Digital PCB Production using Industrial Inkjet Printing

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Abstract
From photo film to digital camera, from letters to emails, from books to e-readers, from vinyl to MP3: the whole world is turning digital. Yet, ironically, the core compound driving the digitization of technologies and products is still being produced using analogue technology. Indeed, printed circuit boards (PCBs) are the beating heart of all digital “alternatives”, but the vast majority of PCBs are still produced using rotogravure print rolls, dry film or coated resists and phototool films. However, digital technology has become available to replace analogue imaging technology: inkjet printing is the digital alternative to the phototooling film process. Even though inkjet printing started off in merely marking/coding and document printing, it grew industrial in wide-format and billboard printing and is now mature enough for implementation in industrial production processes. The market of digital industrial product decoration is growing as we speak. Along with this, inkjet tools have been created for real high end industrial production. Inkjet technology based on UV-curable inks is especially ready for real production implementation. Besides the relatively well-known and readily adopted inks for legend printing on PCBs, UV-curable inkjet inks that are resistant to acidic etching and that can be stripped off in regular PCB production chemicals are now also available. The benefits of digital printing using these UV-curable etch resistant inks are clear and very relevant to PCB production: no time-consuming film production, no film exposure step, no development. With inkjet printing the images are generated on the fly and thus allow dynamic imaging. Since digital printing is an additive process, fewer raw materials are used, causing less waste. These UV curable inks are caustic strippable inks and are thus drop-in for present etch and strip lines. In this paper, the unique position of inkjet printing in PCB production will be highlighted and the chemical technology behind the inks will be explained in detail.

Introduction
When, after the Second World War, the radio tubes were being replaced by semiconductors, the connections moved from soldered copper wires to printed circuit boards (PCB) and it caused the dawn of a new industry. In those 50 years, the PCB construction, the production location and the professionalism of the manufactures changed, yet the basic principles did not. Today, one still starts with a full surface copper, adds a full surface resist, images and develops the resist, etches the copper and strips the resist. Though every year the global electronics industry still uses about fifteen million square meters of PCB film, the technology is now finally evolving: the digital production of PCBs is happening.

Digital technology has become available in the last years to replace analogue imaging technology: inkjet printing is the digital alternative to the phototooling film process. The advent of digital printing techniques about 30 years ago, announced a new era at first in small scale office and home printing, further has emerged in industrial scale printing in a large variety of wide and super wide format applications (posters, billboards, etc.) and is now being rolled out in even more exciting applications ranging from high speed document printing over packaging to product decoration and shows even strong growth in ceramic tile printing. As a result of the maturation of the inkjet process to an overall industrially reliable production step, inkjet printing is now also ready to endeavour into PCB production.

The production of PCBs is a high end application, with low margins, strict quality demands and high requirements in terms of reliability. Especially inkjet technology based on UV-curable inks in piezo-based industrial printheads is ready for real production implementation: UV inks show a long latency (open head time), can be used at high print speeds, exhibit very high and well controllable image and character quality and yield sturdy end products. Investment in the R&D of products to drive the future of PCB production, has led in the last few years to the meanwhile well-known and readily adopted white, yellow and black UV inkjet inks for legend printing on PCBs. As a next step in the digitization of the PCB production, UV-curable inkjet inks that are resistant to acidic etching are now also available. These inks are designed for the production of single layer PCB’s or innerlayers of multi-layer PCB’s. These specific UV-curable etch resistant inkjet inks were tuned to withstand ferric chloride and copper chloride etching and are caustic strippable. As such, they are a perfect drop-in for present etch and strip lines.

The general advantages of digital print also apply to PCB production with inkjet: faster turnarounds, extremely high flexibility and productivity, reduced floor space and less manual labour, all leading ultimately to cost saving.

Although inkjet is the only digital technology for legend printing of PCBs, there are two digital technologies for copper patterning in PCB production: laser direct imaging (LDI) and inkjet printing. In this paper, focus will be on digital printing with inkjet and LDI is mentioned for the sake of completeness and will be compared to inkjet printing. Inkjet printing exhibits clear benefits to the PCB production process compared to the use of resist and film (in case of copper patterning) and screen print (in case of legend printing). The benefits are most easily found in the ability to print variable data easily. As the concept of industrial inkjet printing is not different from inkjet printing at home, one can easily imagine with what ease every single piece of PCB (etch resist or legend) can be printed with a different design. Together with very short print job start-up times this allows for short lead times to the customers and easy variation in copper patterning and legend printing. This makes economical short runs easily accessible. Due to the direct computer-to-print approach, digital printing typically has a cost that is linear in terms of the printed volume. This makes it more economical typically for relatively low volume printing.

Besides economical short run capability, digital print has much more to offer for true PCB production too. As digital printing allows easy incorporation of fully variable information on every single print (variable data printing, VDP), this renders, for example, in terms of unique identification a great asset in comparison to analogue prints: indeed customisation of all single PCBs can be done in the Cu layers or in the legend print. Printing of machine readable codes such as QR codes is possible in one to three dimensions and with great variety, providing a link to extended communication possibilities. In addition to unique identification, customisation in terms of language and other (regional) variations is also very easy to create.

Besides these huge process related benefits, inkjet print also has more environmental and economical advantages. In digital legend printing no more screens need to be produced and stored. This leads to elimination of films and developers to produce the screens and reduces warehousing space and working capital. The same goes for etch resist printing: in the analogue printing method (and also in LDI) a resist is applied covering the whole copper surface and afterwards the excess resist is removed again to waste. Adding to this, in the analogue production method the film needs to be produced and developed using chemicals as well. Inkjet printing with etch resist eliminates the excess resist waste and the development chemicals for the film and the film itself. This results in economical and environmental savings. Furthermore, if integrated in a designated production facility, inkjet printing is, unlike screen print or film based imaging, perfectly suited to comply with just-in- time production methods, yielding an additional cost saving. Finally, the inkjet process is highly automated and printers are very compact in design, resulting in reduced floor space and lowered manual labour.

The following discussion tackles the inkjet ink development on etch resist inkjet printing. Specifically, the chemical breakthrough that makes sure the requirements of the inkjet printing process are met, next to the requirements of the existing etching and stripping lines, is outlined. The inks are jetted onto the substrates by using piezo drop-on-demand inkjet print heads and are cured with UV mercury bulb lamps (doped or not) and/or UV LEDs.

Reliable industrial inkjet printing needs specifically tuned inkjet inks. A key parameter limiting the options to formulate inkjet inks is the allowable viscosity. Industrial inkjet printing is, unlike small office/home office (SOHO) printing which uses thermal printheads and water based inks, mainly powered by piezo-based printheads and UV-curable inks. Several brands offer such type of printhead but as the technology is often licensed from a digital inkjet company's shared-wall design [1], they have more or less the same requirements, especially in terms of viscosity. At a typical printhead operating temperature of 40–45 ºC the viscosity is ideally around 10-12 mPa.s.

In the past, attempts have been made to match the viscosity criterion with the etching requirements by using high molecular weight compounds for etch resistance and reducing the resulting too high viscosity of the high molecular weight by adding organic solvents [2]. However, in inkjet printing, having micron sized nozzles for the inks, typically the solvents will evaporate at the nozzle, clogging it up and showing hence very short latency. Others have made attempts to meet the requirements by not using high molecular weight compounds, but compounds that polymerise upon UV irradiation anyhow [3] . To get the proper etch resistance quality, these compounds are preferably acidic in nature. This is reducing ink stability and hence lowering shelf life. Short latency and short shelf life are not characteristics of a real industrial printing solution, ready for integration in production. Hence, another solution is needed for industrially reliable digital PCB production.

