Catalytic Ink Printing: the REAL Printed Circuit

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Since the beginning of the digital printing era, methods have been sought to employ this knowledge for use in an elegant approach for producing circuitry. As long ago as the early 80s, companies were working with inkjet printing to apply a conductive or catalytic ink to standard circuit substrates in the quest to build an additively printed circuit.

In 1983, I visited a small Silicon Valley startup company, Elf Technology, with Joe Fjelstad. In this small office park, Joe had taken a standard desktop inkjet printer and developed an ink with high enough conductivity to support electroplating. He was able to go from CAM file to inner layer on a desktop followed by electrolytic plating. Unfortunately, the technology never made an impact on the market.

In the mid 1990s, while working at Litchfield Precision Components (now Innovex), I was involved in a development project with a spin off of Bayer AG called AMEG. This small engineering company had developed a UV curable ink that was catalytic to electroless copper and could be photoimaged. We discussed inkjet application at the time, but the project stalled because of continuing problems with the stability of the ink bath.

With advances in both inkjet head technology and ink formulations, the pursuit of this ultimate "printed" circuit has advanced to the point that in 2007 we should see an impact in the market.

Printed Electronics: The Second Coming of the Semiconductor

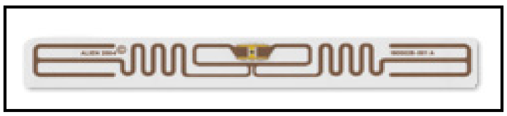

Figure 1: Alien Squiggle Antenna

We have watched with interest the development of printed electronics for years. The best definition for this diverse term is the printing of electronics on common materials such as plastics and papers using conventional printing technologies. Membrane switches and keyboards are among the earliest applications that would fit into this general category. From those somewhat humble beginnings, Printed Electronics has exploded into an emerging market with broad reaching consequences for the circuit world as well as that of general electronic manufacturing.

The most well known Printed Electronics applications is the RFID tag. The first acknowledged use of this technology was a covert listening device invented by a Russian scientist in the 1940s. Today there are a wide variety of applications using a transponder and remote reader to store and retrieve information using radio waves. The applications for this technology range from highly complex, active tags with on board power to simple item level tags for inventory control that will sell for pennies.

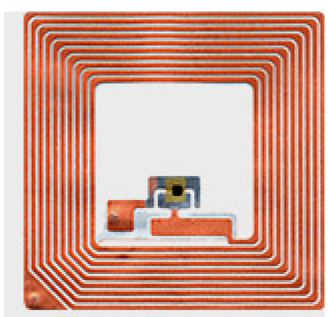

Figure 2: Early Generation 1 Antenna Design

Nokia has recently issued a paper describing their Radio Frequency on Package (RFoP) technology that will have a direct effect on the rigid PWB market. They have designed a chip that incorporates RFID technology that will be imbedded inside multilayer PWBs. This technology would require PWB fabricators to add assembly capabilities so they could place these chips on inner layers prior to lamination.

Although the potential exists for literally trillions of RFID tags to be built annually, it is not one of the largest Printed Electronics market opportunities. Even today, Organic Light Emitting Diodes (OLEDs) represent a much larger market. These are a family of products based on organic emissive layers that has found wide use in displays and lighting.

Figure 3: Sony Large Screen OLED Display

Traditional incandescent and fluorescent lighting are 5 to 25% efficient in their use of energy. Current OLED solid state lighting exceeds 50%. In a world where 22% of the total electricity generated is used to power lighting, the impact can obviously be substantial. This has the potential to completely revolutionize an industry and is a rare example of Printed Electronics as a disruptive technology. For the most part these technologies are creating new applications and functionalities that replace nothing.

The only limitation to the application of Printed Electronics continues to be the imagination of the product design community. Games, sensors, packaging, memory and many other applications will be expanded and transformed by this technology. The Printed Electronic revolution will have the same profound transformational impact on industry as the silicon wafer did many years ago.

Making Printed Electronics Work: The Emergence of Inkjet Printing

The key to the emergence of Printed Electronics is the presence of technologies that support low cost manufacturing on flexible substrates in roll form. Many of today's applications utilize either screen printing or traditional subtractive processing. New manufacturing approaches are needed for this market to reach its full potential.

