



Printed & Flexible Electronics – Surf's Up

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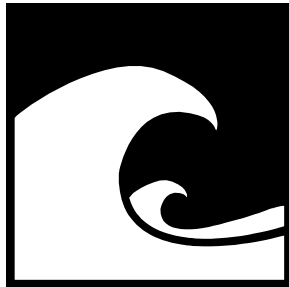
Presentation Outline

Printed & Flexible Electronics

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

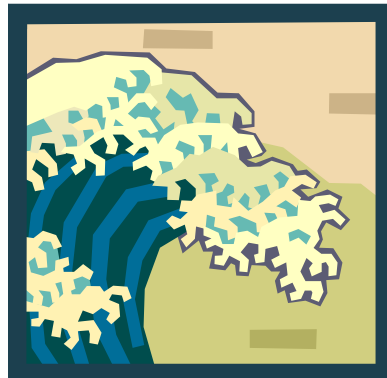
Printed & Flexible Electronics Development Waves

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.

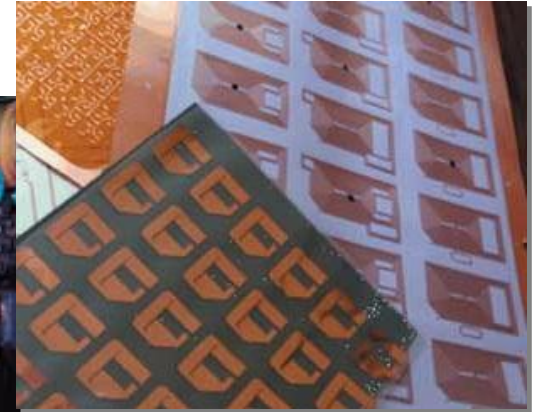
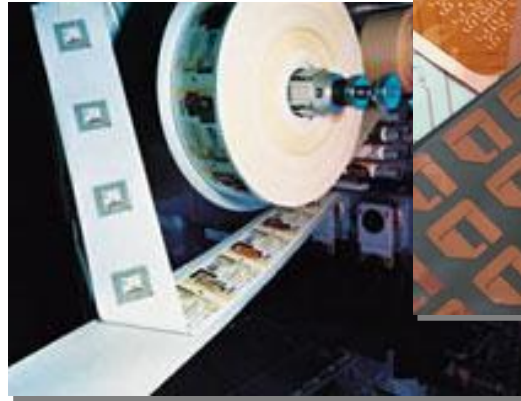
1st PE Wave - RFID

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.

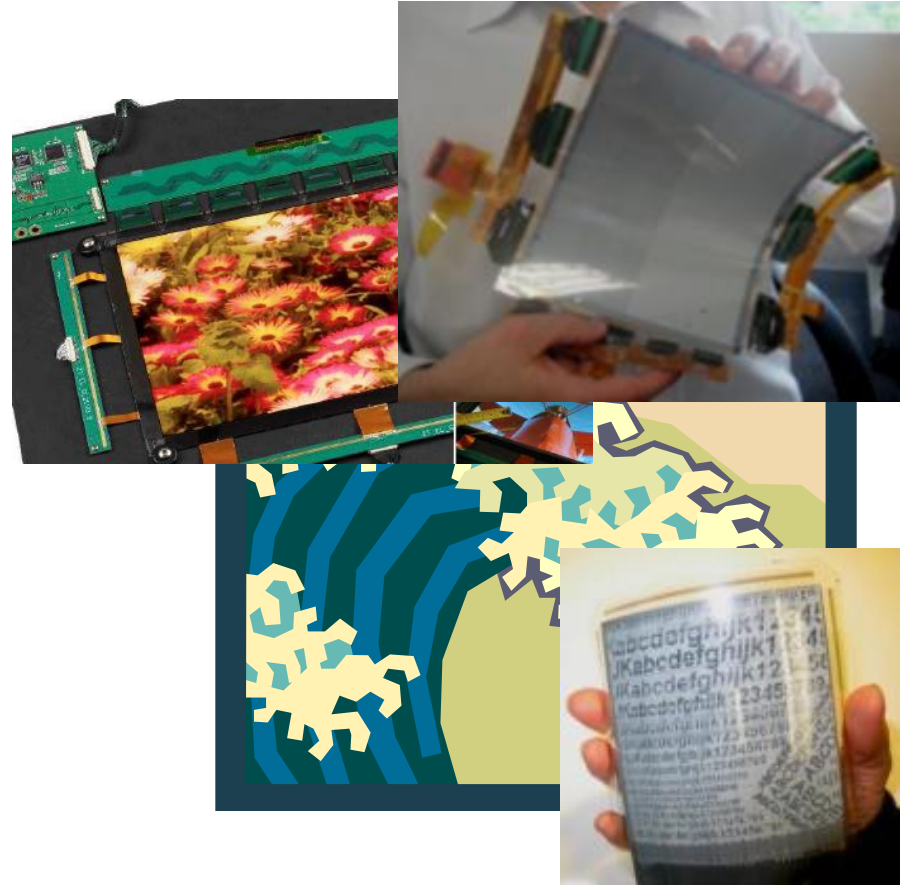
2nd PE Wave – Flexible Displays

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.