Discussion of Methodology

In the following paragraphs, the results will be shown that led to a UV-curable inkjet ink, capable of being etched and stripped in the existing production lines for metal etching and of which the flakes of stripped ink can be turned from large filterable flakes to completely dissolved flakes. Inkjet printing types can be based on different ink classes (aqueous, solvent, oil, UV-curable), but for PCB printing UV-curable inkjet printing systems are best suited because it is the most reliable method, with the highest printing speed and it can be used on many substrate types. UV-curable inkjet inks are essentially made up of colorants (dyes or pigments stabilised using dispersants) in an energy curable monomer matrix (typically consisting of acrylates, methacrylates etc), one or more photoinitiators that capture the UV light and transfer it into free radicals to start the polymerisation of the monomers. Surfactants, oligomers, polymers and other adjuvants might also be added to improve physical properties or image quality.

Specifically, the etch resistance and stripping behaviour impose further requirements within the boundaries of inkjet viscosity limitations. A UV-cured ink layer will indeed be hydrophobic and although this will aid in etch resistance in water based acidic media, it is counteractive in the water based caustic solutions typically used for stripping. For this reason, focus was put on adding alkali-hydrolysable groups in the ink as well as a water absorption controlling compound. Examples of the latter are hydroxyl groups, ethylene oxide groups or oligo-ethylene oxide groups, tertiary amines, acidic groups with a pKa not lower than 3 and a five to seven membered heterocylic group. The hydrolysable polyfunctional monomers or oligomers are responsible for the degradation of the cured inkjet ink pattern in the stripping solution resulting in the cured inkjet ink pattern being completely dissolved or dissolved to flakes in the stripping solution. In order to obtain acceptable manufacturing times when dissolving of ink particles is desired, a second monomer needs to be included. The water absorption controlling monomers are responsible for the swelling of the cured ink pattern in the stripping solution. This accelerates the dissolving of the cured ink pattern by the alkali present in the stripping solution. Please note that some of crucial raw materials needed to get to this innovative product were not commercially available and were synthesised in house.

Data

All materials used in the following example were readily available from standard sources unless otherwise specified. The water used was deionized water.

Material A is a blue anthraquinone dye.

Material B is an isomeric mixture of 2- and 4-isopropylthioxanthone.

Material C is 2-methyl-1-[4-(methylthio) phenyl]-2-morpholino-propan-1-one, a photoinitiator.

Material D is bis (2,4,6-trimethylbenzoyl)-phenylphosphineoxide, a photoinitiator .

Material E is 2,4,6-trimethylbenzoyl-diphenyl-phosphineoxide, a photoinitiator .

Material F is a mixture forming a polymerization inhibitor having a composition according to Table 1:

Table 1 - Composition of Material F

Component	wt%
DPGDA	82.4
p-methoxyphenol	4.0
2,6-di-tert-butyl-4-methylphenol	10.0
Material G	3.6

Material G is aluminium N-nitrosophenylhydroxylamine.

Material H is 2-(2-vinyloxy-ethoxy)-ethyl acrylate.

4-hydroxybutyl acrylate was used.

Material I is pentaerythritol tetraacylate .

Material J is acryloyl morpholine.

A triarylmethane dye was used.

Material K is polyethylene glycol diacrylate having n=4 (Figure 1)

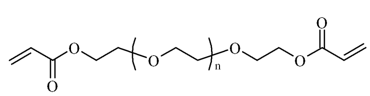


Figure 1 – Material K

Material L is 1,6-hexanediol diacrylate (Figure 2)

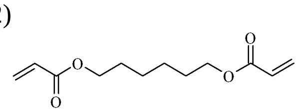


Figure 2 – Material L

Material M is an oxalate monomer similar to Material K (Figure 3). The synthesis route is described in literature [4].

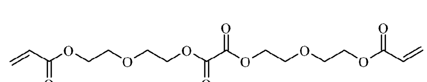


Figure 3 – Material M

Material N is an oxalate monomer similar to Material L (Figure 4). The synthesis route is described in literature [5].

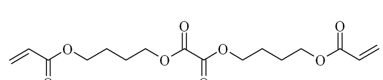


Figure 4 – Material N

Material O is a Cu-plate having a metal surface consisting of an 18µ Cu-laminate.

The etch resistance was evaluated by determining the percentage of the cured inkjet ink layer that remained on the copper plate after etching. An etch resistance of 100% means that the whole cured inkjet ink layer survived the etching bath. An etch resistance of 0% means that no cured inkjet ink could be found to be present on the copper plate after etching. An intermediate percentage, e.g. 80% means that about 80% of the cured inkjet ink could be found to be present on the copper plate after etching. A good etch resistance means a value of at least 80%. Excellent etch resistance means a value of at least 90% but preferably 100%.

The strippability was evaluated by determining the percentage of the cured inkjet ink layer that was removed from the copper plate after stripping. A strippability of 100% means that the whole cured inkjet ink layer was removed. A strippability of 0% means that no cured inkjet ink could be removed from the copper plate. An intermediate percentage, e.g. 30% means that only about 30% of the cured inkjet ink could be removed from the copper plate by stripping. A good strippability means a value of at least 80%. Excellent strippability means a value of at least 90% but preferably 100%. A value of 30% or less is a very poor strippability.

The viscosity of the formulations was measured at 45°C using a production Robotic Viscometer.

A radiation curable inkjet ink was coated on a substrate using a bar coater and a 10 µm wired bar. The coated sample was cured using a production conveyer, equipped with a production UV lamp (D-bulb), which transported the samples under the UV-lamp on a conveyer belt at a speed of 20 m/min. The maximum output of the lamp was 1.05 J/cm2 and a peak intensity of 5.6 W/cm2.

The UV curable inkjet ink INK A to INK E were prepared according to Table 2. The weight percentage (wt%) was based on the total weight of the UV curable inkjet ink. The UV curable inkjet ink INK A lacks a hydrolyzable polyfunctional monomer or oligomer, while the UV curable inkjet ink INK B lacks a water absorption controlling monomer. Inks C to E all exhibit both types of functional compounds.

Table 2 - Composition of inks A to E

wt% of component:	Ink A	Ink B	Ink C	Ink D	Ink E
Material A	1.75	1.75	1.75	1.75	1.75
Material B	5.00	5.00	5.00	5.00	5.00
Material C	5.00	5.00	5.00	5.00	5.00
Material D	3.00	3.00	3.00	3.00	3.00
Material E	2.00	2.00	2.00	2.00	2.00
Material F	1.00	1.00	1.00	1.00	1.00
Material K	52.25	---	---	---	---
Material L	30.00	---	---	---	---
Material H	---	---	---	---	20.00
Material I	---	---	---	26.00	---
Material J	---	---	52.25	26.25	---
Material M	---	52.25	---	---	32.25
Material N	---	30.00	30.00	30.00	30.00

Material O copper plates were cleaned for 5 seconds at 25 °C with a solution which has pH < 1 and contained H_2SO_4, H_2O_2 and Cu^{2+}. During this operation a thin top layer of Cu (0.3 – 0.5 µm) was removed. The plates were then rinsed with a water jet for 90 seconds.

