

# Printed & Flexible Electronics – Surf's Up

*Daniel Gamota – Jabil, Inc.*

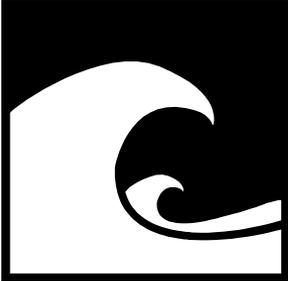
# Presentation Outline

## Printed & Flexible Electronics

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

# Printed & Flexible Electronics Development Waves

The 1<sup>st</sup> PE Wave:  
***RFID***



2002

The 2<sup>nd</sup> PE Wave:  
***Flexible Displays***



2007

The 3<sup>rd</sup> 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.

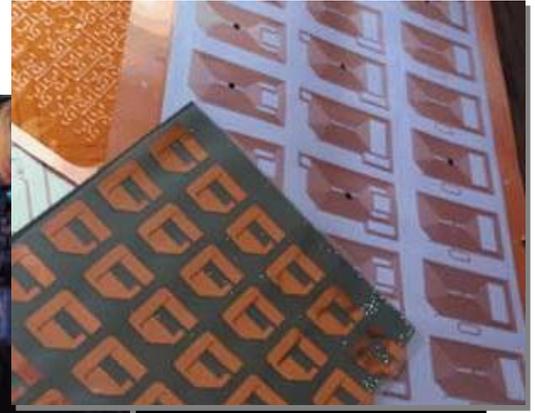
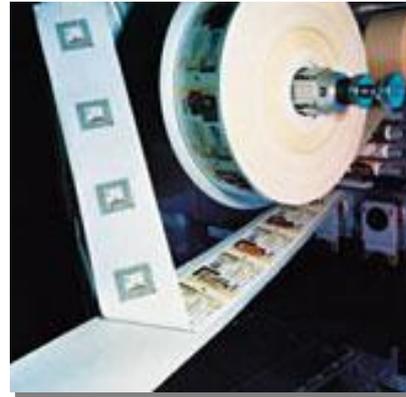
# 1<sup>st</sup> PE Wave - RFID

## 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.



1<sup>st</sup> PE Wave increased visibility and promoted the opportunities that could be realized.

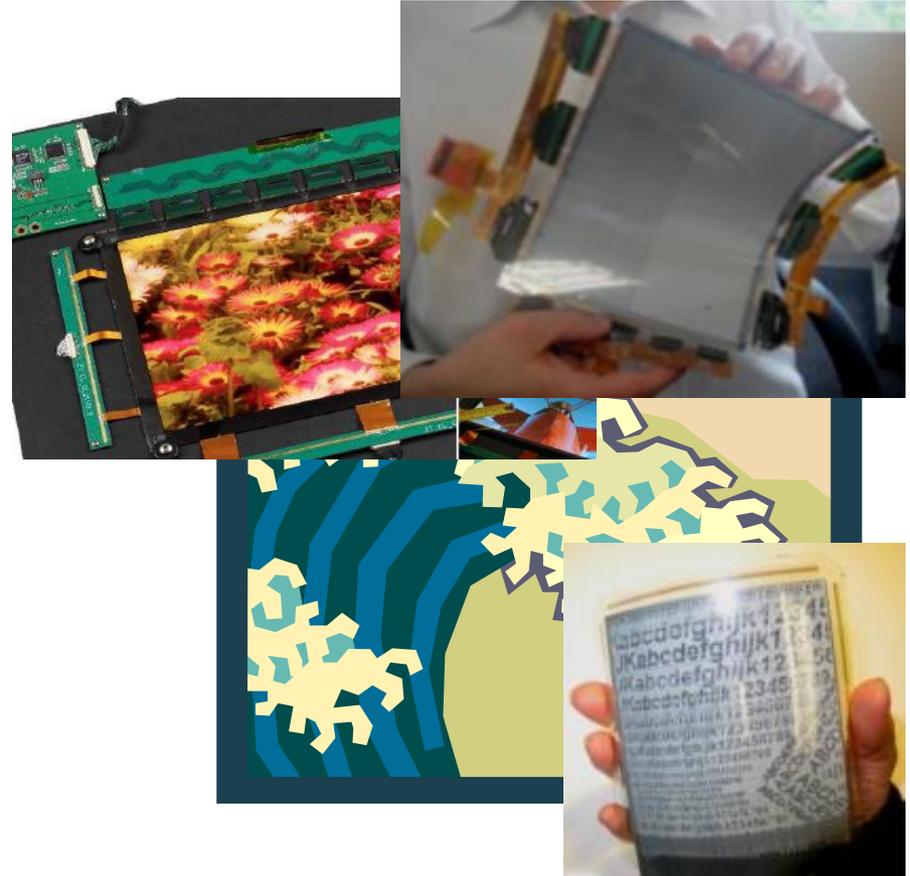
# 2<sup>nd</sup> PE Wave – Flexible Displays