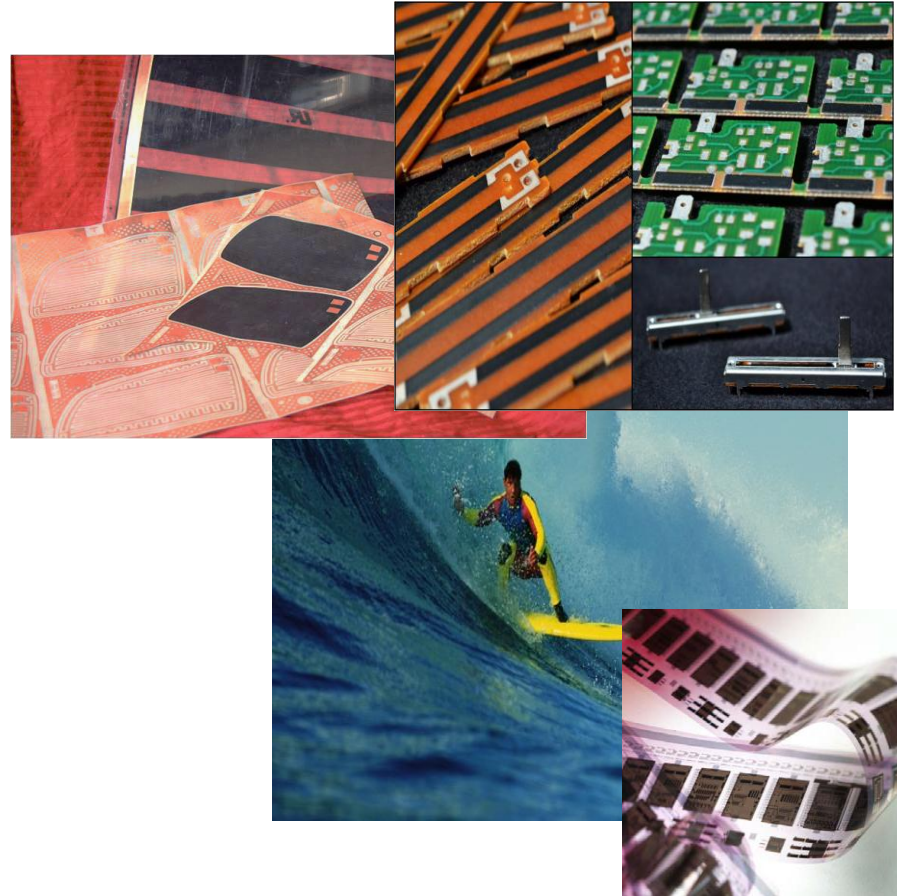
3rd PE Wave – Integration and Hybrid Architectures

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.

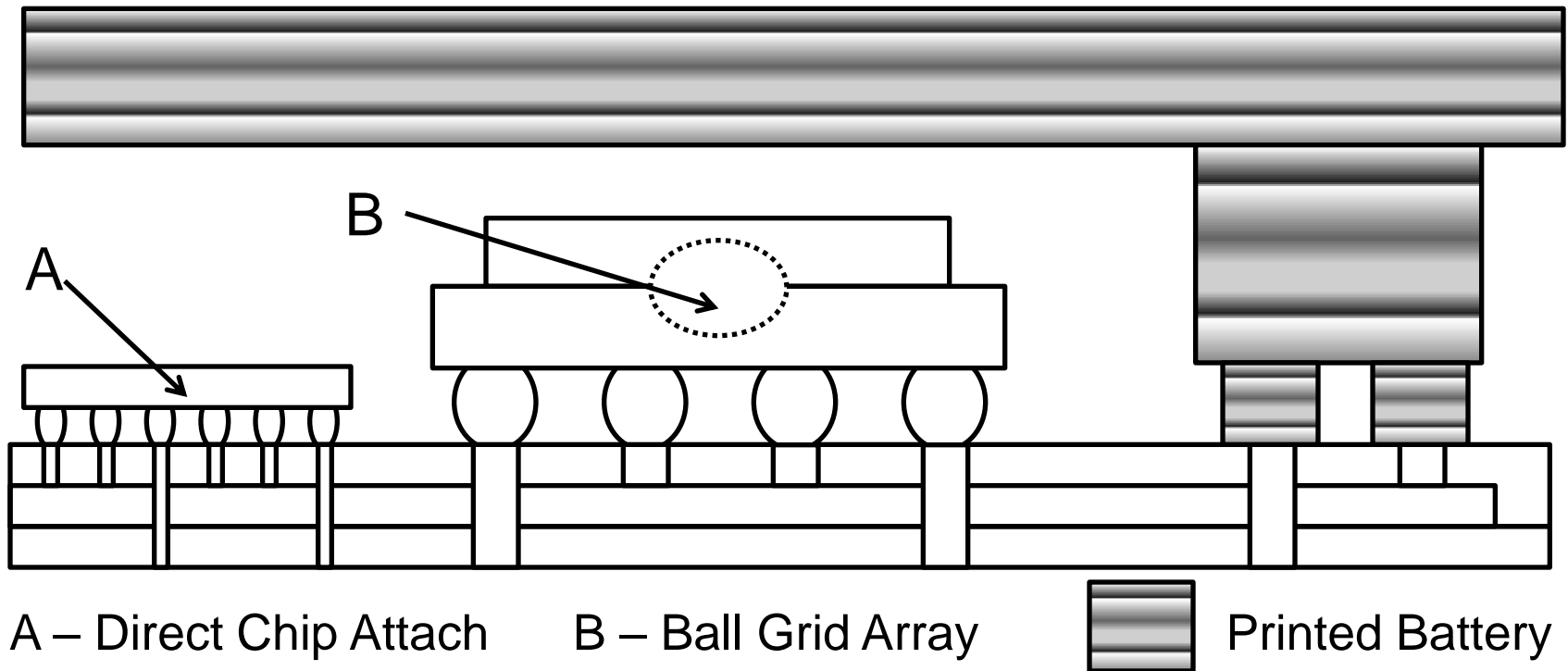
Outlook: Surf's Up

- 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:

