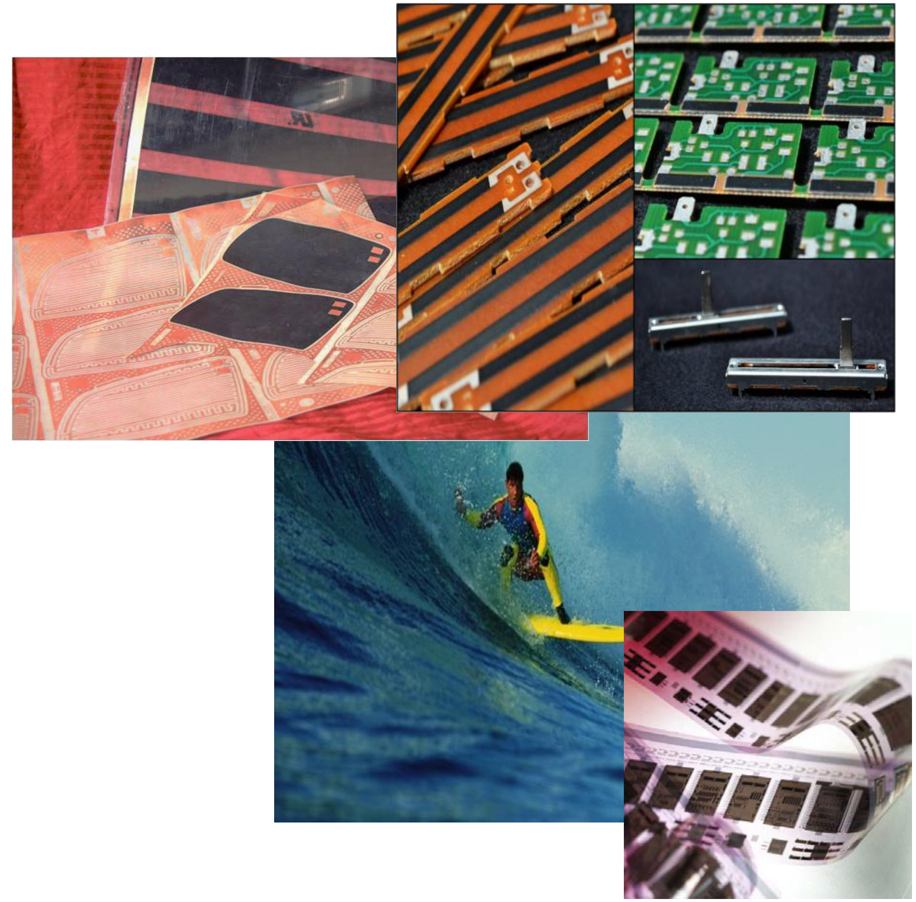
- Low profile, light weight, and conformal displays for “content anywhere.”
- Marketing studies compelling for a display offering untethered, mobile data.
- Cost of glass-based, vacuum-processed a-Si AM backplanes offered PE an opportunity for success.
- Unlike RFICs, PE based displays did not demand high performing TFTs.
- Level of investment continued for improving fabrication processes, establishing a PE supply chain, and the necessary supporting infrastructure.

Result: Gnarly and Bail Out

- Accelerated cost reduction curve experienced by conventional a-Si AM driven displays (i.e., manufacturing economies of scale).

2nd PE Wave expanded visibility of technology and fueled development of infrastructure for manufacturing and commercialization.

3rd PE Wave – Integration and Hybrid Architectures



Drivers

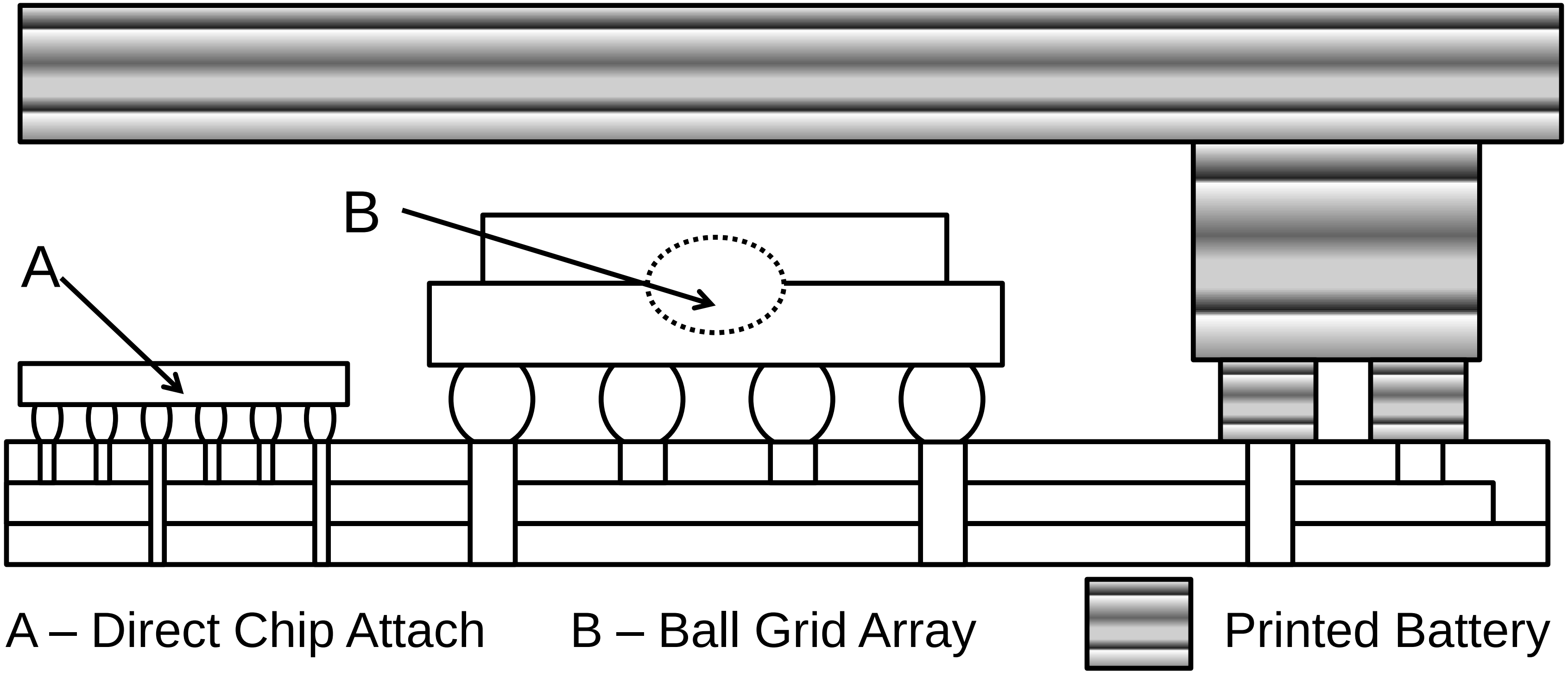
- Wave forming by companies and "technology pull" versus by entrepreneurs and "technology push".
- Companies have vested interest and opportunity to expand product portfolios.
- Technology accepted due to in-field performance and not for potential given several more years of investment.