A pattern of the UV curable inkjet inks INK A, INK B and INK C to INK E was applied at a thickness of 10 µm on the copper plate and cured by the production conveyer, equipped with the production UV lamp (D-bulb), which transported the samples for full curing twice under the UV-lamp on a conveyer belt at a speed of 20 m/min. The maximum output of the lamp was 1.05 J/cm2 and a peak intensity of 5.6 W/cm2.

Results

The plates were subjected to an acidic etch bath (the acid etchant , pH 2, contains $FeCl_3$) for 75 seconds at 35 °C. The plates were subsequently rinsed for 90 seconds with water and dried. An evaluation of the etch resistance was then made as shown in Table 3.

The etched copper plates were subjected for 5 minutes at 50°C to an alkaline strip bath (containing 5 % NaOH), then rinsed for 90 seconds with water, dried, and evaluated for strippability and the shape of the stripped ink layer. The results are shown in Table 3.

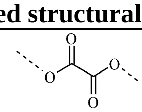
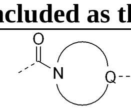
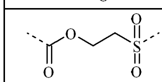
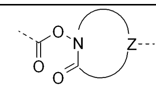
Table 3 - Results of etch resistance and strippability of inks A to E when applied to a Cu-plate

UV Curable Inkjet Ink	Etch Resistance	Stripping (after 5 min)	
		Strippability	Visual Shape
INK A	100%	100%	large flakes
INK B	100%	100%	small flakes
INK C	100%	100%	fully dissolved
INK D	100%	100%	fully dissolved
INK E	100%	100%	fully dissolved

From Table 3, it should be clear that the UV curable inkjet inks INK C to INK E provided results for etch resistance and strippability that are comparable to those of the UV curable inkjet inks INK A and INK B, with the exception that the cured ink pattern in the alkaline stripping bath fully dissolved into a blue coloured liquid within 5 minutes. Ink A exhibited perfect etch resistance and the flakes were large filterable flakes. In the case of Ink B the flakes were significantly smaller.

The above elaborated example is one out of many. In more general wordings, it was found that the alkali hydrolysable group located in the atomic chain between two polymerizable groups is best selected from the structures P1, P2, P3 or P4 in Table 4.

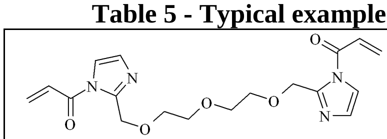
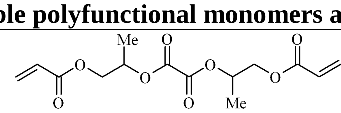
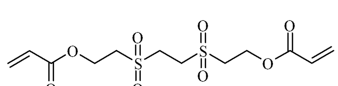
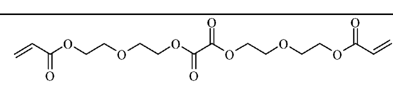
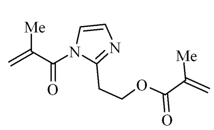
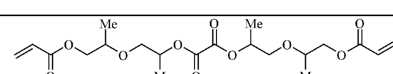
Table 4 - Preferred structural moieties to be included as the alkali hydrolysable group

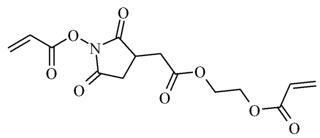
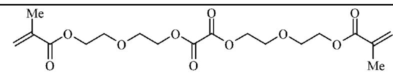
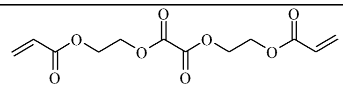
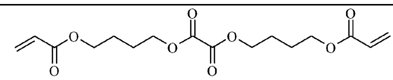
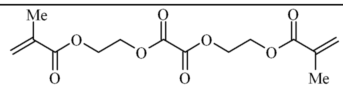
	P1		P3
	P2		P4

Q represents the necessary atoms to form a five membered aromatic ring group; Z represents the necessary atoms to form a five or six membered ring group; and the dashed lines represent the bonds to the rest of the polyfunctional monomer or oligomer. In this way, variants of P3 are an imidazole group, a benzimidazole group, a triazole group and a benzotriazole group, whereas variations on P4 lead to a succinimid group and a phtalimid group. Finally, molecules carrying group P1, the oxalate ester group, are found to be of specific interest. In terms of concentration, it was found that preferably the molecules carrying these moieties are present in concentrations of at least 30 wt% based on the total weight of the UV curable inkjet ink.

Typical examples of hydrolyzable polyfunctional monomers and oligomers having at least one alkali hydrolyzable group located in the atomic chain between two polymerizable groups of the polyfunctional monomers and oligomers are given in Table 5.

Table 5 - Typical examples of hydrolyzable polyfunctional monomers and oligomers

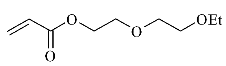
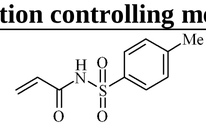
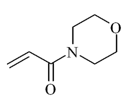
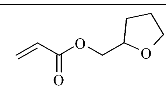
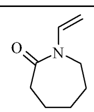
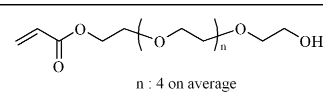
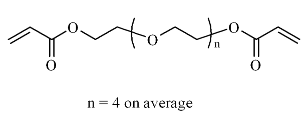
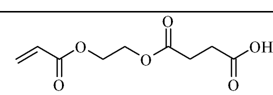
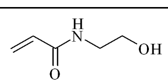
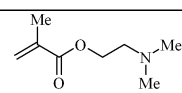
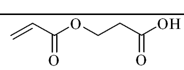
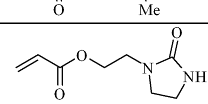
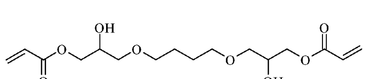
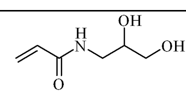
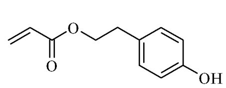
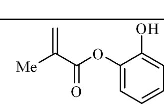
	Hydro-1		Hydro-7
	Hydro-2		Hydro-8
	Hydro-3		Hydro-9

	Hydro-4		Hydro-10
	Hydro-5		Hydro-11
	Hydro-6		

Besides the hydrolysable groups, specifically if the etch resist inks are to be dissolved in the caustic, the UV-curable inkjet ink preferably contains one or more water absorption controlling monomers. A water absorption controlling monomer is a monofunctional or difunctional monomer containing at least one functional group selected from the group consisting of a hydroxyl group, an ethylene oxide or oligo-ethylene oxide group, a tertiary amine, an acidic function having a pKa not lower then 3 and a five to seven membered aromatic or non aromatic heteroring. Preferred examples of these structures are a hydroxyl group, an ethylene oxide or oligo-ethylene oxide group, a carboxylic acid group, a phenolic group, five to seven membered lactam group and a morpholino group.

Suitable water absorption controlling monomers are given in Table 6.