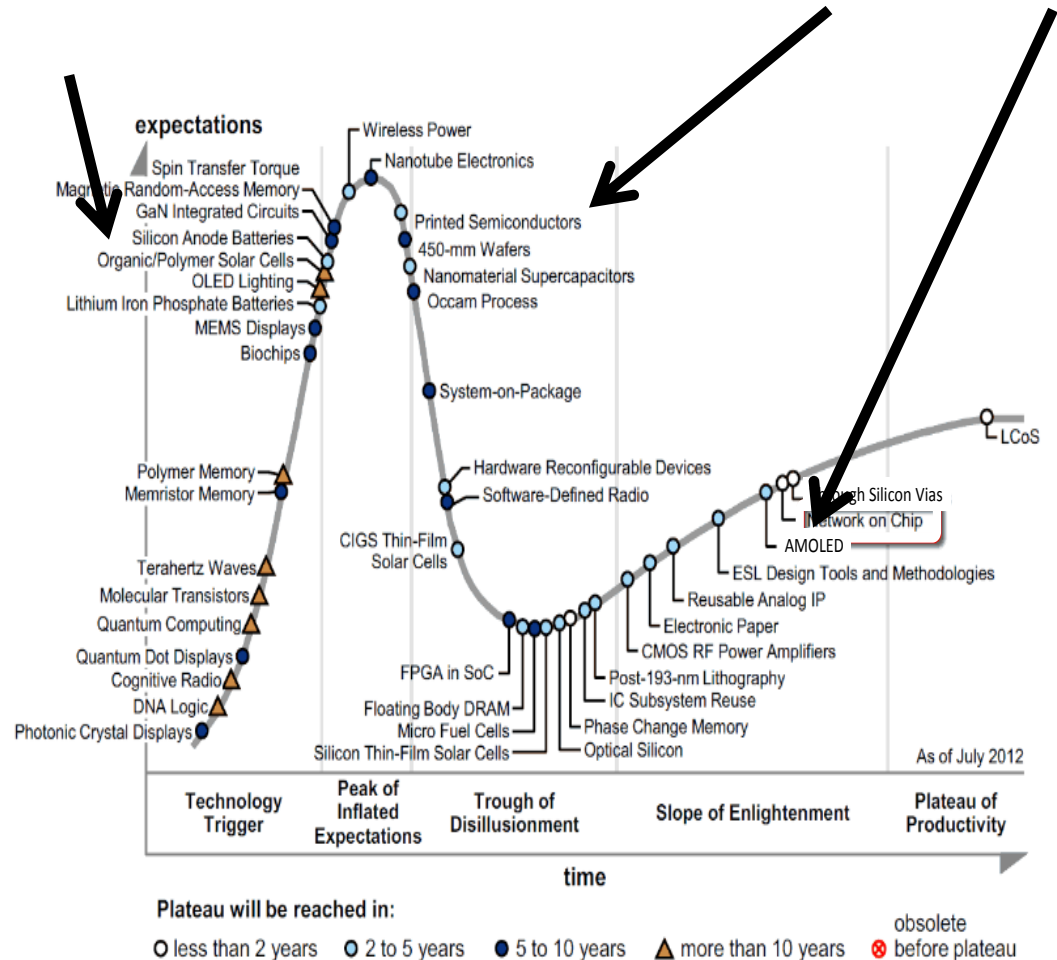
The Time is Approaching

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



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**

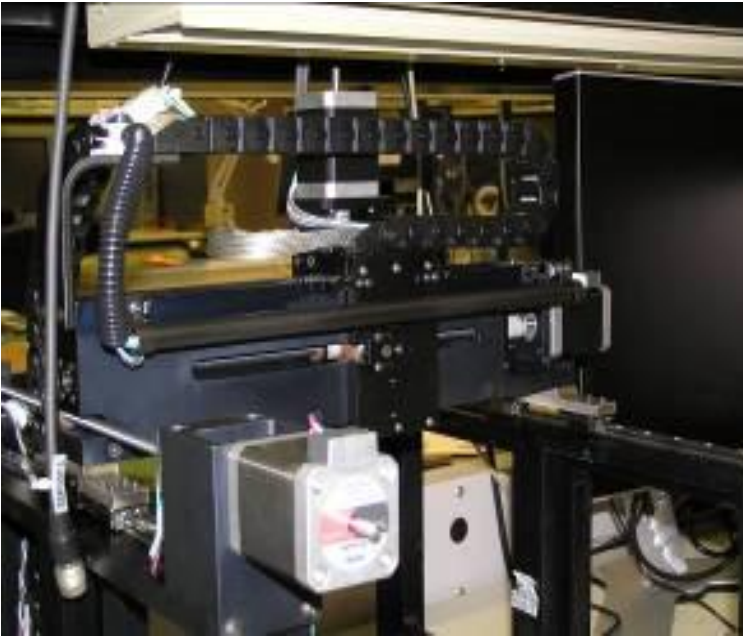
▪ **Embossing**

▪ **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



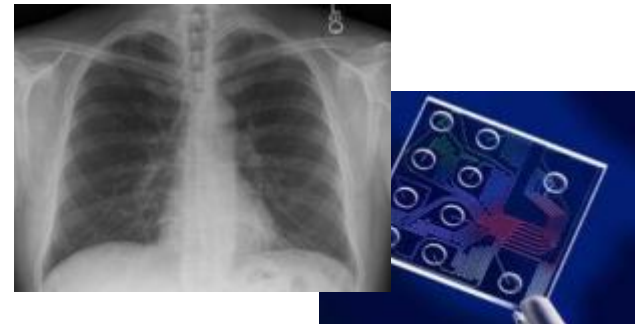
Automotive Opportunities



Communications Opportunities



Medical Opportunities

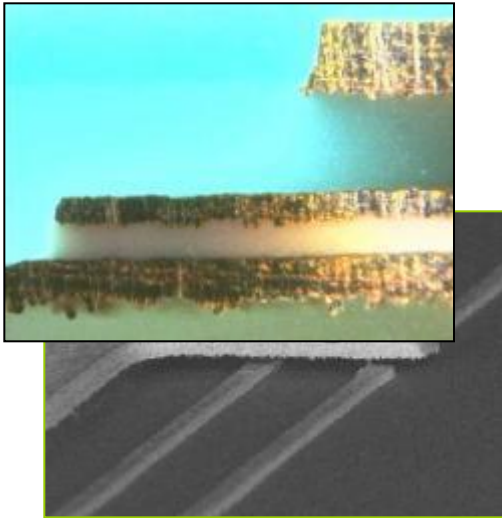


Printed & Flexible Electronics is a technology platform that enables a portfolio of new products in large markets – display, lighting, sensors, power, etc.