Outlook: Surf's Up

- Products using functional inks have achieved commercial success.
- Customers are better educated for its limitations and have a design philosophy that PE will not replace an incumbent.
- PE promoted providing greatest benefit when integrated with mature technologies to enable hybrid architecture.

3rd PE Wave continues to strengthen the infrastructure as commercial launches are realized.

3rd PE Wave – Integration and Hybrid Architectures



An example of a hybrid structure – printed component (flexible primary/secondary battery) with non-printed microelectronics topology (flex substrate or FR4 populated with area array packages and discrete devices).

Printed & Flexible Electronics

Essentials

Printed & Flexible Electronics:

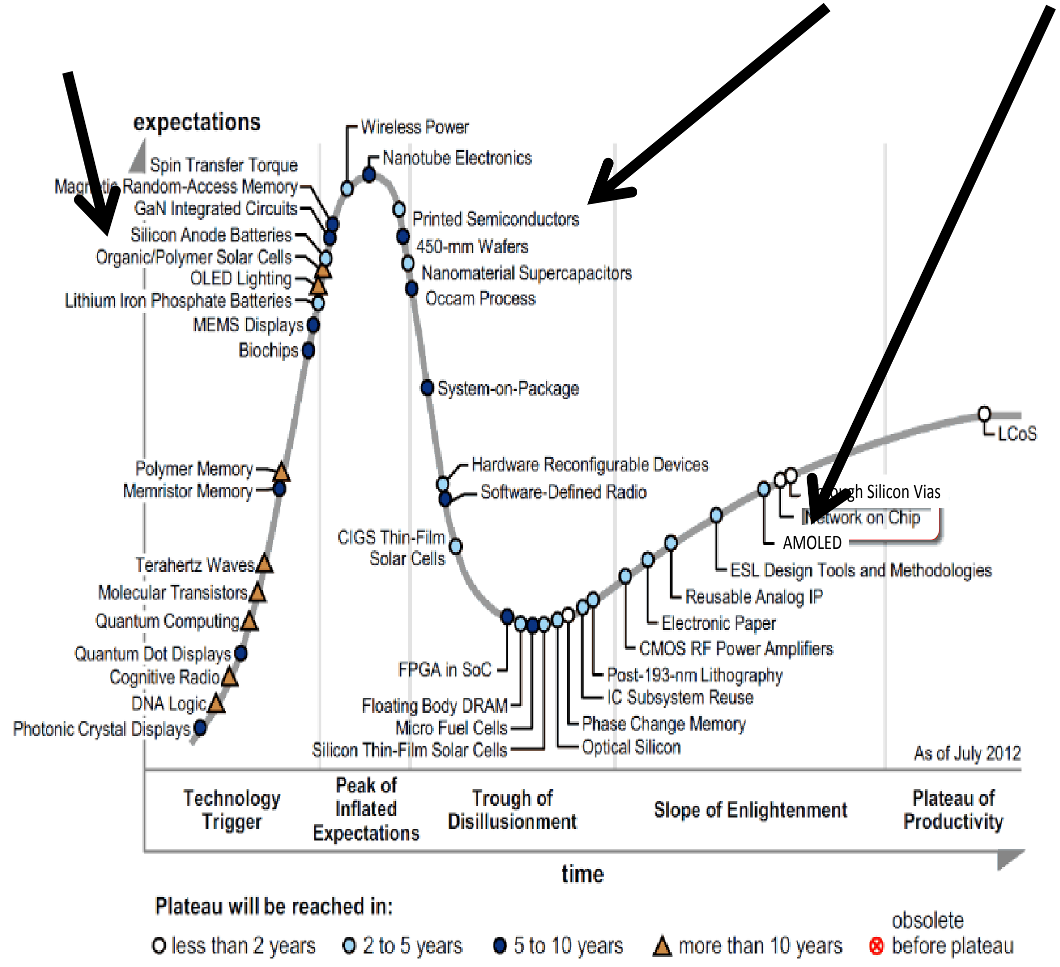
The Time is Approaching

Investments Continue

- Increased
  - Korea, China, Japan, Singapore, Russia
- Slight Increase
  - EU - Framework Programs
- Stable
  - US - Investors sought from outside the US to accelerate product commercialization

Product Launch Schedule

- Sensors – Near
- Signage – Near
- OLED – Near/Mid
- OPV – Near/Mid
- RFID – Long



Source: Gartner (July 2012)

Printed & Flexible Electronics:

Definition Blurred

Traditional Electronics Processes

- **Thin Film Deposition**
  - Physical Vapor Deposition (sputtering, pulsed laser, etc.)
  - Chemical Vapor Deposition (PECVD)
  - Molecular Beam Epitaxy (MBE)
  - Atomic Layer Deposition (ALD)
  - Spin coating
- **Pattern Transfer**
  - Photolithography
  - Nanolithography
  - Soft Lithography
  - Liquid Imaging
- **Implantation**
  - Ion Implantation
  - Diffusion Furnace
- **Removal**
  - Reactive Ion Etch
  - Dry Etch, Wet Etch
  - Plasma Ashing
  - Chemical Mechanical Planarization