Table 6 - Suitable water absorption controlling monomers

	Control-1		Control-9
	Control-2		Control-10
	Control-3		Control-11
	Control-4		Control-12
	Control-5		Control-13
	Control-6		Control-14
	Control-7		Control-15
	Control-8		Control-16

Finally, an interesting observation was made when the colorant of the inkjet ink was a dye which decolorizes at a pH of more than 10. It was found that by replacing the colorant Material A by triarylmethane dye that the colored cured ink pattern in the alkaline stripping bath fully dissolved into a colourless liquid within 5 minutes. By using the triarylmethane dye as a dye that decolorizes at a pH of more than 10, two advantageous effects were obtained. Firstly, the cured ink pattern could be visually inspected before etching. Secondly, when the stripping solutions start to get colored after multiple strippings, this forms an indication to replace the stripping solution.

Conclusions

It is clear that inkjet printing for a demanding application such as PCB production requires a strategy dedicated to this application. Functional inks of this kind do not pop-up in so-called Friday afternoon experiments. Some of the functional compounds were synthesised from scratch as no commercial sources were available. The lack of truly appropriate commercial compounds is probably one of the reasons not many companies are attempting to tackle this subject with such good match to all properties. The dedicated research and development of specific compounds such as monomers and photoinitiators led to an innovative product. Even though the inks are only part of the solution, it should be clear that breakthrough research led to the identification of key functional molecular moieties allowing industrially reliable digital PCB production.

The etch resist inkjet inks are designed as part of a portfolio of functional inkjet inks. The inks are based on the above mentioned chemical principles and are targeted primarily at the PCB market. Nevertheless, other companies have reached out to use this same technology in non-PCB applications where acidic etching and caustic stripping are also in use. The inks are already successfully used for manufacturing of other etched products typically found in the field of photochemical machining: nameplates, flexible dies and other chemically milled objects in general. Indeed, these inks adhere not only to copper but also to (stainless) steels, brass and aluminium allowing for digitally powered image-wise chemical etching of these metals. The interest of these markets in inkjet is readily explained: these applications require mass customization necessitating a digital technique as described earlier.

References

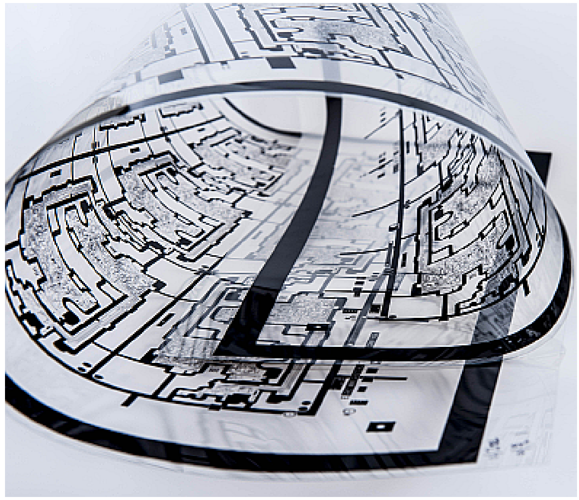
1. Xaar.
2. US8270368 patent, Videojet.
3. WO2004/106437patent, Avecia.
4. WO2015132020 patent.
5. WO2015132020 patent.

Digital PCB Production Using Industrial Inkjet Printing

Dr. Frank Louwet
Agfa

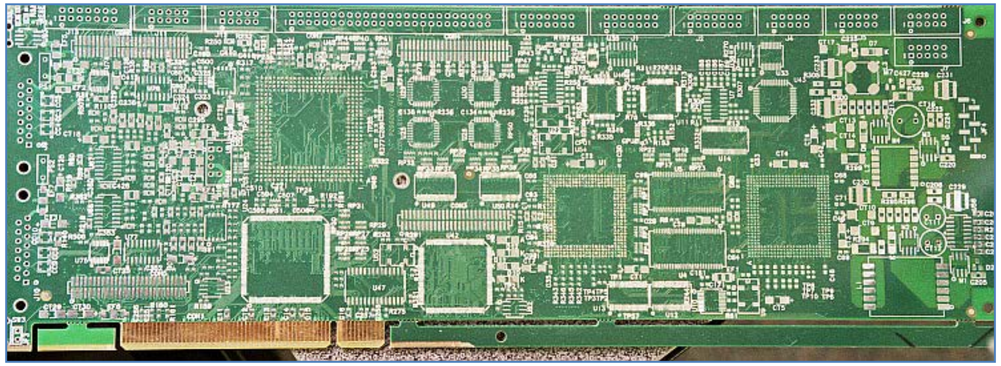
IPC APEX EXPO 2016, Las Vegas, USA

The whole world becomes digital, well, almost

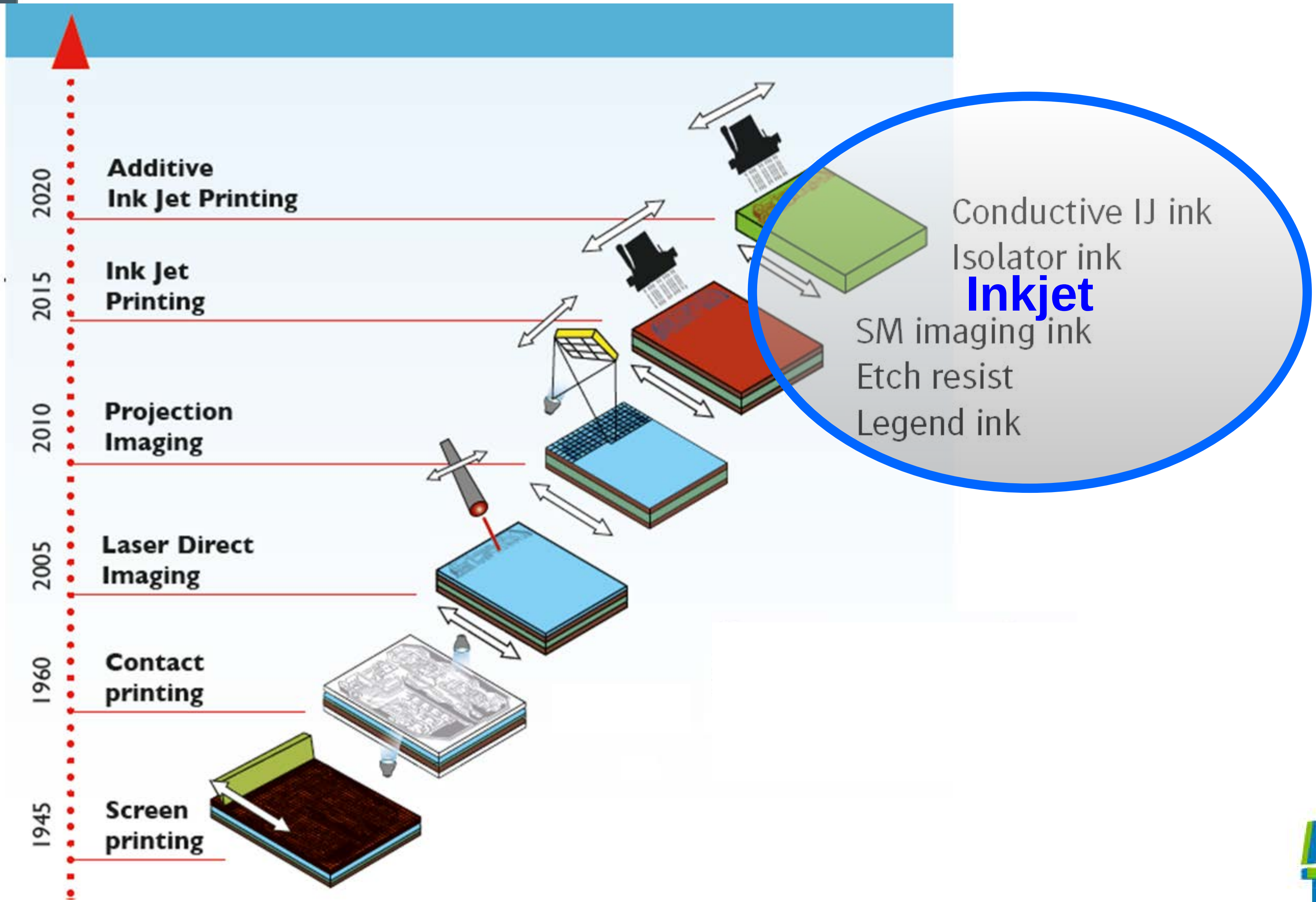


- Photo film → digital camera
- Letters → emails
- Books → e-readers
- Vinyl → MP3