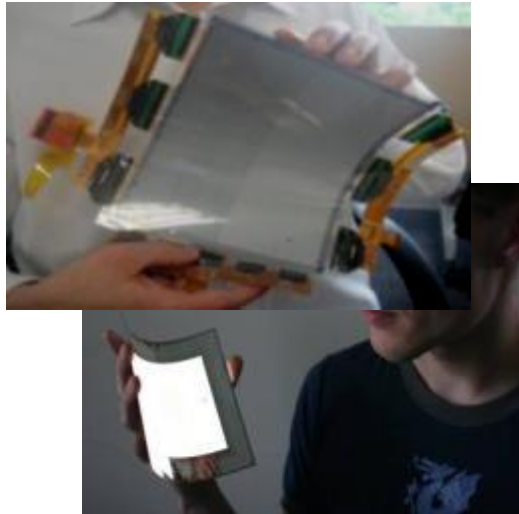
Printed & Flexible Electronics:

Devices, Modules & Units, and Final Products

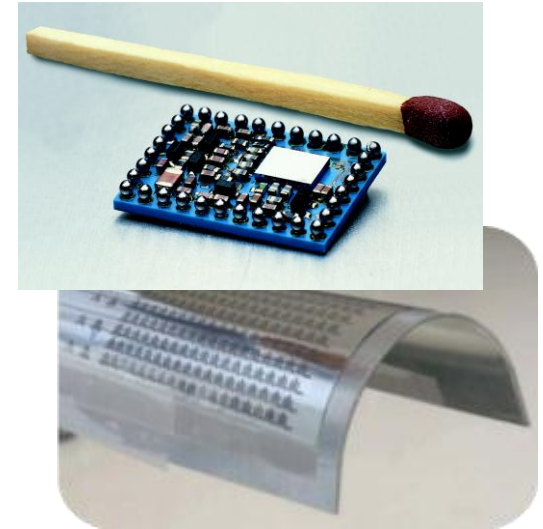
Devices



Modules & Units



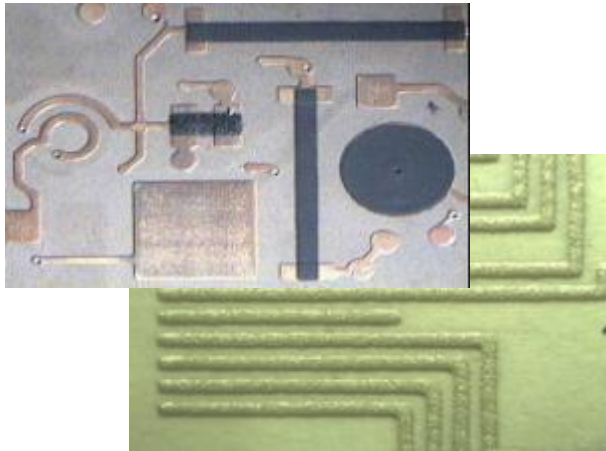
Final Products



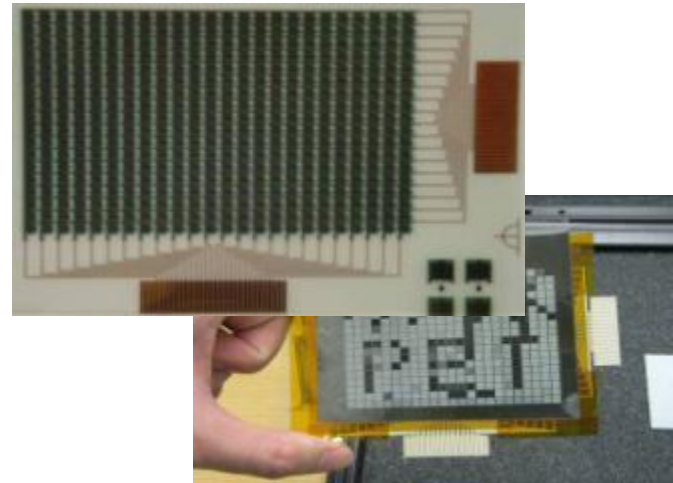
Three classes of printed & flexible electronics hardware: 1) **Devices** – passive (resistors, capacitors, inductors) and active (thin film transistors and OMEMs); 2) **Modules & Units** – display (emissive, reflective), lighting (OLED, EL), power (primary, secondary); 3) **Final Products** – Bluetooth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

Printed & Flexible Electronics: *Devices*

Passive Devices



Active Devices



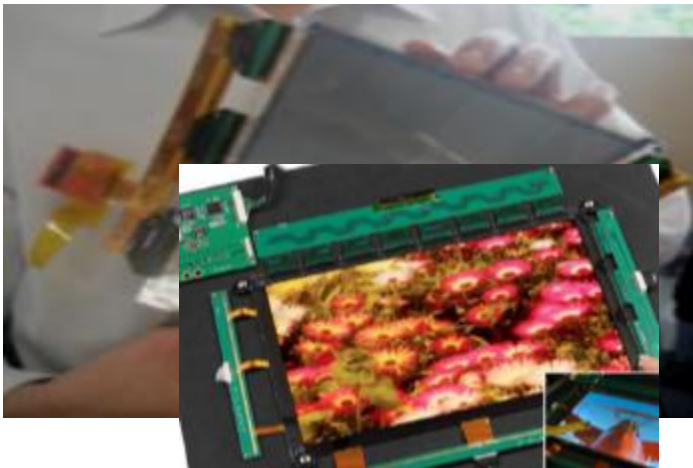
Passive Devices – a single printed layer and one processing step to fabricate resistors, membrane switches, etc. Minimal risk for manufacturing yield.