## 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).



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

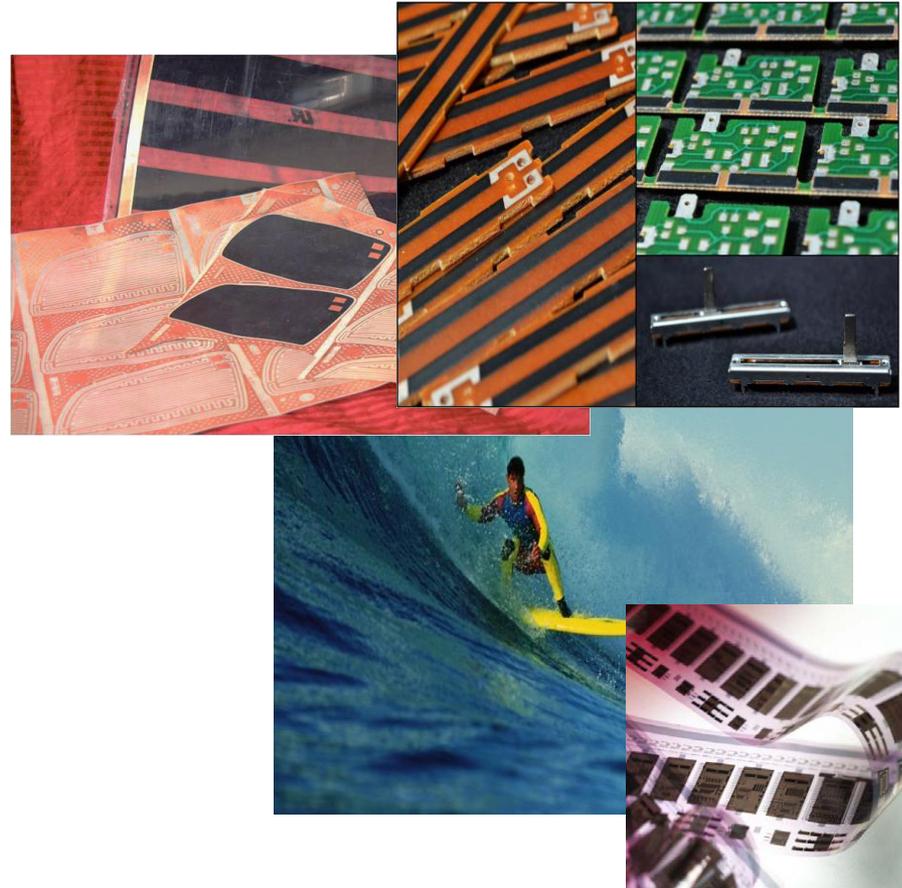
# 3<sup>rd</sup> PE Wave – Integration and Hybrid Architectures

## 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.

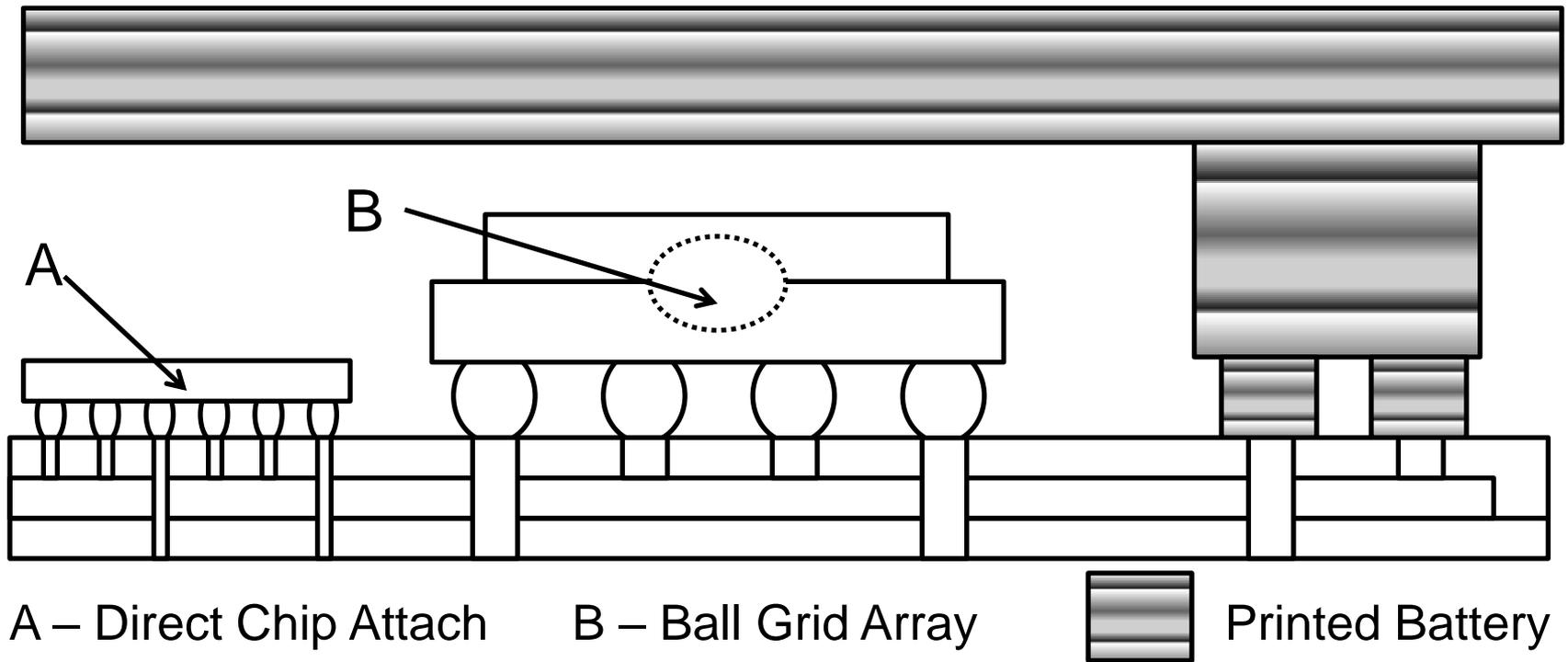
## Outlook: Surf’s Up

- 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.



3<sup>rd</sup> PE Wave continues to strengthen the infrastructure as commercial launches are realized.