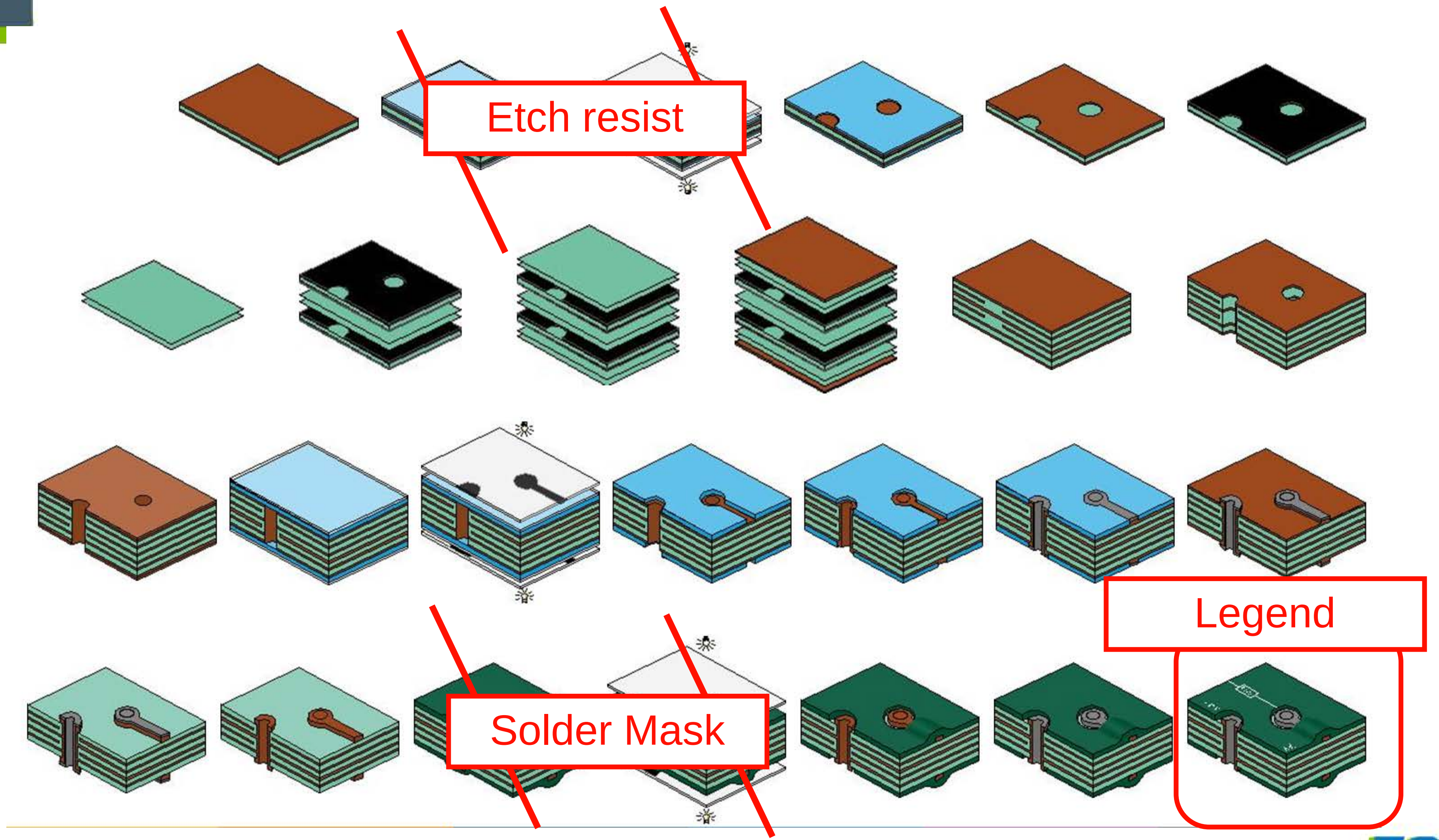
- PCB:
  - core compound driving digitization: beating heart of all digital “alternatives”
  - IRONY: PCB still mainly produced with analog technology



Digitization of PCB: from where to where ?



Digitization of PCB: from where to where ?

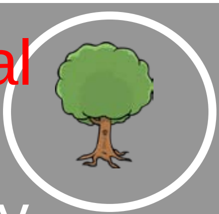


Why inkjet for PCB ?

→ PCB industry is under pressure:

Cost:
footage
material
manpower

Environmental concerns:
less chemistry
shorter workflow



Speed + flexibility:
short runs
fast deliveries

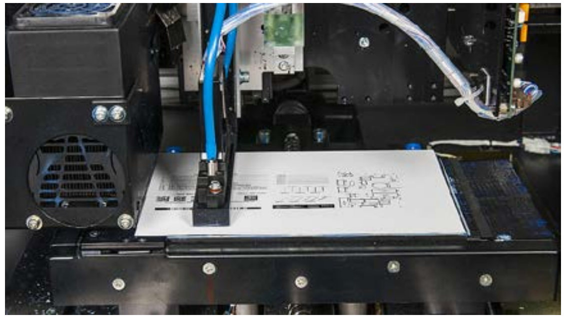
Analog:
100 m² + 5 FTE
Inkjet:
10 m² + 1 FTE

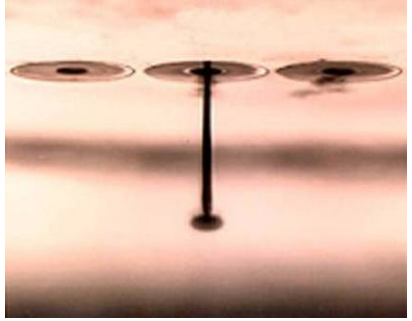
IJ prints only
where you need it:
less resist
no developer

Variable data
printing without
make-ready time

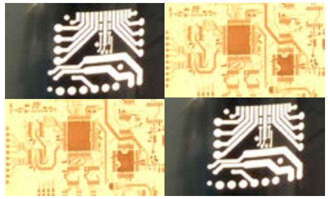
Status of inkjet printing

- Process: Digital, non-contact printing
  - No master (plate or sleeve)
  - Direct from image file to substrate
  - Just like your IJ print @ home
- Equipment:
  - Industrially reliable: matured in graphics industry
  - High resolution (1 – 3 pl droplets)
  - High printing speeds
- Ink
  - Legend printing is established technology in PCB industry
  - Opacity and whiteness
  - Tunable adhesion in harsh conditions
  - Tunable surface tension for image quality
  - Long shelf life (>1y)
  - UV curable for non-absorbing substrates and speed