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



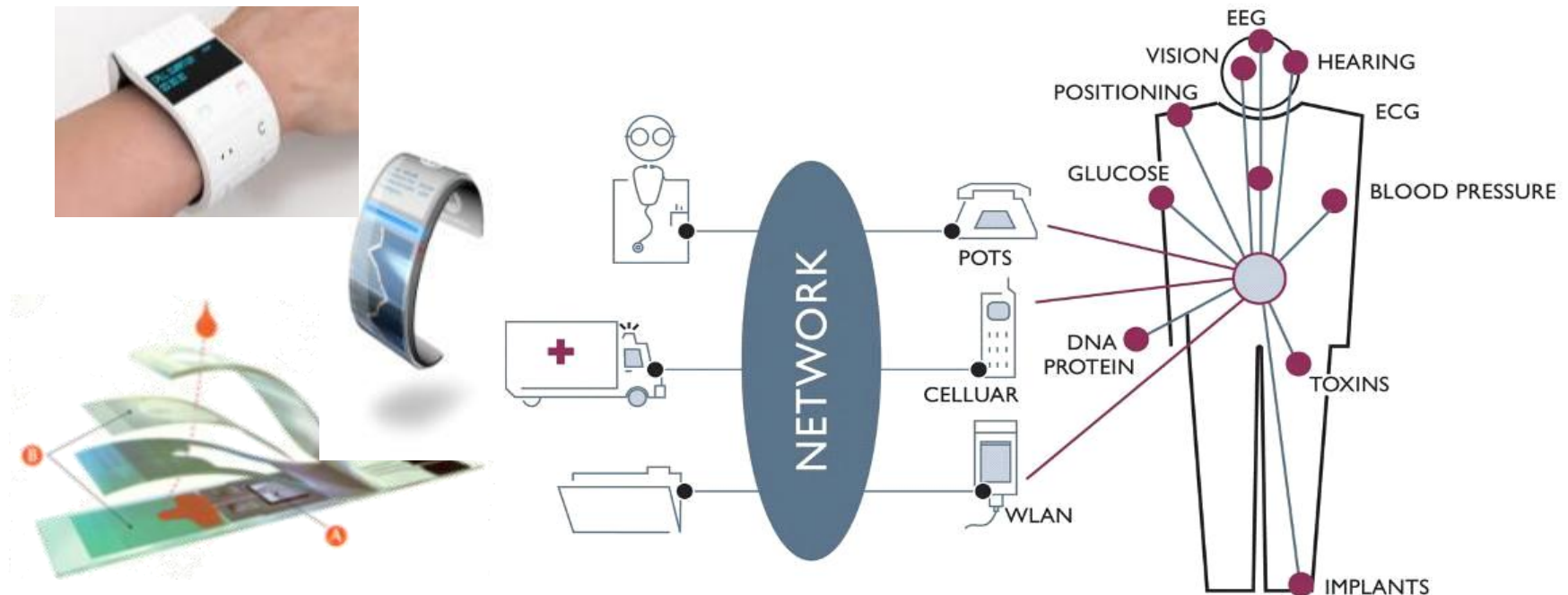
Displays – several advanced materials e.g. electro-optic, reflective/emissive, semiconductor. Low manufacturing risk; greatest risk associated with material performance.

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



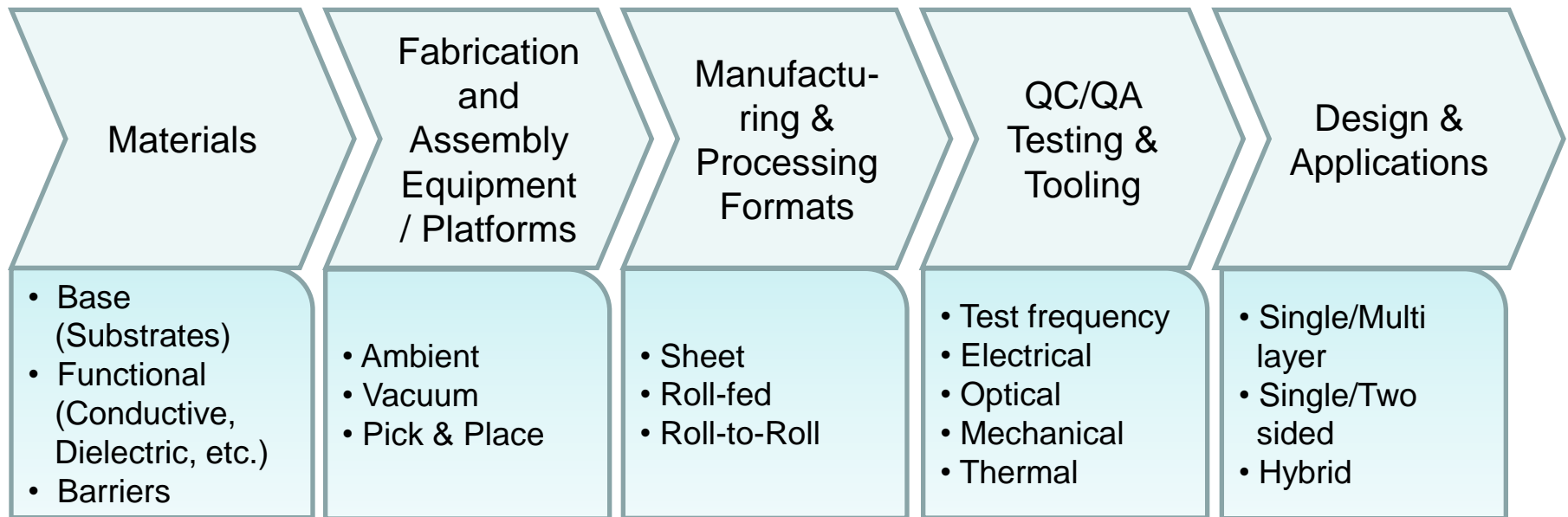
On-body Sensor Systems – communications hardware, novel materials, unique body-conformal designs, and redundant architectures. Moderate manufacturing risk; several high risks: accuracy of data generated during use, biocompatibility of interfaces, flexibility/conformal, network/signal integrity, and data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