Printed Electronics Processes

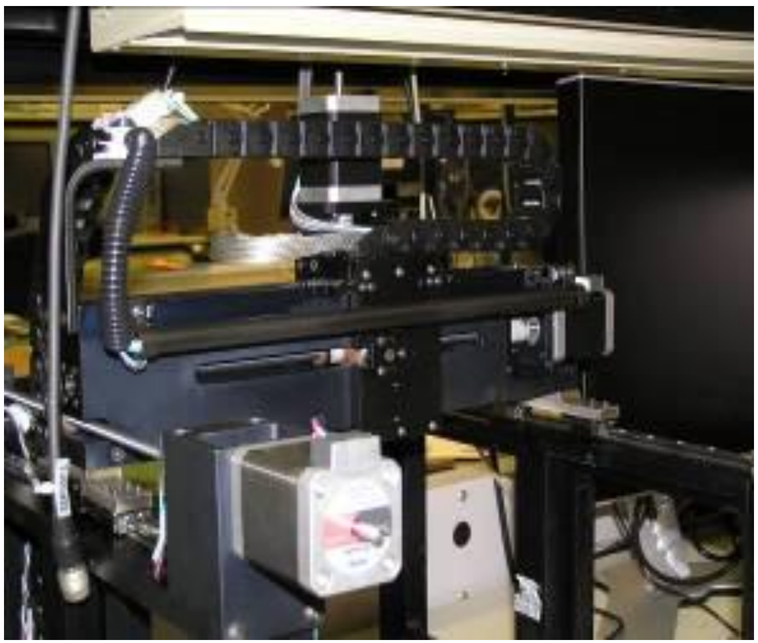
- **Gravure**
- **Flexography**
- **Screen**
- **Ink Jet**
- **Embossing**
- **Micro/nanoimprint**

All-printed or a blend of hybrid technologies may be optimal for a particular manufacturing flow (cost, yield, scalability, product design flexibility, etc.).

Printed & Flexible Electronics:

Hybrid or All-Printed Processes

Pick and Place



Printing

Manufacturing technologies are mature but integrating them on the same platform is relatively new and unproven at typical production web speeds.

Printed & Flexible Electronics

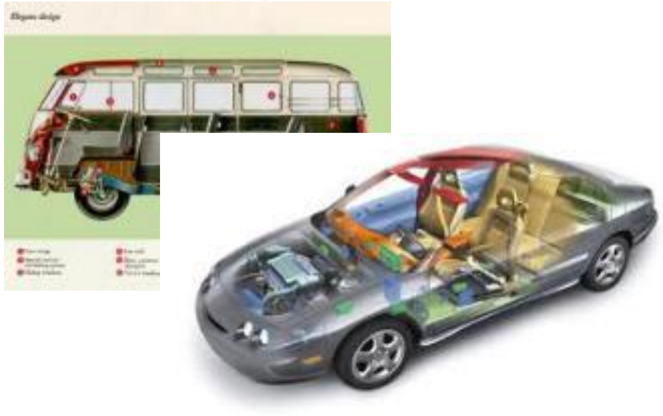
Products and Applications

Printed & Flexible Electronics:

Markets and Opportunities

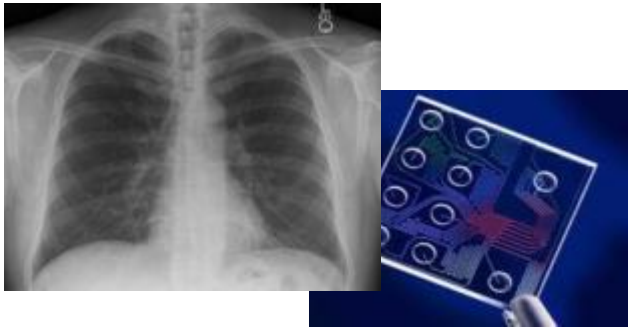
Aerospace Opportunities

Automotive Opportunities



Communications Opportunities

Medical Opportunities

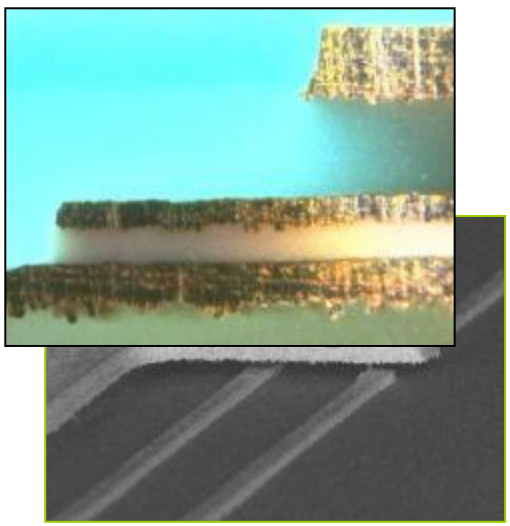


Printed & Flexible Electronics is a technology platform that enables a portfolio of new products in large markets – display, lighting, sensors, power, etc.

Printed & Flexible Electronics:

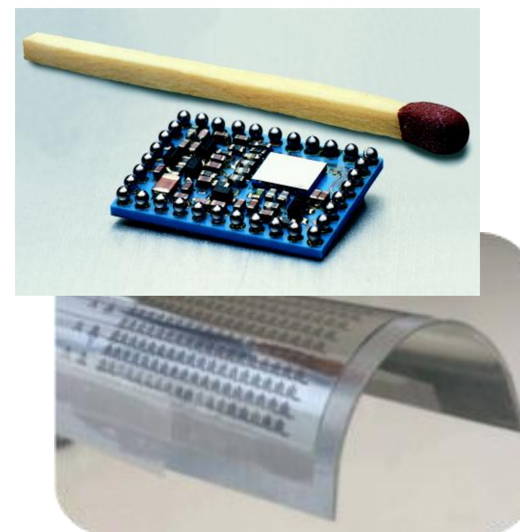
Devices, Modules & Units, and Final Products

Devices



Modules & Units

Final Products

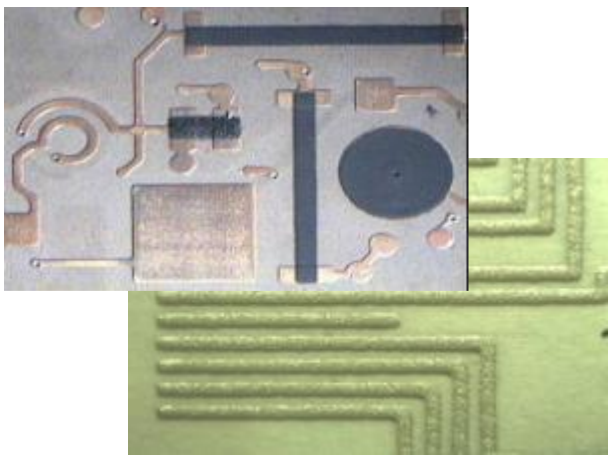


Three classes of printed & flexible electronics hardware: 1) **Devices** – passive (resistors, capacitors, inductors) and active (thin film transistors and OMEMs); 2) **Modules & Units** – display (emissive, reflective), lighting (OLED, EL), power (primary, secondary); 3) **Final Products** – Bluetooth headset, on-body sensor system.