There are many different techniques used in the printing world; screens, offset, gravure and others. All of them, except for inkjet, require tooling to create the printed image. While there are advantages and disadvantages to each technique, the ability to digitally create an image without tooling was a main driver for the development of inkjet technology.

Inkjet printing is already in use in a wide variety of Printed Electronics applications, from MEMS to displays and solar cells. These applications use a wide variety of inks and deposit multiple layers of materials to create these structures. For creating circuits, most of the work that has been done has involved conductive particles in some type of carrier solution. After deposition, these solutions are heated to drive off solvents and coalesce the conductive materials into a structure that provides conductivity. For the most part these inks have been silver or aluminum.

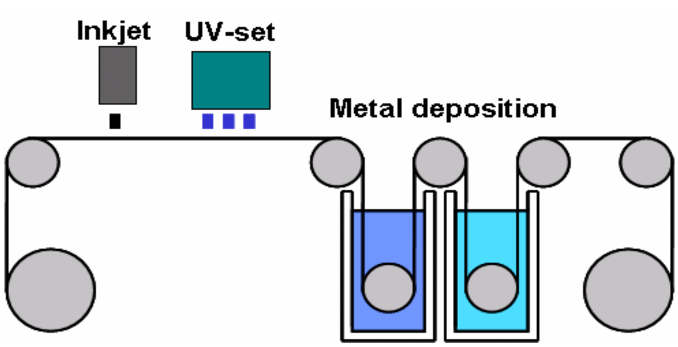

Figure 4: Catalytic Inkjet Process

Printable conductive metal pastes have always had to reach a compromise between the rheological and conductive properties of the material. Binders and carriers used to provide flow during printing and adhesion to substrates impact the conductivity of the final composite layer and impede current flow through the conductive track. Through a collaborative development effort between ink and process equipment companies, a process has been developed that can support the direct creation of solid-copper designs using an additive, inkjet printing line.

One solution is a web-based, high speed digital printing system combined with an innovative tank based electroless copper plating process that allows for the creation of solid-copper printed circuits at speeds up to 30 meters per minute. With web widths of up to 305 mm on the current generation of equipment, this system has the capability of producing enormous quantities of material rapidly and at a low cost. Gone are the cost and struggle associated with photoresist application and definition, etching, stripping and the waste treatment challenges associated with all of those processes. Maybe more importantly, the time between circuit development and actual production is minimized as digital printing can be changed on the fly.

The two-stage process allows the ink to be separately optimized for different substrate materials and different printing vehicles without impacting the conductivity of the final process. Most standard electroless metals can be used, including nickel, but most commonly and widely used is copper. The two stages of the process can be implemented in-line or the electroless plating can be performed later as a batch process.

Typical growth rates for copper range from around 20 nm/min to 90 nm/min (bulk copper equivalent), giving a 30 mO/square sheet resistance in around 10 minutes of plating. Testing has shown that this thickness is adequate for many applications. Evaluation of a 2.45 GHz antenna showed a drop in gain from 3.7 dB to 2.5 dB but was still deemed more than adequate. Bend testing and accelerated thermal aging tests have been passed at several qualification sites.