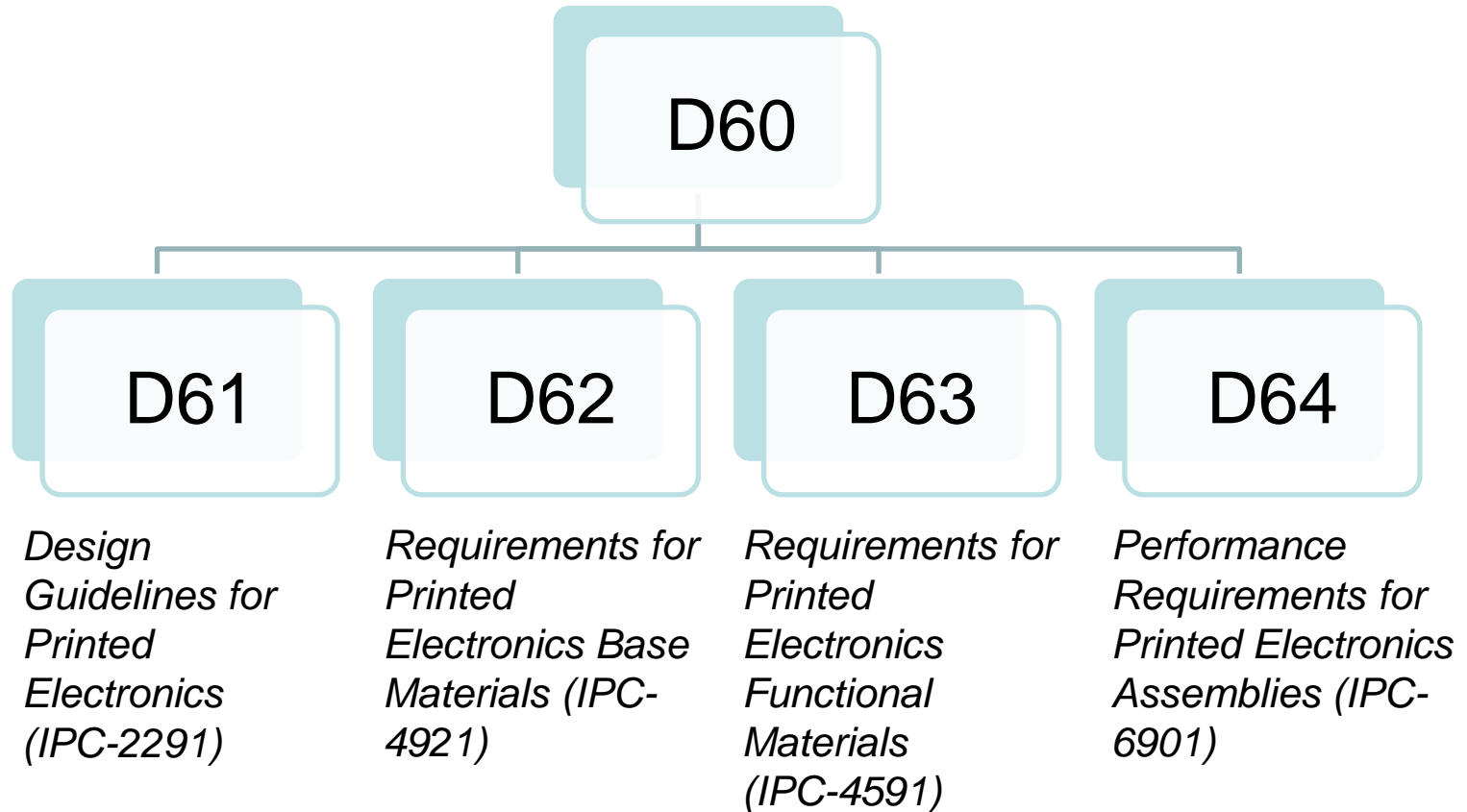
Printed Electronics:

Standards Development Community



Standards community expanding to include representatives from various organizations.