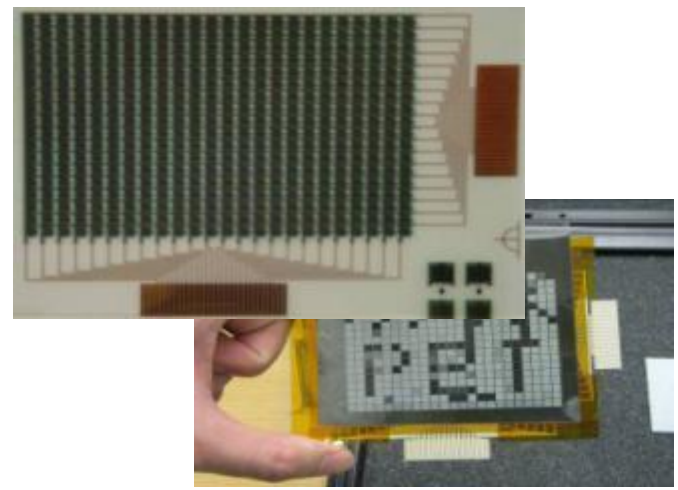
Printed & Flexible Electronics:

Devices

Passive Devices



Active Devices

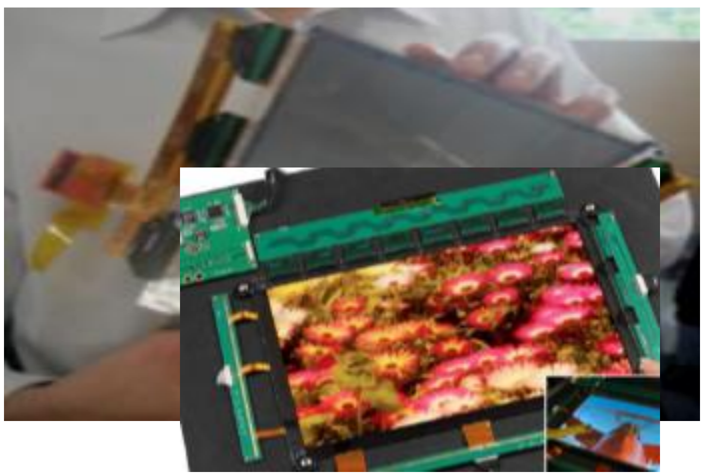


Passive Devices – a single printed layer and one processing step to fabricate resistors, membrane switches, etc. Minimal risk for manufacturing yield.
Active Devices – multiple printed layers and at least five processing steps requiring registration and resolution control to fabricate an active matrix pixel driver for emissive and reflective displays. Increase in manufacturing complexity demands greater process control.

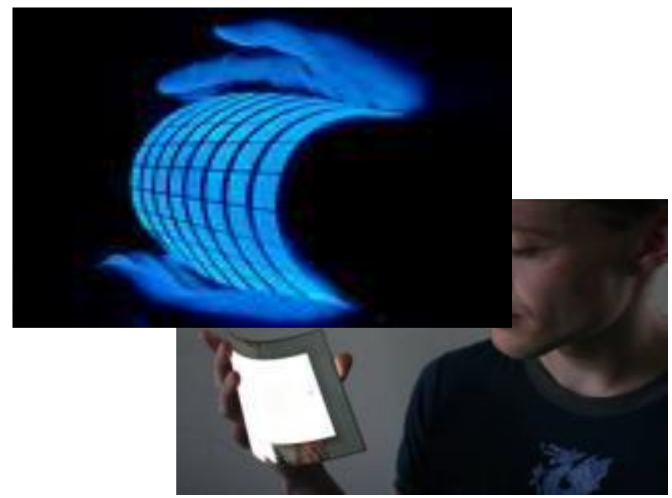
Printed & Flexible Electronics:

Modules & Units

Displays



Lighting



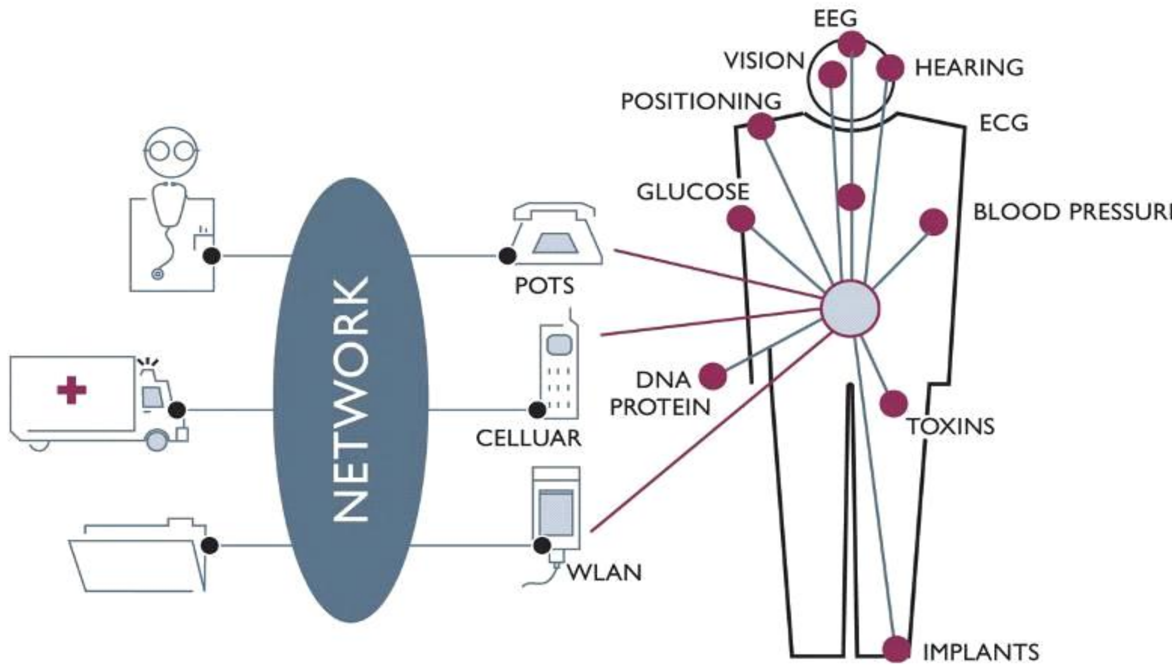
Displays – several advanced materials e.g. electro-optic, reflective/emissive, semiconductor. Low manufacturing risk; greatest risk associated with material performance.