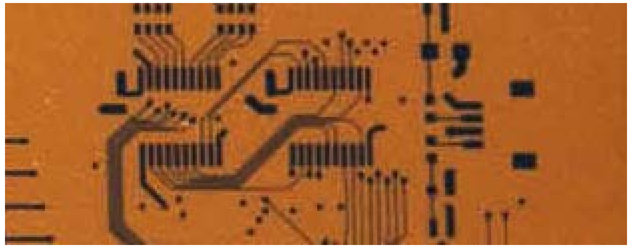




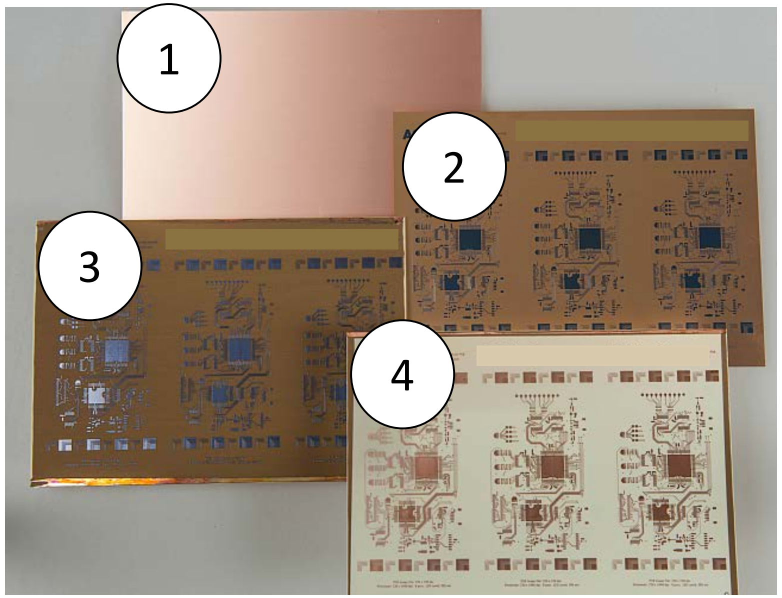
Now there is etch resist inkjet ink



- Replaces phototooling film/DFR or LDI/DFR
  - High contrast blue inkjet ink
  - L/S down to 75 microns



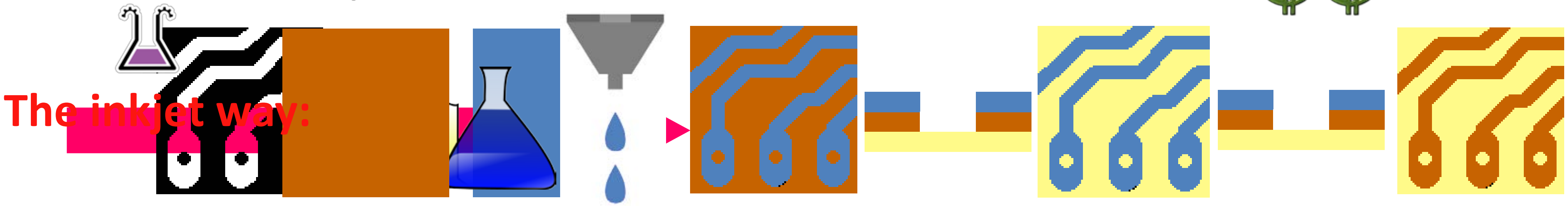
- Same technology as for legend inks but now for etch resist digital printing
  - Fast : Digital and UV cure
  - Less Waste: Additive



- No changes to current industrial processes
  - etching in $FeCl_3$ or $CuCl_2$ up to 1 hour
  - Fast stripping in alkaline solutions, no solvents needed

Benefits of inkjet for digital etch resist and copper patterning

- Easy variable data printing + short start-up → economical short runs (digital: print cost linear function of run length)
- Variable data print → unique identification, mass customisation inside the PCB Cu layers
- No films, no development chemicals, less ER waste: $$



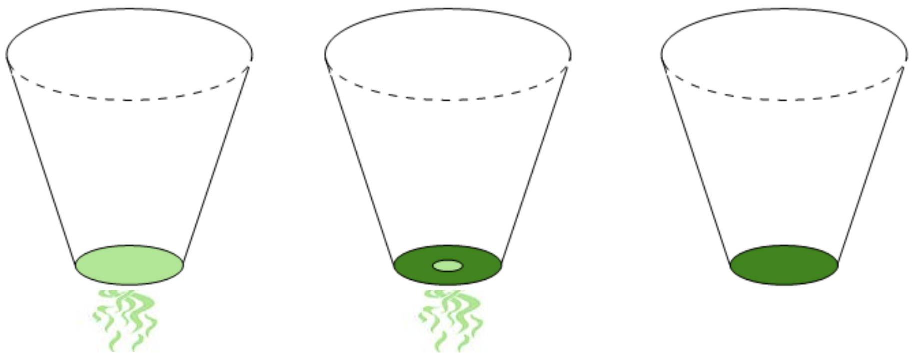
- Inkjet allows for Just-in-time production

How to inkjet print ER inks

Inkjet → low viscosity

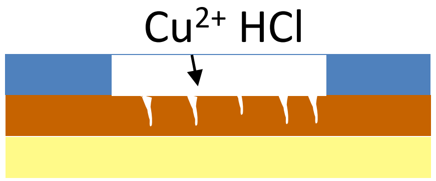
- **Concept 1:** add solvents to high viscous, high molecular weight, etch resistant compounds

Latency problem:

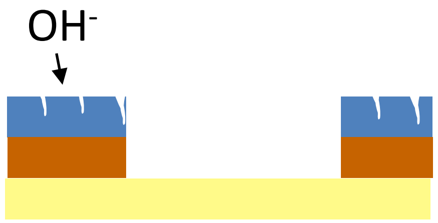


- **Concept 2:** Acidic compounds → shelf life problems
- **Concept 3:**
  - UV curable chemistry: hydrophobic in nature: OK for etch resistance
  - Alkali-hydrolysable groups: ensure partial or complete dissolution of the ER inks
  - Absorption controlling monomers: determine the reaction speed of the hydrolysis

Etch:

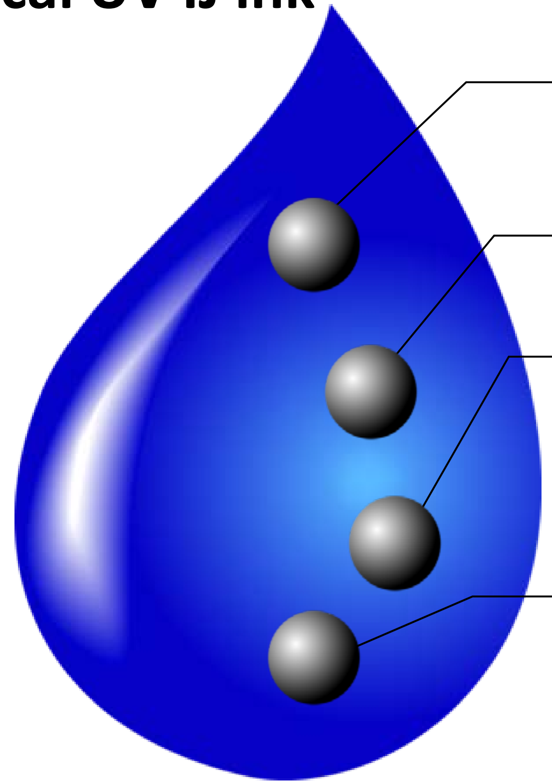


Strip:



How does the etch resistance and the susceptibility to stripping work ?