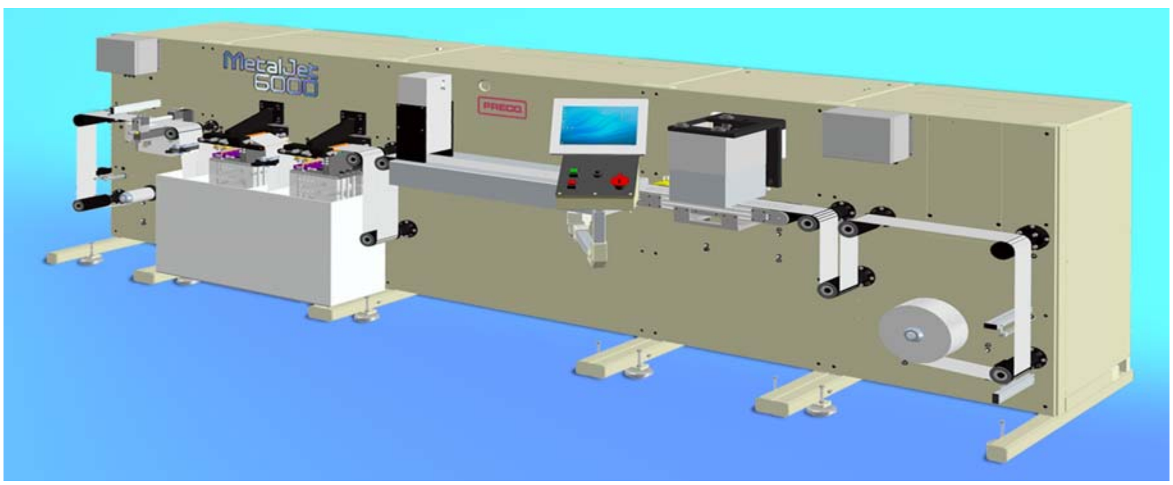

Figure 5: Metal Jet 6000 Roll-to-Roll Circuit Line

Conclusion

Fully additive circuitry based on inkjet technology will have a significant impact on the future of the electronics market. Both catalytic and conductive inks are in advanced stages of development that can be applied directly to a variety of substrates to avoid the challenges of subtractive and semi-additive processing. The performance of thin copper circuits built by roll to roll application of a catalytic ink has been demonstrated to be adequate for many low current applications.

Catalytic Inkjet Printing: The Real Printed Circuit

Presented at APEX 07

By Joel Yocom

Printed Electronics Overview

- The application of organic or inorganic conductive materials to flexible films to create some type of functional circuit
- Printing of electronics onto common media such as paper, plastics or textiles using conventional printing technologies
- Very large area product creation possible
- Applications limited only by materials and imagination
- Typically not “replacing” anything

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MOSTLY ADDITIVE TECHNOLOGY!