Lighting – multiple materials electro-optic, OLED/ILED, electroluminescent. Low manufacturing risk; greatest risk associated with material performance.

Printed & Flexible Electronics:

Final Products

On-body Sensor Systems



On-body Sensor Systems – communications hardware, novel materials, unique body-conformal designs, and redundant architectures. Moderate manufacturing risk; several high risks: accuracy of data generated during use, biocompatibility of interfaces, flexibility/conformal, network/signal integrity, and data encryption.

Printed & Flexible Electronics

Technology and Infrastructure Development

Printed & Flexible Electronics:

Technology Development Efforts

Materials	Fabrication and Assembly Equipment / Platforms	Manufacturing & Processing Formats	QC/QA Testing & Tooling	Design & Applications
• Base (Substrates) • Functional (Conductive, Dielectric, etc.) • Barriers	• Ambient • Vacuum • Pick & Place	• Sheet • Roll-fed • Roll-to-Roll	• Test frequency • Electrical • Optical • Mechanical • Thermal	• Single/Multi layer • Single/Two sided • Hybrid

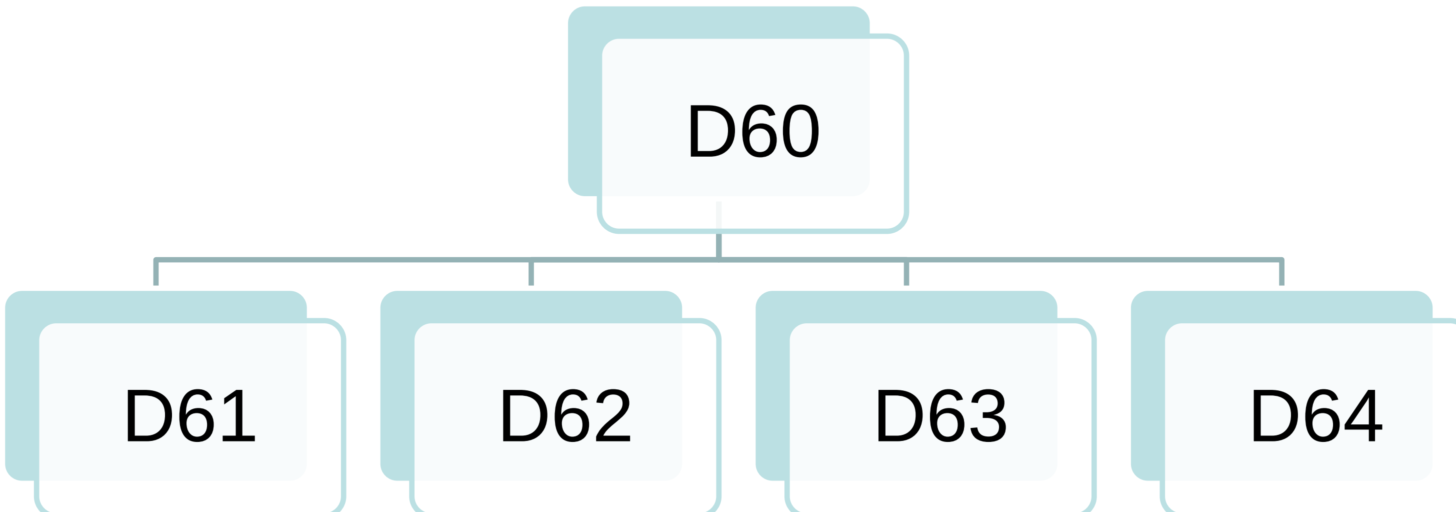
Significant printed & flexible electronics technology development efforts are underway at academia, national laboratories, and in industry.

Printed Electronics:

Standards Development Community

Standards community expanding to include representatives from various organizations.

IPC PE Standards Portfolio



Design Guidelines for Printed Electronics (IPC-2291)

Requirements for Printed Electronics Base Materials (IPC-4921)