# 3<sup>rd</sup> 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:

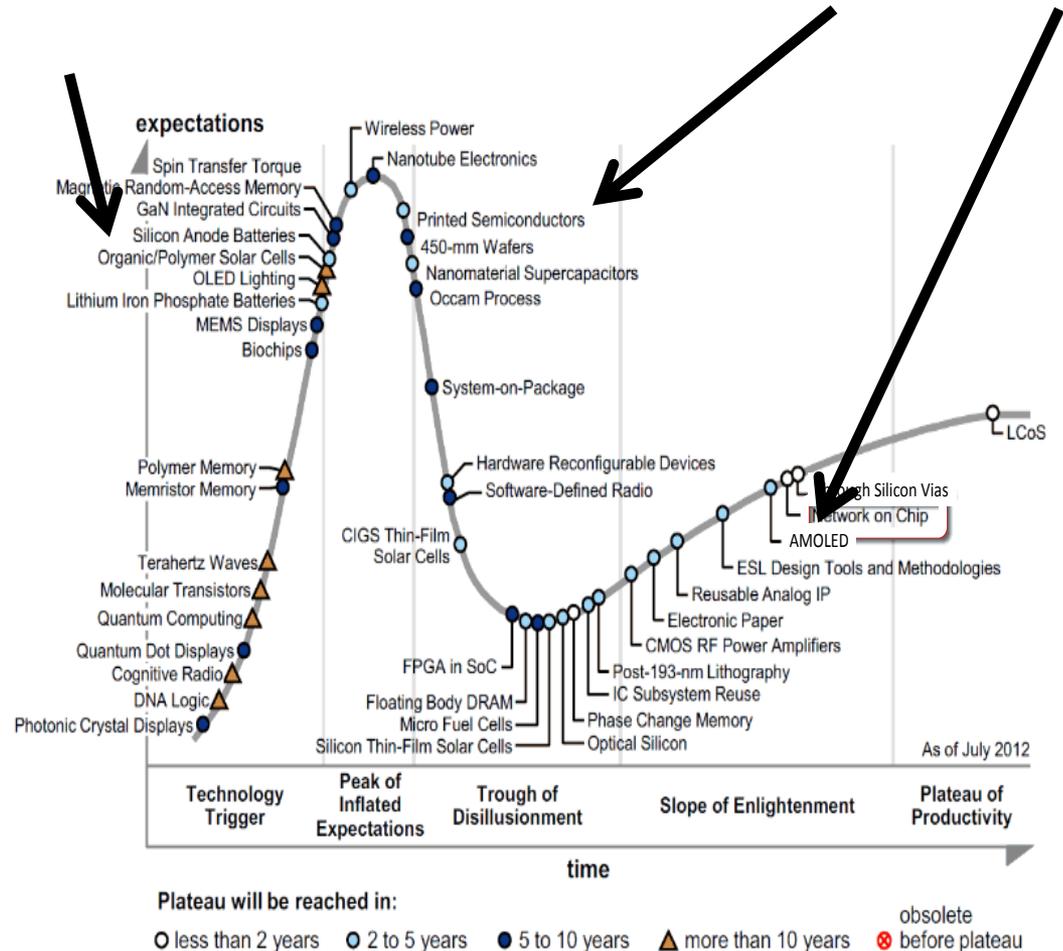
## *The Time is Approaching*

### 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



# 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**

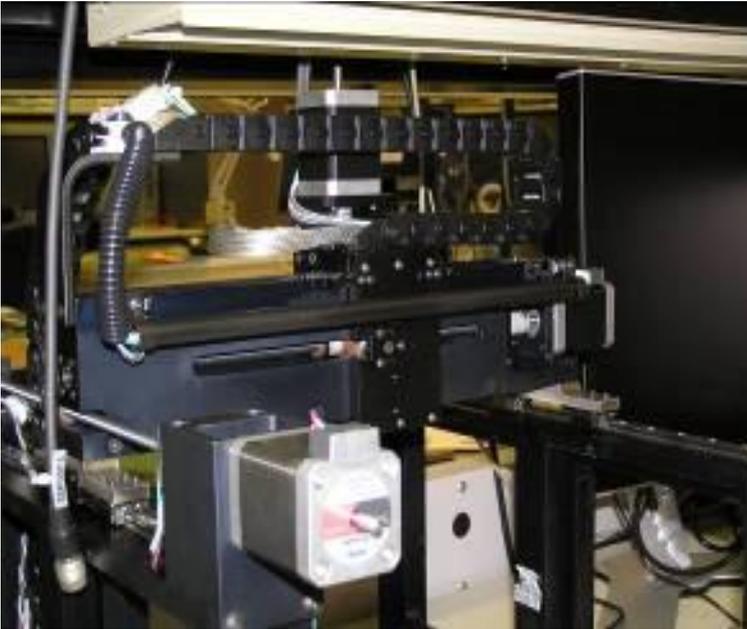
#### ▪ **Embossing**

#### ▪ **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



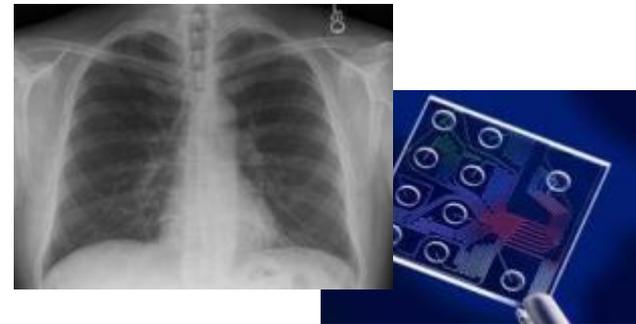
## Automotive Opportunities



## Communications Opportunities



## Medical Opportunities

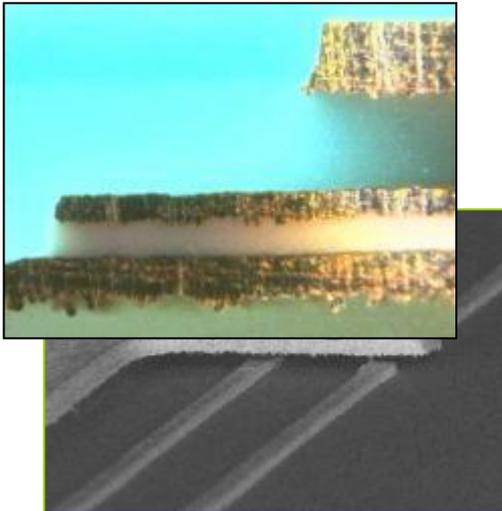


Printed & Flexible Electronics is a technology platform that enables a portfolio of new products in large markets – display, lighting, sensors, power, etc.