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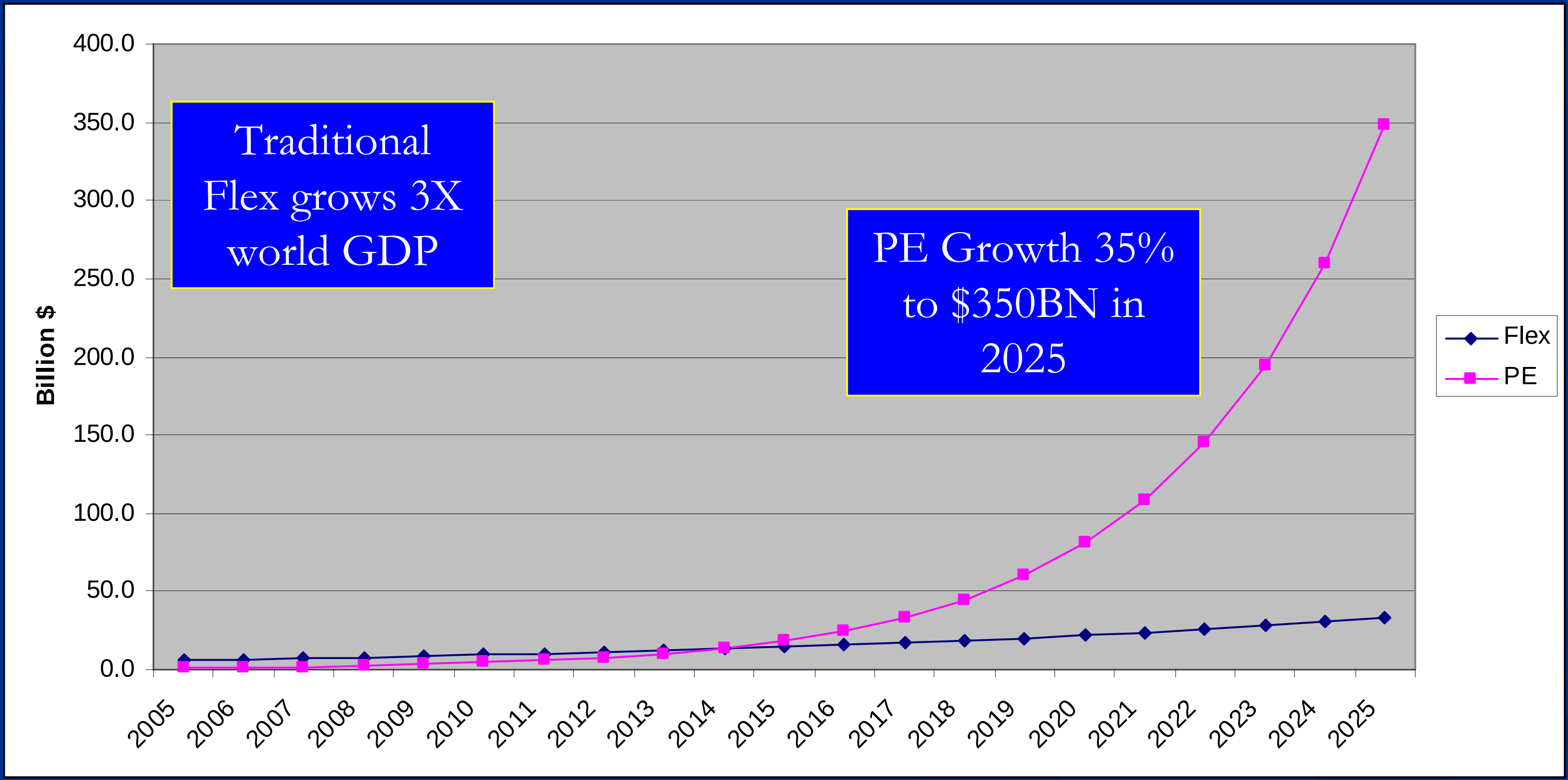
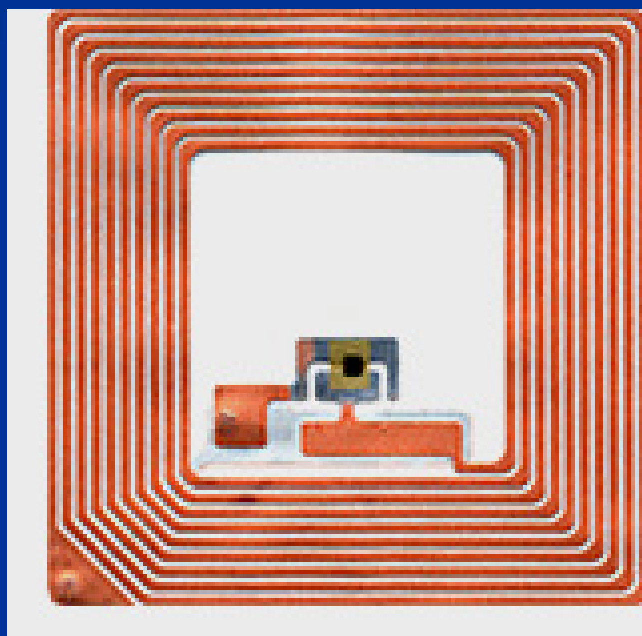
Printed Electronic Forecast