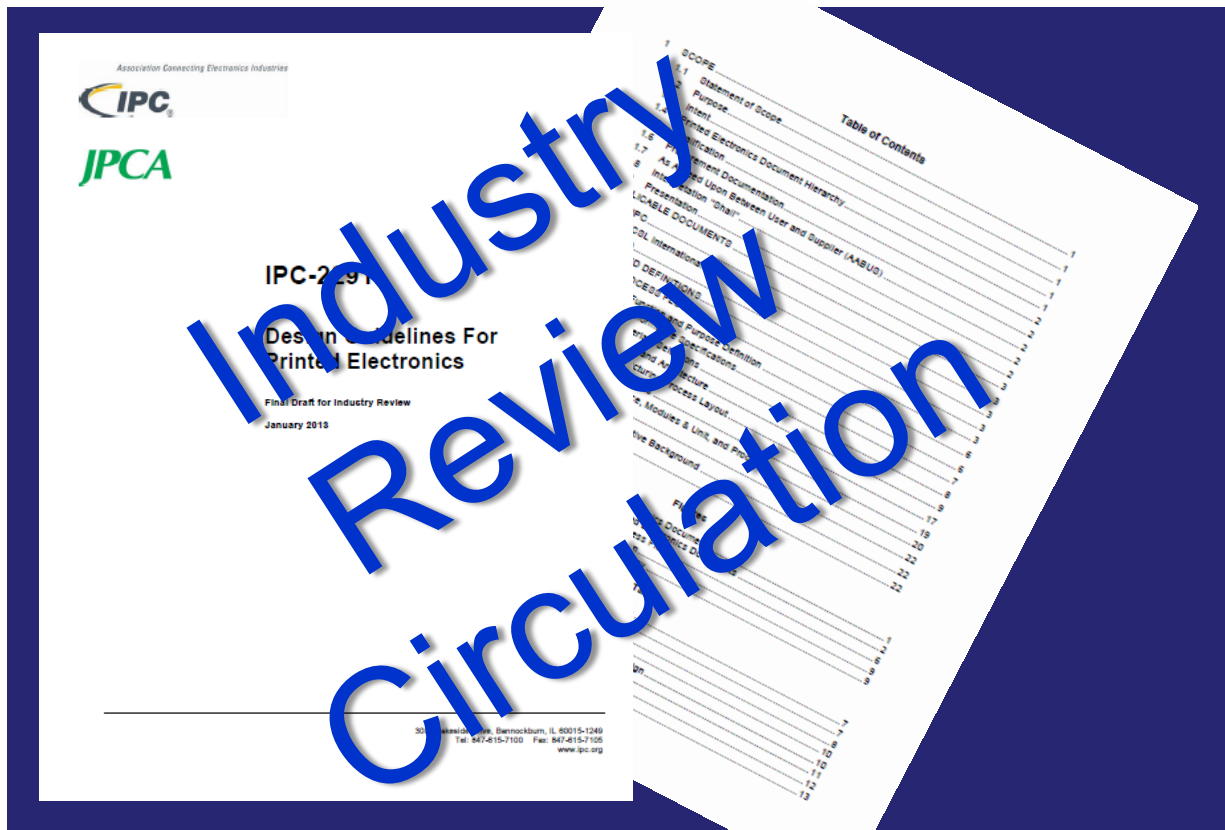
IPC PE Standards Portfolio



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

IPC 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.

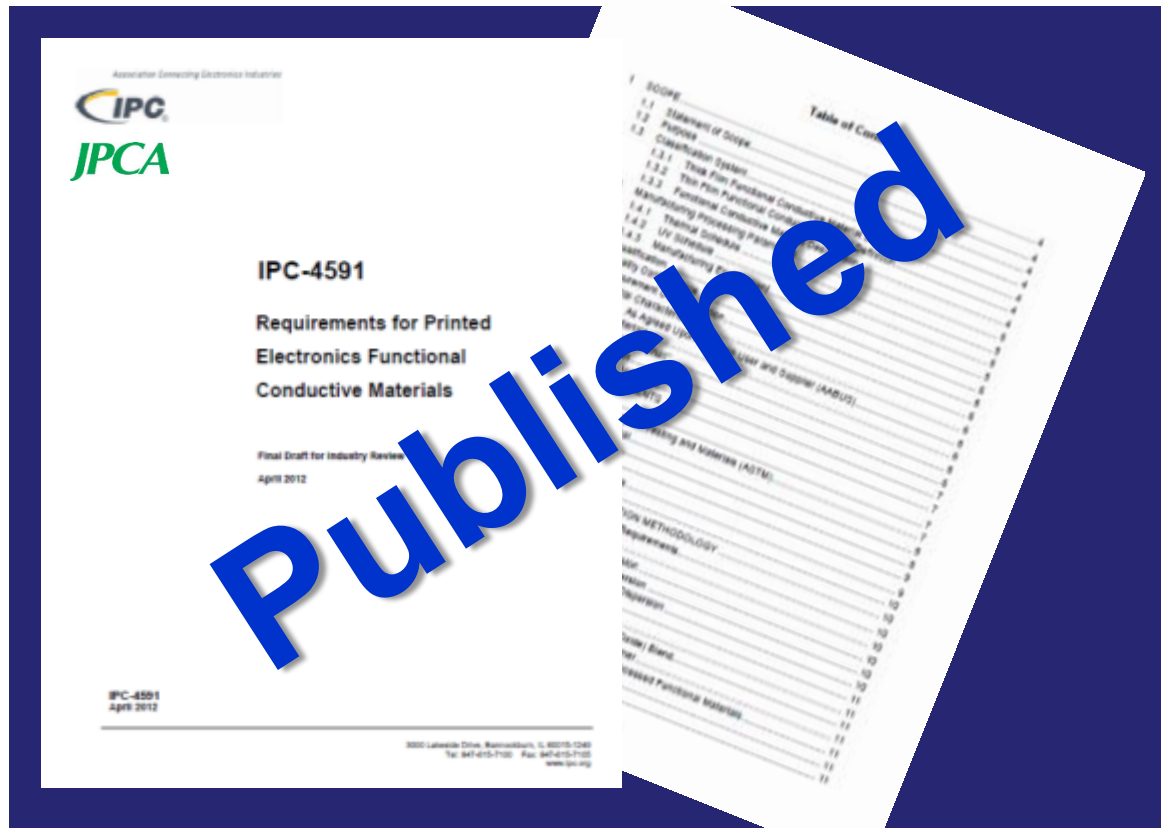
Materials Requirements

- 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.