# Printed & Flexible Electronics:

## *Devices, Modules & Units, and Final Products*

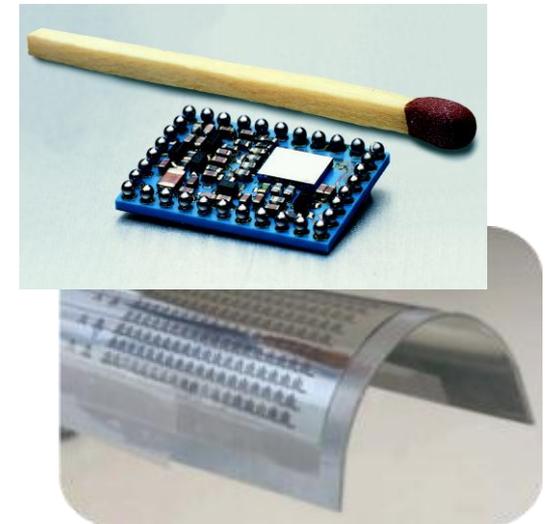
### Devices



### Modules & Units



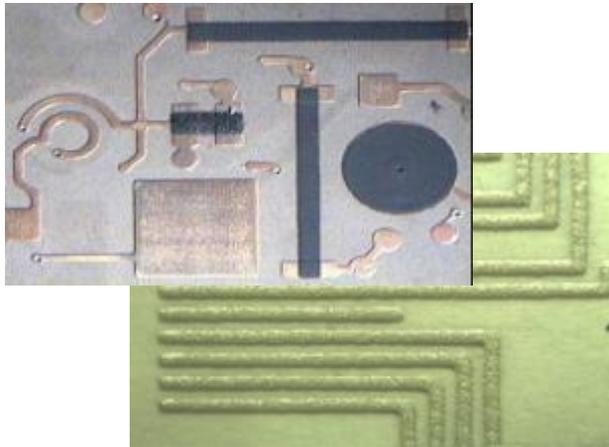
### Final Products



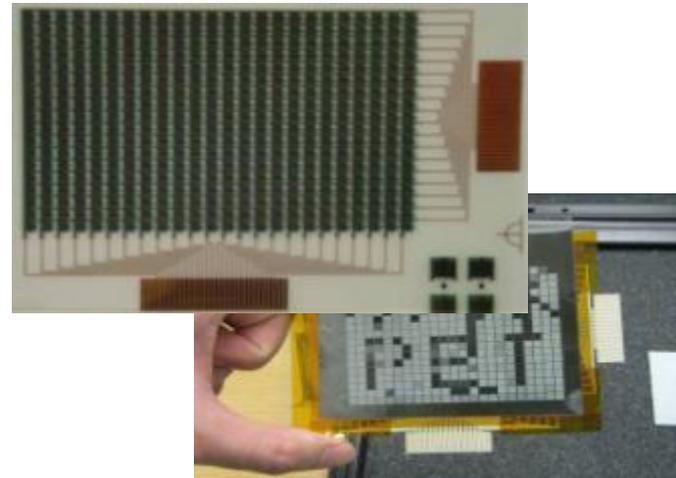
Three classes of printed & flexible electronics hardware: 1) **Devices** – passive (resistors, capacitors, inductors) and active (thin film transistors and OMEMs); 2) **Modules & Units** – display (emissive, reflective), lighting (OLED, EL), power (primary, secondary); 3) **Final Products** – Bluetooth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



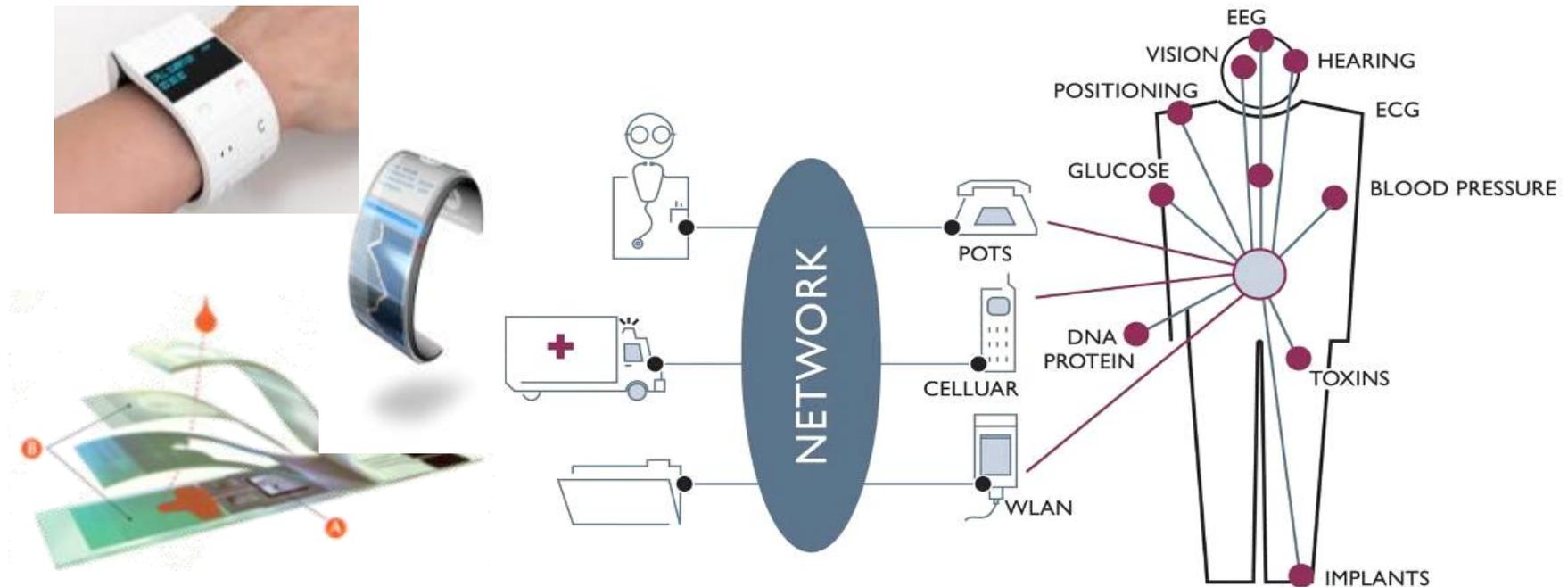
**Displays** – several advanced materials e.g. electro-optic, reflective/emissive, semiconductor. Low manufacturing risk; greatest risk associated with material performance.