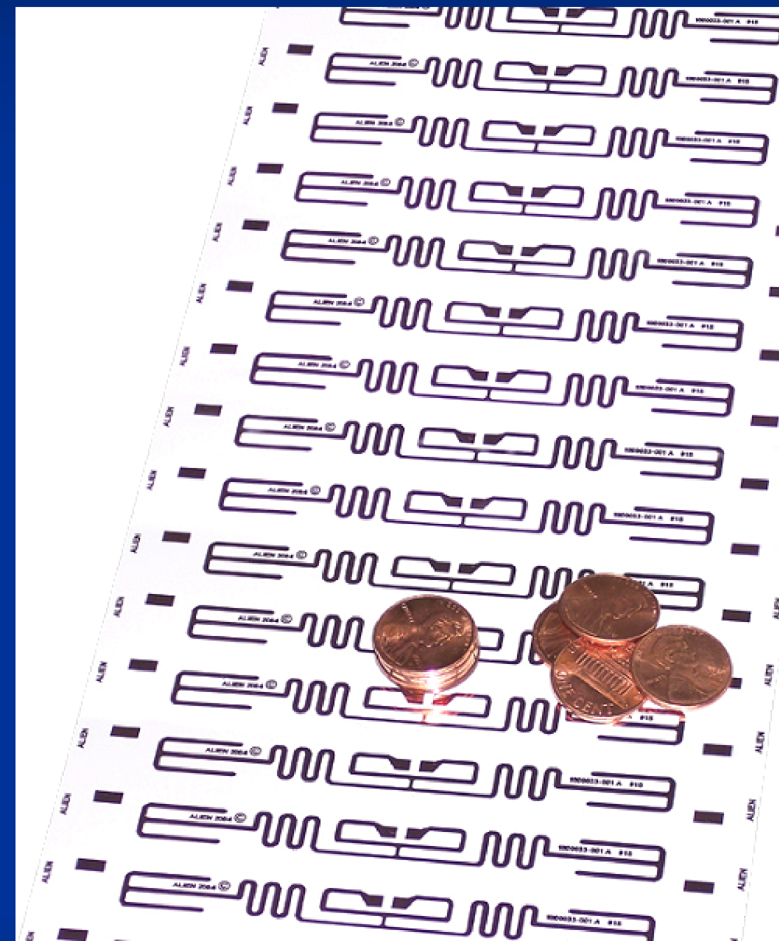


Radio Frequency Identification (RFID)

- Relatively small component of PE potential
- The use of radio frequencies to read information on a small device called a tag
- 1 bit to 128+ bits of information
- Chip vs. Chipless
  - 45% Chipless by 2016

RFID Tags





RFID Potential (billions/year)

Animals	1
Blood	2
Air Freight and Baggage	4
Tickets	20
Drugs	30
Pallets	40
Books	50
Cigarette Packages	100
Postal	650
Retail Items	10,000

Ubiquitous Sensors

- Ubiquitous Sensor Network (USN)
  - Sensors using RFID technology everywhere
  - Massive investment in Korea
- Sense movement of rocks for early warning of avalanche
- Tags on key trees for early warning of fires
- Monitoring of the elderly in the home
  - Invasive dignity
- US Military "Smart dust"

Organic Light Emitting Diode (OLED)

- LED where the emissive layer is an organic thin film
- No backlight required, lower power requirements
- No glass substrate required
- Issues with life of display
- Largest current PE app

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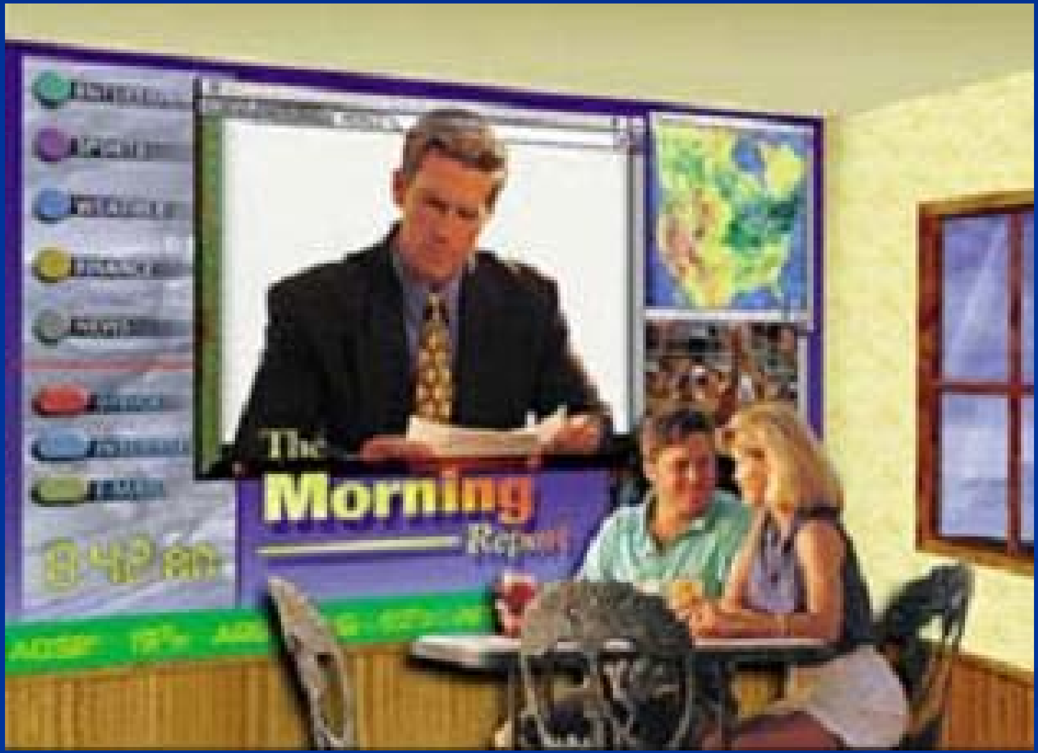
Ubiquitous OLED Displays