Typical UV IJ ink



Colorant: dye or dispersed pigment

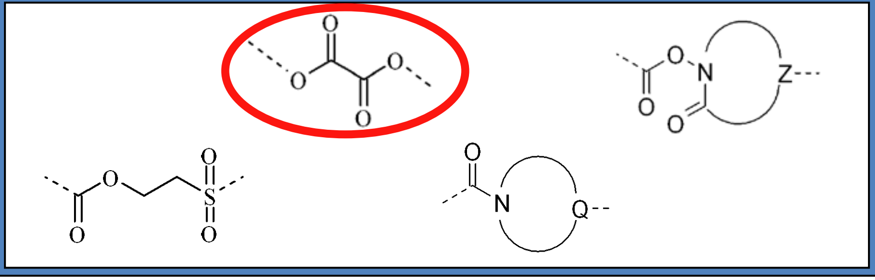
Photoinitiator(s)

Energy curable monomer(s): e.g. (meth)acrylates

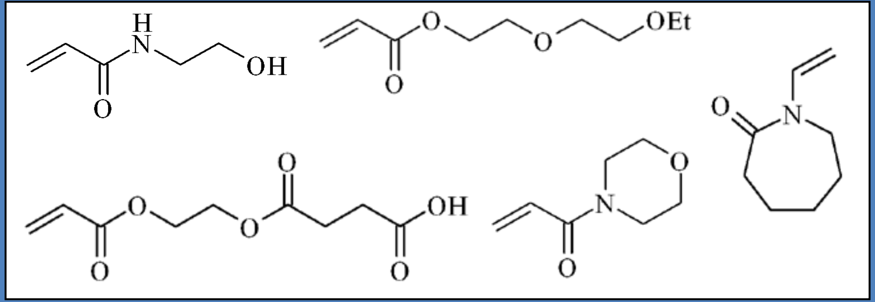
“Adjuvants”: surfactants, stabilisers, oligomers, polymers etc.

After UV cure: organic, hydrophobic layer, resistant to aquatic etching bath

Hydrolyzable groups: allow destruction of the polymerized acrylate monomers



Swellable molecules: increase alkaline “strippability” of the polymerized acrylate monomers



Examples

Colorant: dye or dispersed pigment

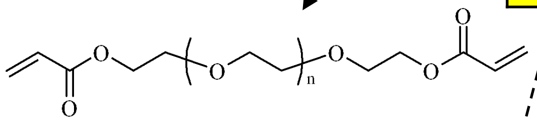
Photoinitiator(s)

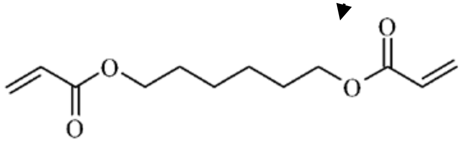
"Adjuvants": surfactants, stabilisers, oligomers, polymers etc.

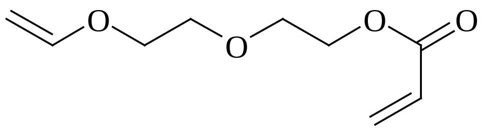
Energy curable monomer(s): e.g. (meth)acrylates

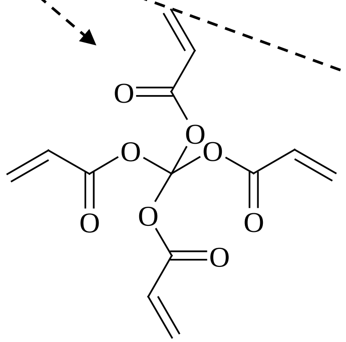
wt% of component:	Ink A	Ink B	Ink C	Ink D	Ink E
blue anthraquinone dye	1.75	1.75	1.75	1.75	1.75
isomeric mixture of 2- and 4-isopropylthioxanthone	5.00	5.00	5.00	5.00	5.00
2-methyl-1-[4-(methylthio)phenyl]-2-morpholino-propan-1-one	5.00	5.00	5.00	5.00	5.00
bis(2,4,6-trimethylbenzoyl)-phenylphosphineoxide	3.00	3.00	3.00	3.00	3.00
2,4,6-trimethylbenzoyl-diphenyl-phosphineoxide	2.00	2.00	2.00	2.00	2.00
Material F	1.00	1.00	1.00	1.00	1.00
polyethylene glycol diacrylate	52.25	---	---	---	---
1,6-hexanediol diacrylate	30.00	---	---	---	---
2-(2-vinyloxy-ethoxy)-ethyl acrylate	---	---	---	---	20.00
pentaerythritol tetraacylate	---	---	---	26.00	---
acryloyl morpholine	---	---	52.25	26.25	---
oxalate monomer similar to polyethylene glycol diacrylate	---	52.25	---	---	32.25
oxalate monomer similar to 1,6-hexanediol diacrylate	---	30.00	30.00	30.00	30.00

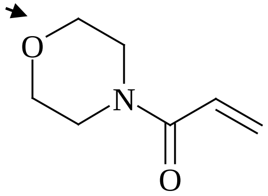
Material F	wt%
DPGDA	82.4
p-methoxyphenol	4.0
2,6-di-tert-butyl-4-methylphenol	10.0
N-nitrosophenylhydroxylamine	3.6

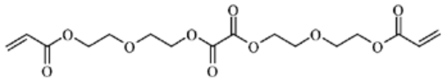


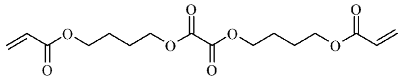






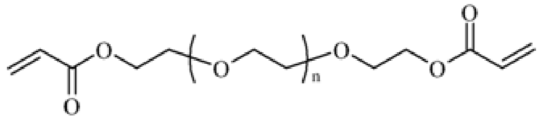
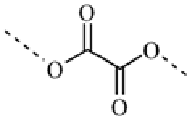
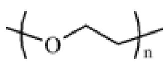
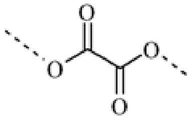
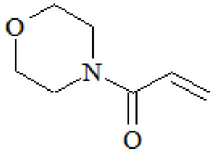
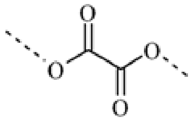
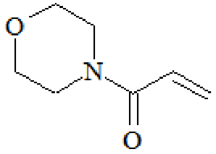
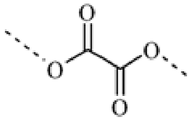
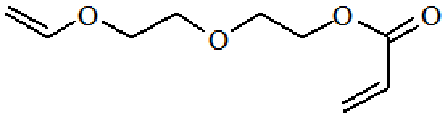