**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*

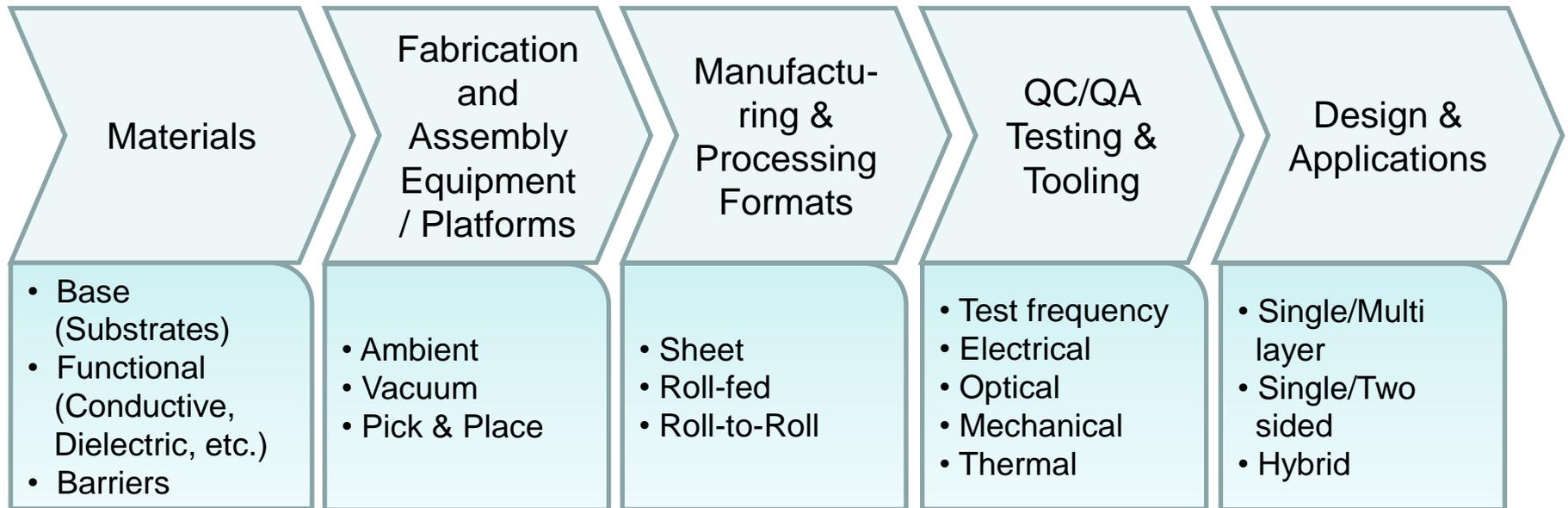


**On-body Sensor Systems** – communications hardware, novel materials, unique body-conformal designs, and redundant architectures. Moderate manufacturing risk; several high risks: accuracy of data generated during use, biocompatibility of interfaces, flexibility/conformal, network/signal integrity, and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

# Printed & Flexible Electronics

*Technology and Infrastructure  
Development*

# Printed & Flexible Electronics: *Technology Development Efforts*



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

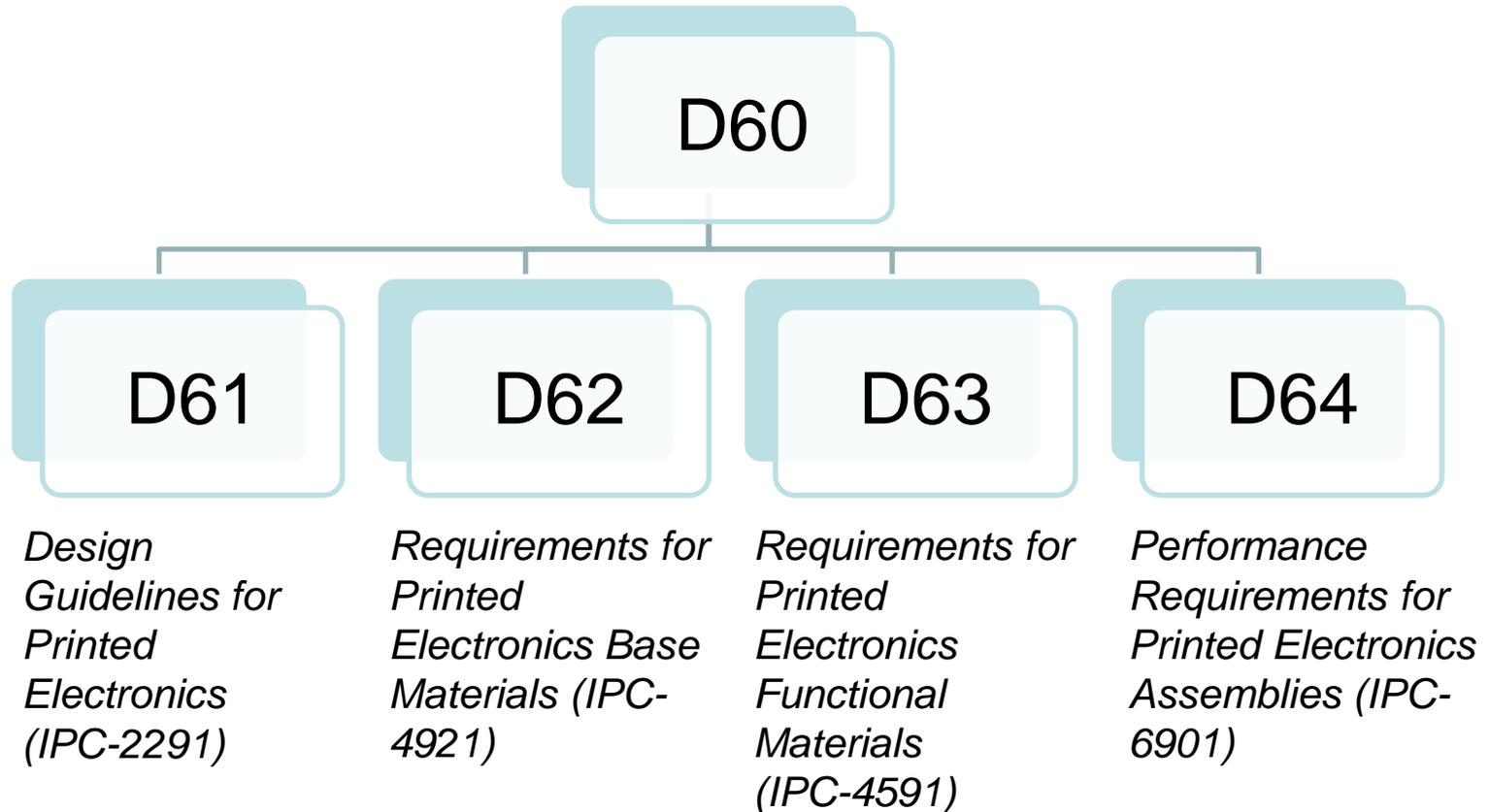
# Printed Electronics:

## *Standards Development Community*



Standards community expanding to include representatives from various organizations.

# IPC PE Standards Portfolio

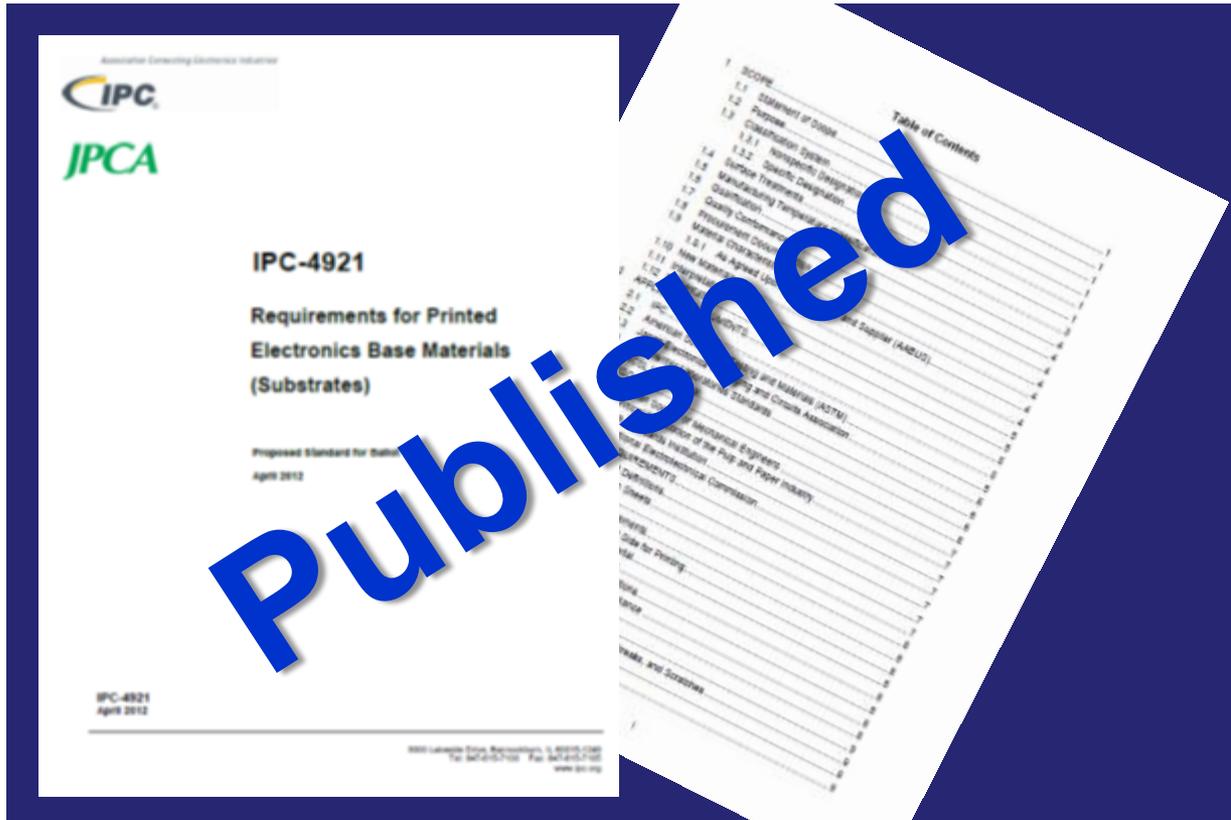


Four subcommittees established to develop standards. Ongoing discussion to form new subcommittees for critical printed electronics topics.