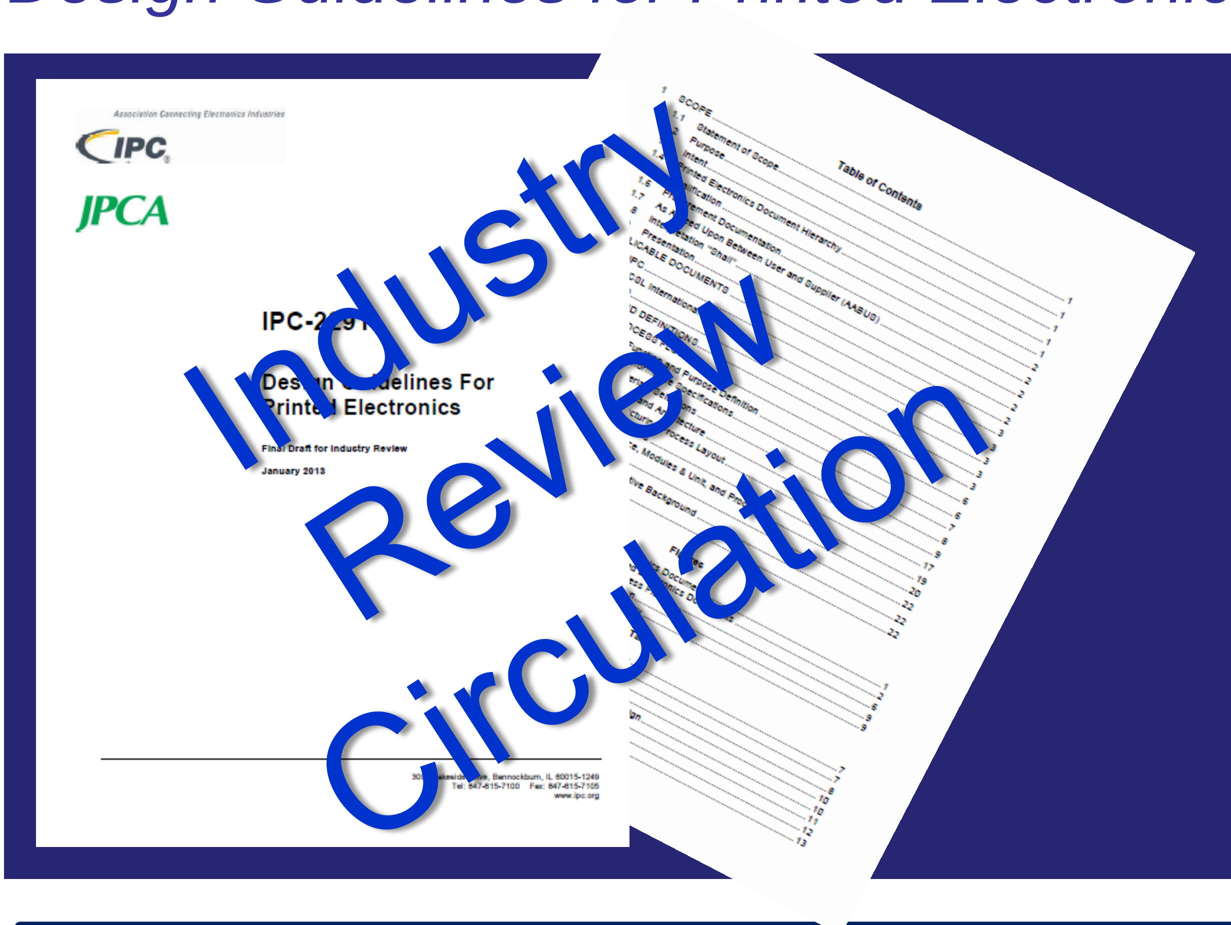
Requirements for Printed Electronics Functional Materials (IPC-4591)

Performance Requirements for Printed Electronics Assemblies (IPC-6901)

Four subcommittees established to develop standards. Ongoing discussion to form new subcommittees for critical printed electronics topics.

IPC D61 Subcommittee

Design Guidelines for Printed Electronics (IPC/JPCA-2291)



Motivation

- Establish a design process flow to facilitate the practice of printed electronics.

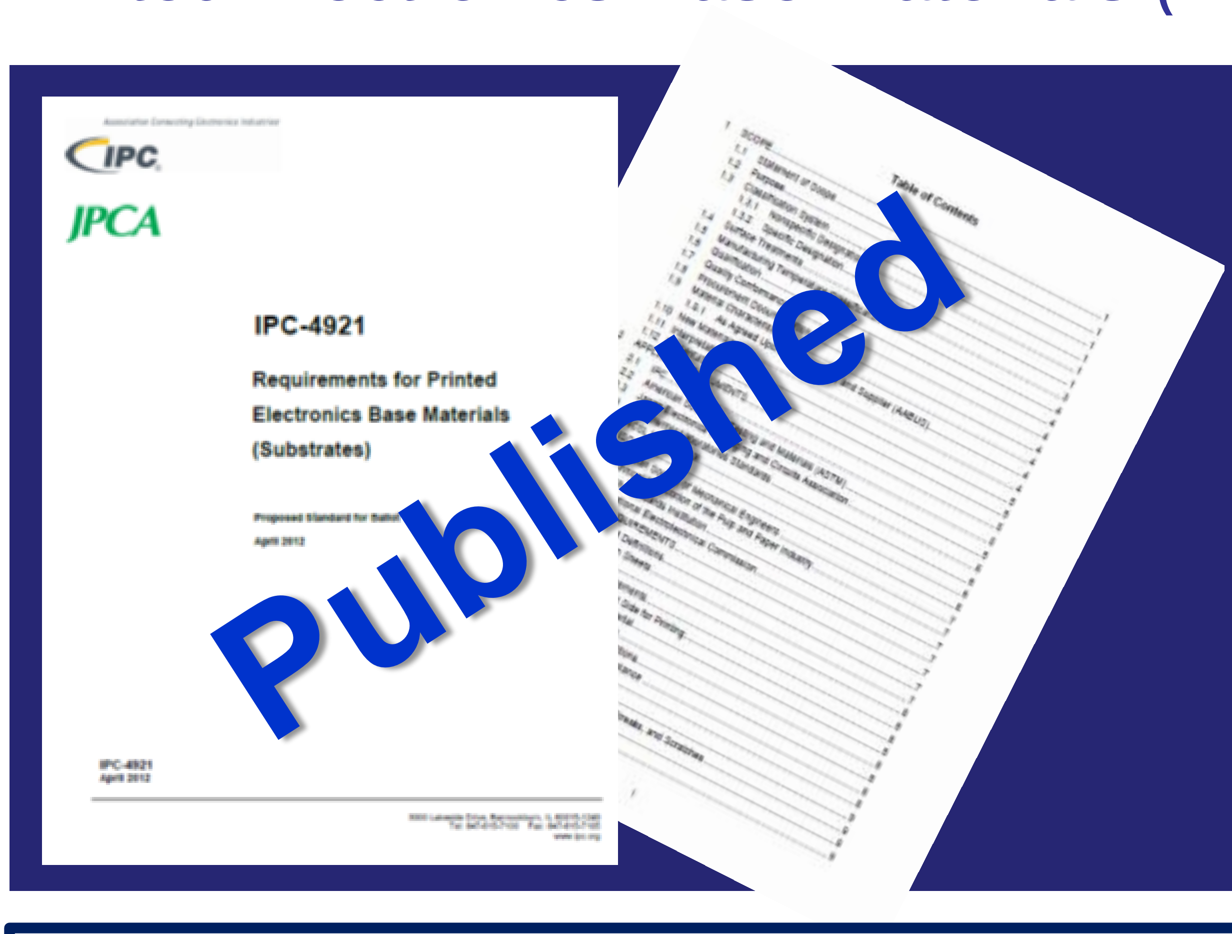
Requirements

- Performance Specifications
- Materials Selection
- Design and Architecture
- Manufacturing Process Layout

Final Draft for Industry Review of IPC/JPCA-2291 in circulation for review and comment until February 25, 2013.

IPC D62 Subcommittee

Printed Electronics Base Materials (IPC/JPCA-4921)



Motivation

- Base (substrate) material strongly influences final device performance.