OLED Lighting

- Flat, printable onto common flexible substrates
- More efficient lighting
  - Incandescent 5% efficient
  - Fluorescent 25% efficient
  - OLED 25% efficient and up
- 22% of world's electrical power consumed by lighting
- Environmentally challenging to make and dispose of existing lighting structures
- OLED Lighting has no form constraints
- Solid State lighting is the second semiconductor revolution

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DISRUPTIVE TECHNOLOGY!

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Thin Film Transistor Circuits (TFTC)

- Printed Logic and Memory
- Use of nano-materials to print transistors for logic and memory
- Replace Silicon in some applications
  - $10MM fab instead of $5B
- 2 gb Memory thought to be achievable
  - Postage stamp Library of Congress

Functional PE

- Dermal Patches
  - Current opens pores and enhances absorption
  - Iontophoresis
- iPod Controllers printed on jacket sleeves
- Portable Window
- Electronic games as part of the package

Smart Packaging: the Cool Stuff

- Pill dispensing and monitoring
  - Instructions and history
  - 50% of people take drugs incorrectly
- Product interrogation to avoid allergic reactions
- Self adapting expiration dates based on thermal exposure
  - Biosensors
- Talking bottle top to announce contest winner

Smart Packaging: the Cool Stuff

- Tag all surgical instruments to detect what got left behind
- Smart refrigerators
  - What is inside and what has spoiled?
- Artistic enhancement
  - Lighted clothing (Dubai)

Inkjet Printing: The Real Printed Circuit

Inkjet Printing: The Real Printed Circuit

- Elf Technology -1980s
  - Inkjet printing conductive ink using standard print head
- AMEG – 1990s
  - UV curable catalytic ink
- What now? - 2000s

Inkjet Printing

- Limited participants in the market
- Requires specialized skill sets in materials not common to the electronics industry
- Conductive Inks
- Catalytic Inks
- Dielectric layers

Inkjet Printing Basics

- Two major types
  - Thermal
  - Piezoelectric
- Piezoelectric most common for material deposition
  - Apply current
  - Create pulse
  - Discharge dot on demand

Inkjet Printing Basics

- Two types of configuration
  - Moving head
  - Fixed head
- Advantages and disadvantages to both
  - Speed
  - Feature Density
  - Flexibility
  - Roll to Roll support

Conductive Inks

- Normally Silver or Copper
- Print very thin Silver paste then electroplate copper
  - Meco
- Print nano-particles of Silver or Copper and sinter
  - Photonic sintering by NovaCentrix