# IPC D62 Subcommittee

## *Printed Electronics Base Materials (IPC/JPCA-4921)*



### Motivation

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

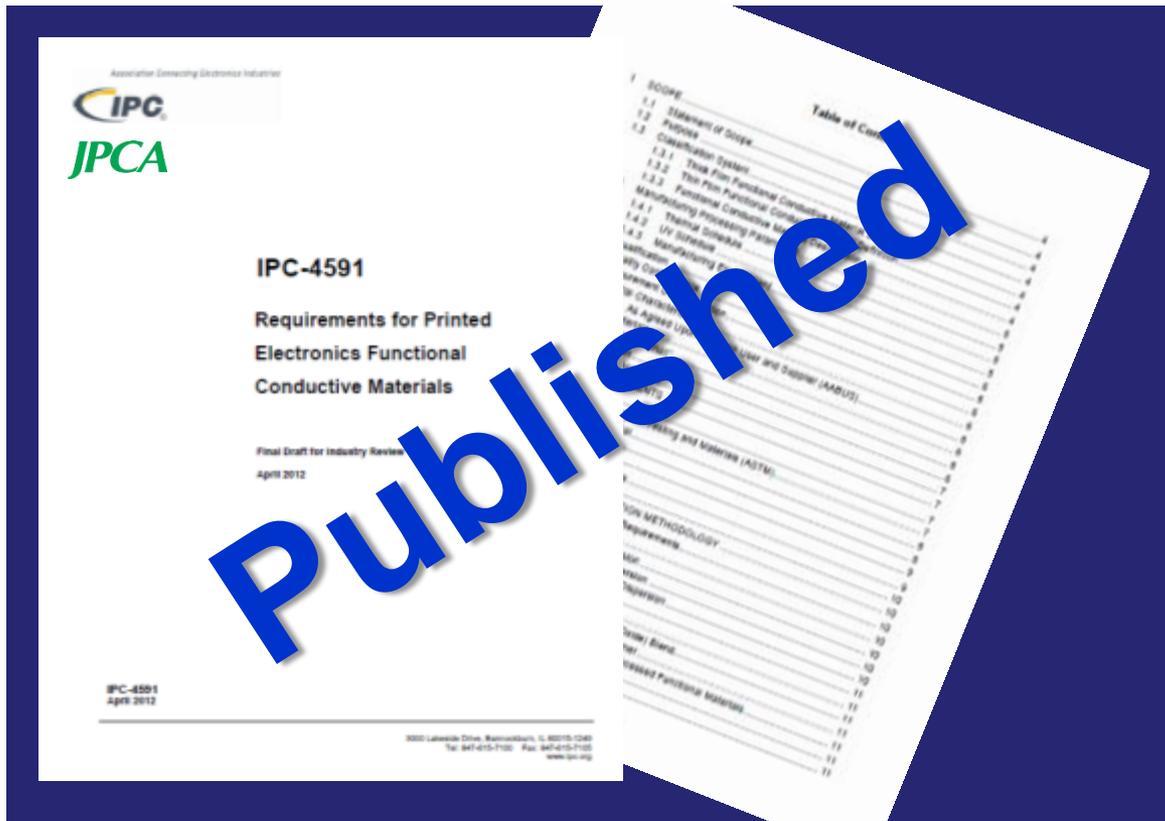
### Materials Requirements

- 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.

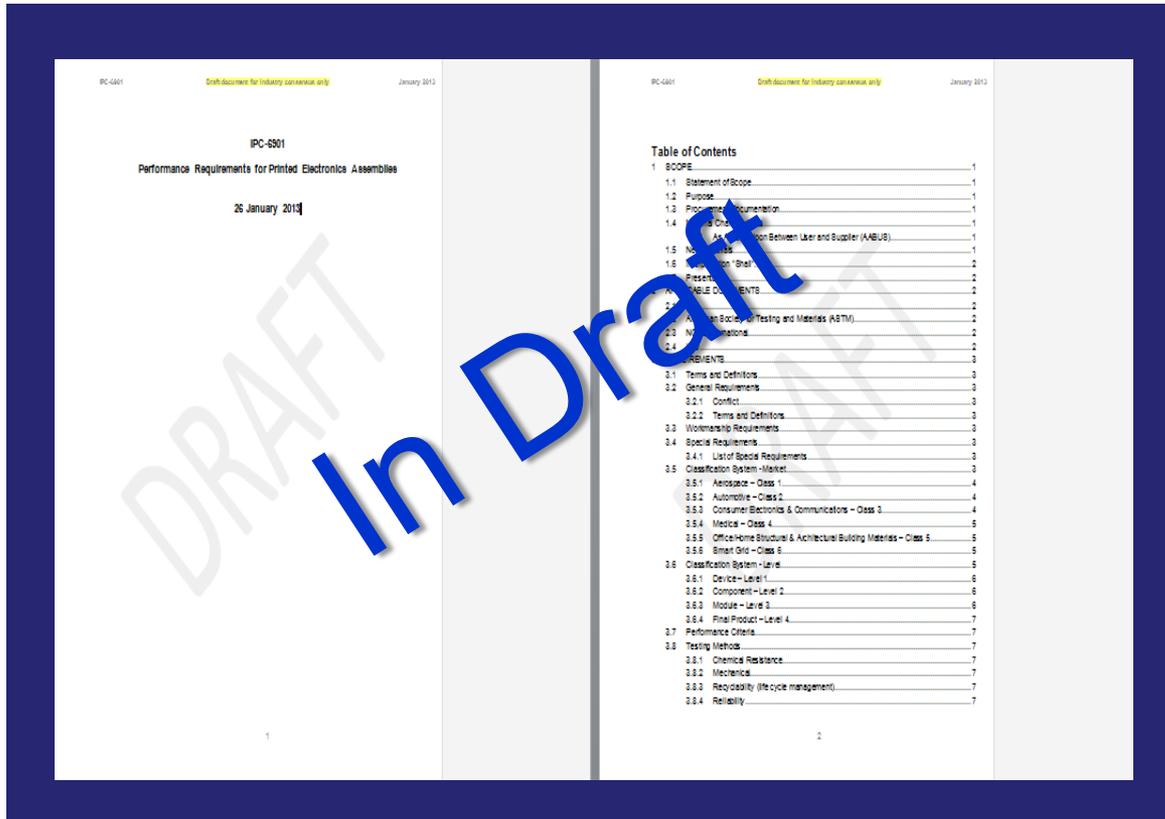
### Requirements

- 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

IPC ROADMAP2013

**Part B – Technology Trends  
Section B7 – Printed Electronics**

**OVERVIEW**  
Printed Electronics has suffered from a personality complex over the past 12 years. In 2000, it was proclaimed that the technology would revolutionize many aspects of our daily lives. Many would suggest that it was considered the poster child for driving "smarter everything", "virtual everything", and "interconnected everything". Since the term Printed Electronics was first used it has gained familiarity but it has few success stories to warrant the publicity that it received in the past. The future is brighter for Printed Electronics as companies have removed the hype and scaled back the demands on the technology.