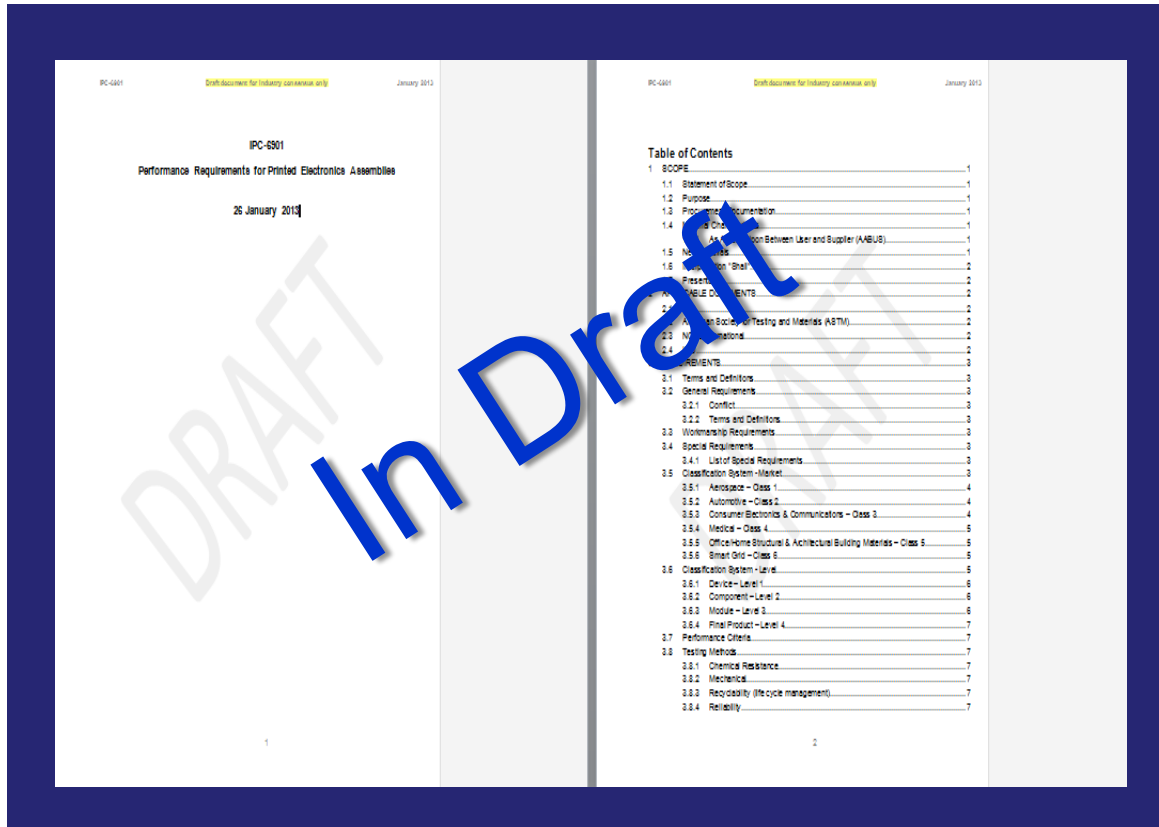
Requirements

- 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

IPC ROADMAP 2013

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 "smart 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 Roadmap is providing unique functionality – flexible, distributed, low profile, large area – to the printed electronics 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 technical models. The IPC Printed Electronics Roadmap will attempt to focus on products that have the 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).

1st PE Wave: RFID
The 1st PE Wave was driven by the opportunity to offer a RFID solution at a fraction of the cost associated with silicon based RFICs - \$0.25 for a silicon-based RFID versus \$0.01 for a PE-based RFID. The wave proposed by using non-vacuum printing manufacturing processes to fabricate the RFID and minimal or final assembly cost were highlighted during this 1st PE Wave.

Unfortunately, several factors led to the "backlash" of the 1st wave. The most commonly cited were the electrical performance of solution processed semiconductor materials were not adequate to the vision of devices that could operate at the frequencies as mandated by EPC standards. The second factor was the materials system that could facilitate the shrinking of the circuit footprint and the third factor was the demands placed on the light operating window and the need for high performance transistors (TFTs) during volume manufacturing, and finally the need for a well-defined display technology.

2nd PE Wave: Flexible Displays
The 2nd PE Wave was fueled by the vision of a low profile, lightweight and conformal display that could provide information real-time and anywhere as long as one was within line of sight. Consumer marketing studies were compelling and the price point for a PE-based display offering untethered, mobile data downloads 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 RFICs that required circuit operating speeds of high MHz, the PE based displays did not demand such high performing transistors e.g. kHz.

Although, the 2nd PE Wave did not appear to have as great of technical challenges as the 1st 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

burdened by the evolution of the technologies that it hopes to supplant. Table B7-6 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 complementary active PE based on PE base materials	Silicon based ICs with complementary active PE based on PE base materials	Silicon based ICs with multiple different active PE based devices assembled on PE base materials	Silicon based ICs with multiple different active PE based devices assembled on PE base materials
Stability	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
Barriers/ Packaging	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 platform for production PE	Non-specific production platform for production PE	Dedicated mid volume production PE platforms	Dedicated high volume production PE platforms
Testing Equipment	Non-specific PE testing equipment e.g. leveraging and reuse	Non-specific PE testing equipment e.g. leveraging and reuse	Dedicated PE testing equipment	Dedicated PE testing equipment systems for higher throughput

Table B7-6 Potential solutions and paradigm shifts

SUMMARY
Printed Electronics (PE) technology has great promise. It has survived several product focused waves and has not yet resulted in a successful product launch. Since 2011, the future for PE has been brightened. Site-promoting and super-hyping has been replaced with product realization. This is a turning point for designer adoption and respect as a robust technology option for 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 1-4: Bare Material Type Designation
IPC-4951 Table 1-3: Composition Designation
<http://www.ipc.org> Minority Report
<http://science.washington.edu> Terminator
Design Guidelines for Printed Electronics, IPC-2291
Design Guidelines for Printed Electronics, IPC-2291

IPC International Technology Roadmap for Electronic Interconnections B7-1

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)

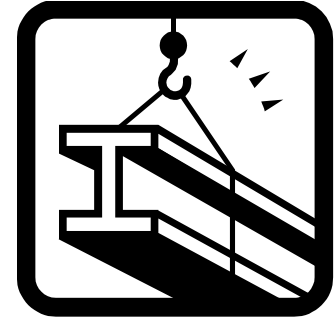
** Training now available to all interested dudes.*



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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