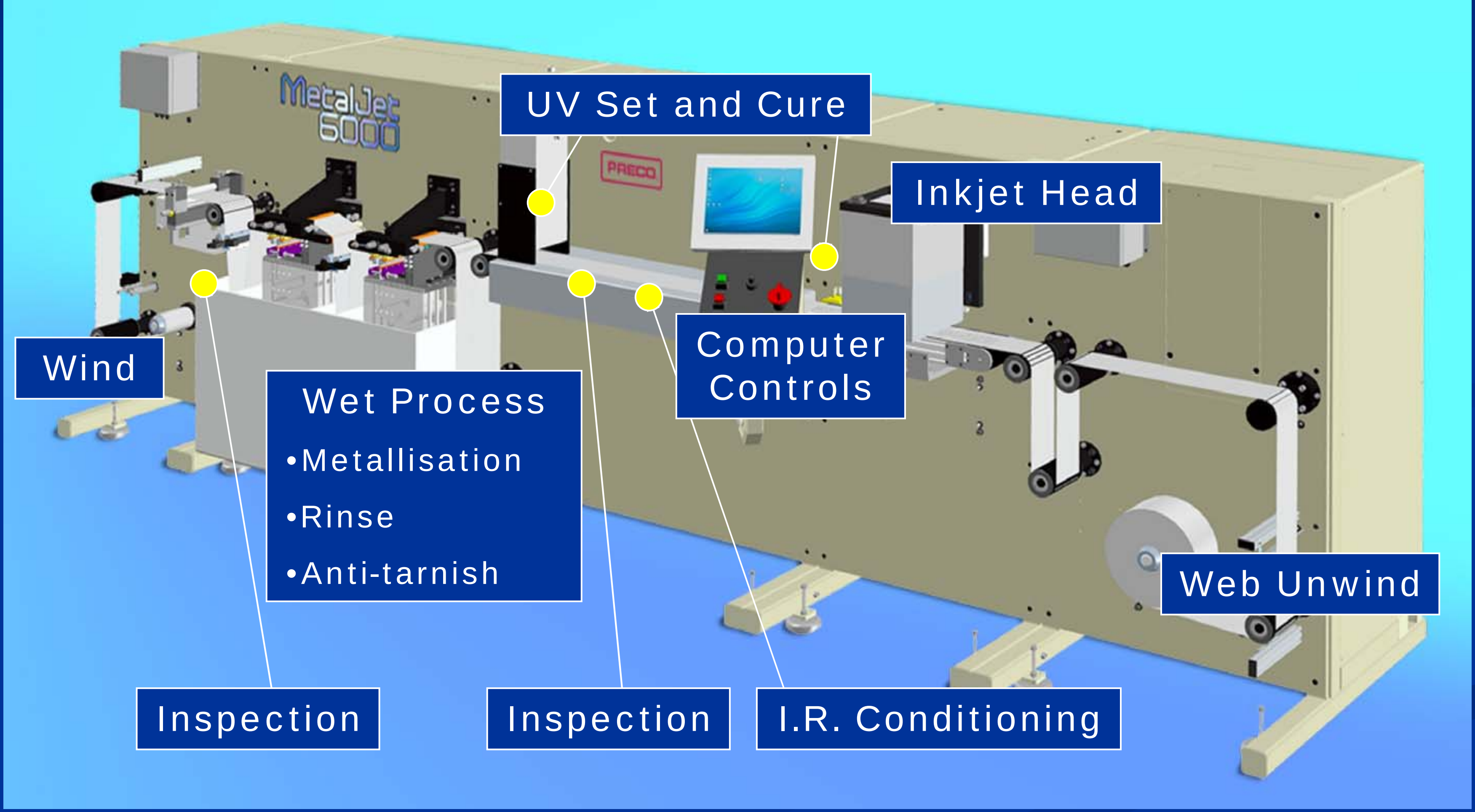
Catalytic Inks

- Contain Palladium
- Typically UV curable so can be patterned
- Catalytic in Copper, Nickel and other electroless plating solutions

Fixed Head Inkjet Printing

- Roll to Roll continuous printing under fixed nozzle configuration
- Speeds of over 100 fpm readily achievable
- Copper thickness generally limited
- Fixed grid design rules
- Density constrained by nozzle pitch
- Nozzle pitch dictated by inkjet head manufacturers
  - Control of material under the head stack
- Thin Copper solution of 0.5 to 1.0 microns
  - 30 – 50 mohms/square resistance

Example of Roll to Roll Fixed Head Line



Conclusions

- Printed Electronics will be an explosive driver of industry growth
- 2007 will see the emergence of Inkjet printing as a significant force in the circuit industry
- Room for more players in the development of technology

MetalJet 6000® - Munich - November 2005

CONDUCTIVE
INKJET
TECHNOLOGY

MetalJet 6000

PRECO