**SCOPE**  
In an effort to appreciate the status of Printed Electronics and to realize that the term Printed Electronics encompasses a variety of materials and processes, the Printed Electronics Application field, the term itself has become an "umbrella" to capture commercial products and technologies in the stages of qualification for commercial launch, laboratory proof-of-concept, and physical models. The IPC Printed Electronics Roadmap will attempt to focus on products that have a high potential for commercialization as well as the most promising technologies that have minimal roadblocks to overcome before embarking on the path to commercialization.

**CURRENT TECHNOLOGY STATUS**  
Printed Electronics (PE) technology can be discussed in terms of three waves with each wave representing a different period of growth (Figure B7-1).

**1<sup>st</sup> PE Wave: RFID**  
The 1<sup>st</sup> PE Wave was driven by the opportunity to offer a RFID solution at a fraction of the cost associated with silicon based RFID's - \$0.25 for a silicon-based RFID versus \$0.01 for a PE-based RFID. The low cost was achieved by using non-vacuum printing manufacturing processes to fabricate the RFID and minimal or no final assembly cost were highlighted during this 1<sup>st</sup> PE Wave.

Unfortunately, several factors led to the "backlash" of the 1<sup>st</sup> wave. The most commonly cited were the electrical performance of solution processed semiconductor materials that were not appropriate for the frequencies that could operate at the frequencies as mandated by EPC standards. The lack of a robust and reliable materials system that could facilitate the shrinking of the chip size and the high dielectric constant materials placed on the light operating windows and the need for vacuum processed transistors (TFTs) during volume manufacturing, and a lack of a well-established supply chain for PE.

**2<sup>nd</sup> PE Wave: Flexible Displays**  
The 2<sup>nd</sup> PE Wave was fueled by the vision of a low profile, lightweight and conformal display that could provide information anytime and anywhere as long as one was within range of an access point. Consumer marketing studies were compelling and the price point for a PE-based display offering untethered, mobile data connectivity was highly desired. Also, the cost of the competing silicon based, vacuum processed amorphous silicon TFT active matrix backplanes offered PE an opportunity for commercial success. Moreover, unlike RFID's that required circuit operating speeds of high MHz, the PE based displays did not demand such high performing transistors e.g. IZO.

Although, the 2<sup>nd</sup> PE Wave did not appear to have as great of technical challenges as the 1<sup>st</sup> Wave, it ultimately was "backlash" due to the accelerated cost reduction curve experienced by conventional amorphous silicon TFT active matrix driven displays (i.e., manufacturing economies of scale). During this

IPC ROADMAP2013

buttressed by the evolution of the technologies that it hopes to supplant. Table B7-5 lists several PE topic solutions and paradigm shifts during the time period from 2013 to 2023.

Topic and Attributes	Current 2013-2016	Near Term 2016-2018	Mid Term 2017-2019	Long Term 2019-2023
Hybrid Architecture	Silicon based ICs with a component assembly and PE links assembled on PE base materials.	Silicon based ICs with components assembled on PE links assembled on PE base materials.	Silicon based ICs with active PE based devices assembled on PE base materials.	Silicon based ICs with multiple different active PE based devices assembled on PE base materials.
Printed Interconnects	Long term stability links established at low volume production.	Long term stability links established in low volume production.	Small portfolio of long term stability active links.	Large portfolio of long term stability active links.
Printed Drivers/Passives	Reuse of non-specific PE barriers.	Introduction of PE specific barriers.	Introduction of low cost PE specific barriers.	Introduction of lower cost PE specific barriers.
Manufacturing Platforms	Non-specific production level production PE reuse.	Introduction of production level production PE platforms.	Dedicated mid volume production PE platforms.	Dedicated high volume production PE platforms.
Testing Equipment	Non-specific PE testing equipment e.g. screening and testing.	Introduction of PE testing equipment.	Dedicated PE testing equipment.	Dedicated PE testing systems for higher throughput.

Table B7-5: Potential solutions and paradigm shifts

**SUMMARY**  
Printed Electronics technology has great promise. It has survived several product focused waves that did not result in a successful product launch. Since 2011, the future for PE has been brightened and super-hyping has been replaced with product realization. This is an exciting turning point for designer adoption and respect as a robust technology option for their next product development. The IPC PE Section identifies several critical areas that must be addressed and others that must continue to receive focus. The success of these activities in addition to the continued development and improvement of the enabling PE technologies will ultimately determine the long term success.

IPC-4951 Table 1-0: Base Material Type Designation  
IPC-4951 Table 1-0: Composition Designation  
<http://www.ipc.com>, Minority Report  
<http://www.knowledgeworldwide.com> Terminology  
Design Guidelines for Printed Electronics, IPC-2291  
Design Guidelines for Printed Electronics, IPC-2291

IPC International Technology Roadmap for Electronic Interconnectors

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](http://www.surfing-waves.com/surf_talk1.htm#P))

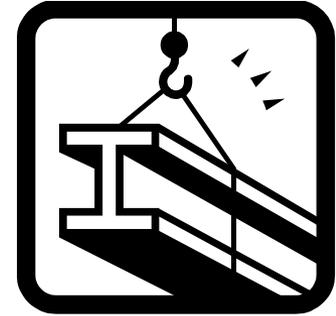
*\* Training now available to all interested dudes.*



# 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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