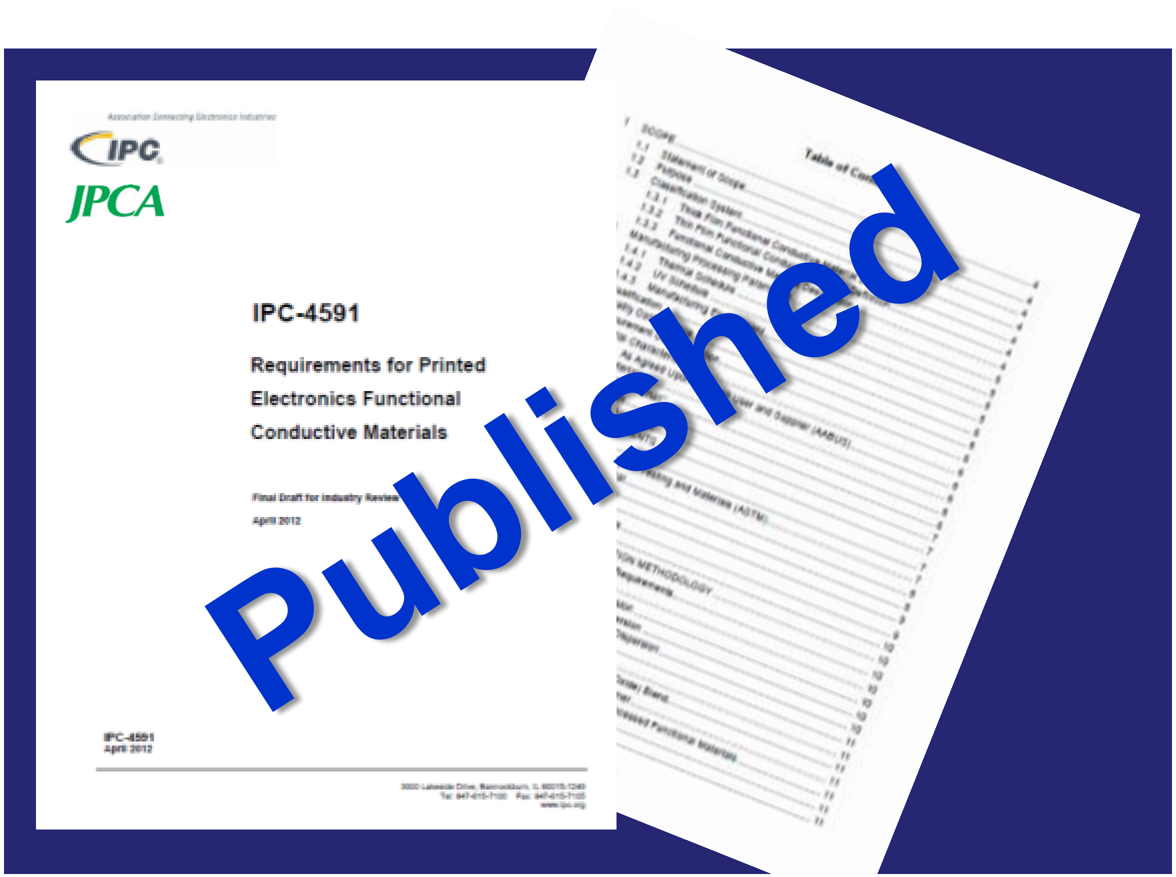
Materials Requirements

- Chemical
- Electrical
- Mechanical
- Optical

Approved by Consensus Body – Ballot Closed on June 1, 2012 (Released to Public July 2012).

IPC D63 Subcommittee

Printed Electronics Functional Materials (IPC/JPCA-4591)



Motivation

- Multiple classes of conductive functional materials available.

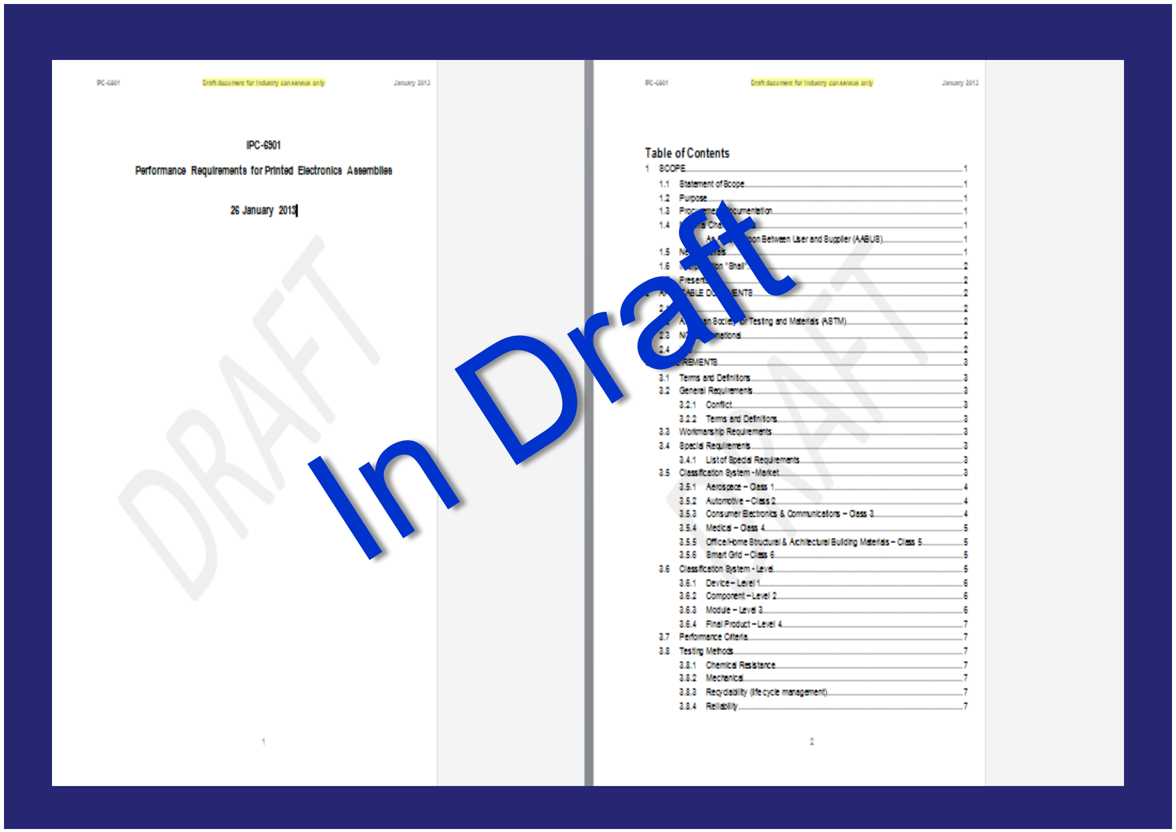
Requirements

- Mechanical Properties
- Electrical Properties
- Optical Properties
- Test Vehicle Designs
- Shelf and Working Life

Approved by Consensus Body – Ballot Closed on October 8, 2012 (Released to Public December 2012).

IPC D64 Subcommittee

Printed Electronics Final Assembly (IPC/JPCA-6901)



Motivation

- Provide developers the tools to design and manufacture printed electronics assemblies.

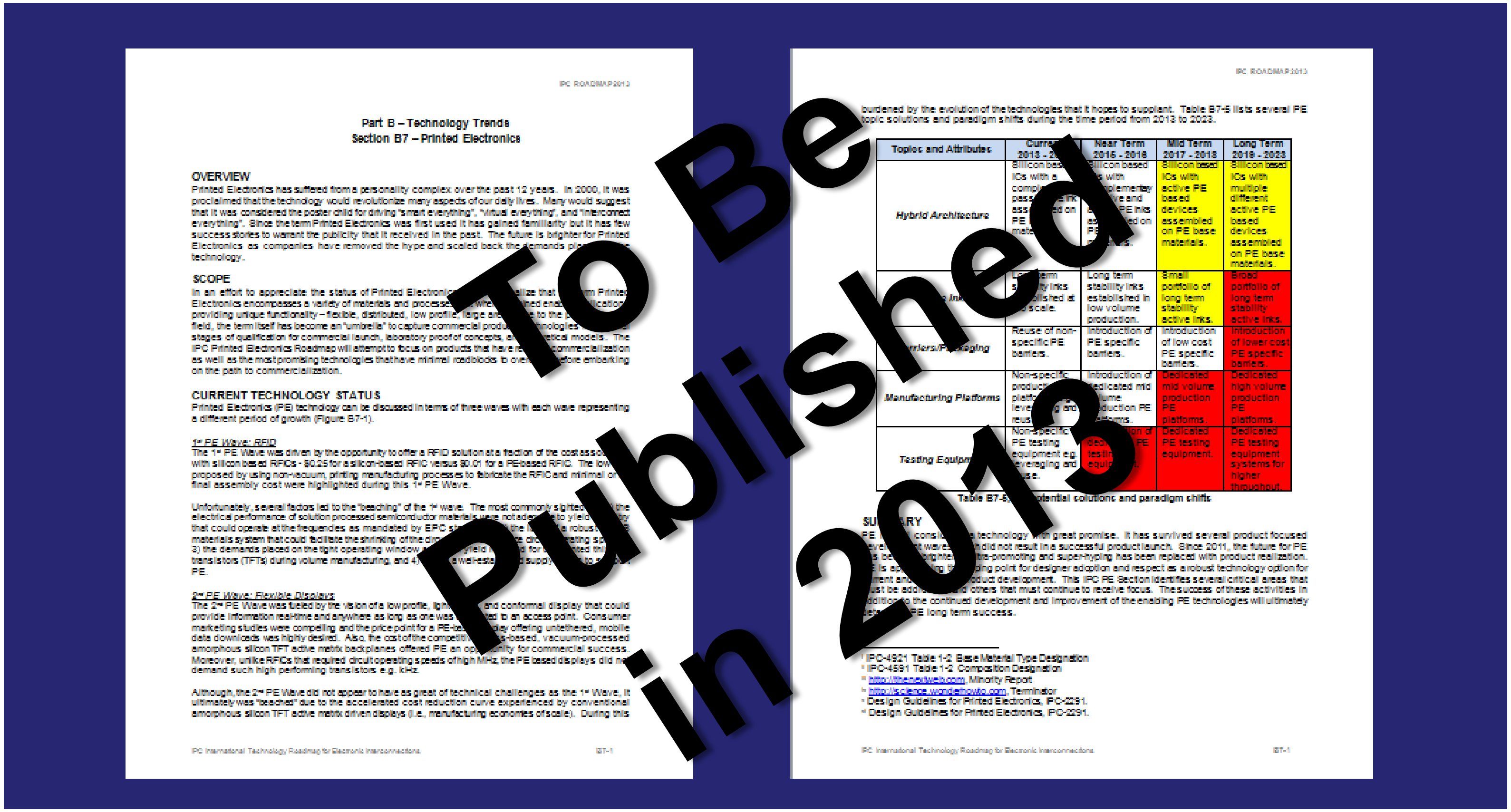
Requirements

- Classification System - Market
- Classification System - Level
- Performance Criteria
- Testing Methods

D64 Subcommittee identifying the necessary technical structure to design and manufacture printed electronics assemblies that meet conformance to industry established metrics as determined by industry accepted testing methods.

IPC PE Roadmapping Initiative

8-61 PE Technology Roadmap Subcommittee



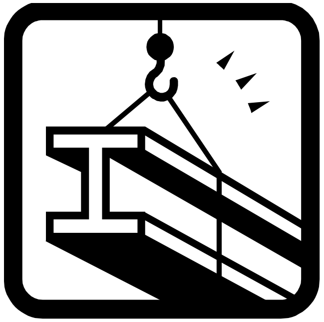
PE Technology Roadmap Subcommittee Published Chapter for Inclusion in IPC 2013 Roadmap.

Printed & Flexible Electronics Pipeline – *Experts Only**

Pipeline - This is the classic Hawaiian wave — amazing, barreling, and mean. It's one of the most famous and most photographed waves there is. If you have just read surfing lesson one – catching waves and are ready to go out and try surfing for the first time, then Pipeline is probably the last place on the planet you want to be. (http://www.surfing-waves.com/surf_talk1.htm#P)

** Training now available to all interested dudes.*

Acknowledgements



- D61 Subcommittee Members
- D62 Subcommittee Members
- D63 Subcommittee Members
- D64 Subcommittee Members
- 8-61 Subcommittee Members
- IPC Staff

Thank You

Questions ?

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