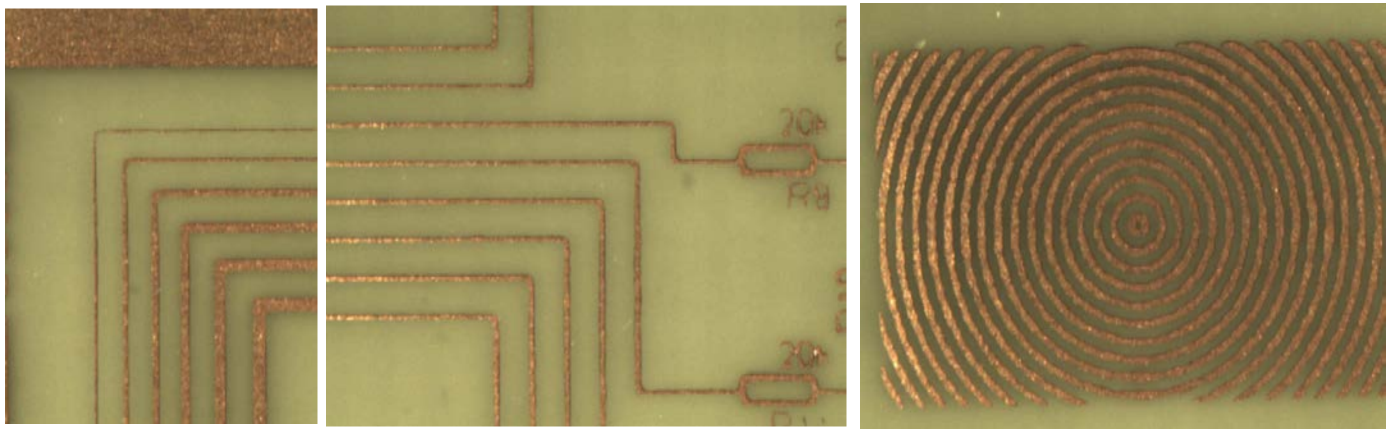
Results

UV Curable Inkjet Ink	Etch Resistance	Stripping (after 5 min)	
		Strippability	Visual Shape
INK A	100%	100%	large flakes
INK B	100%	100%	small flakes
INK C	100%	100%	fully dissolved
INK D	100%	100%	fully dissolved
INK E	100%	100%	fully dissolved

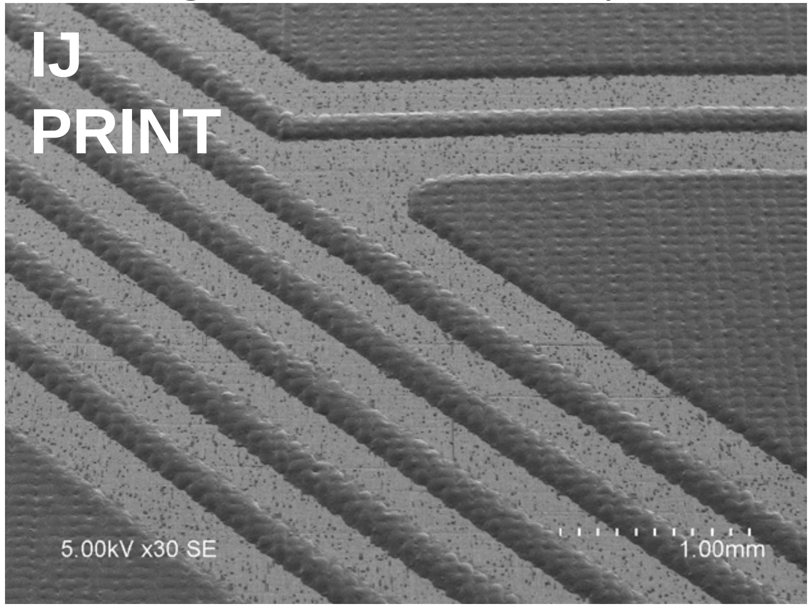
Ink	Hydrolysis	Swelling
A		
B	2x 	
C		
D		
E	2x 	

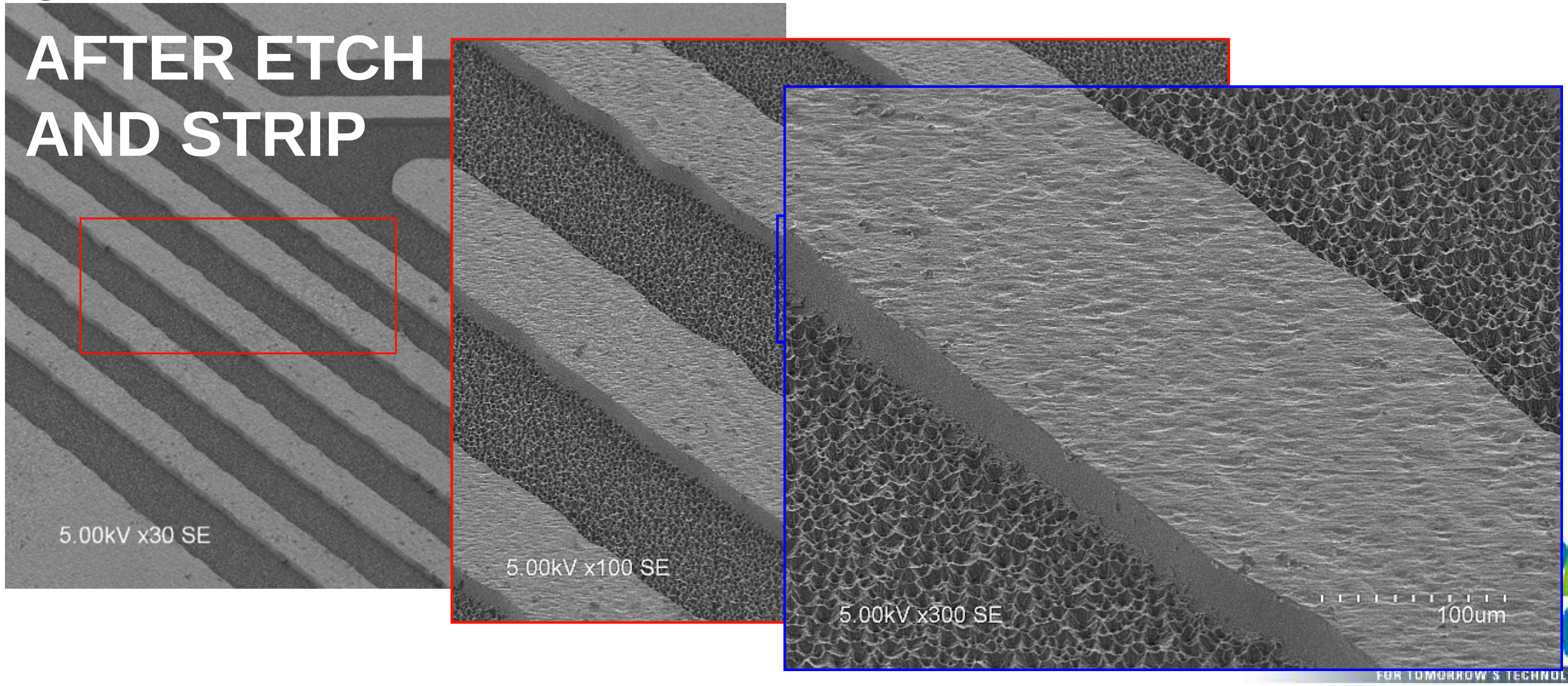
ER inkjet ink in practice: Cu laminate

Microscopic images after etching and stripping:

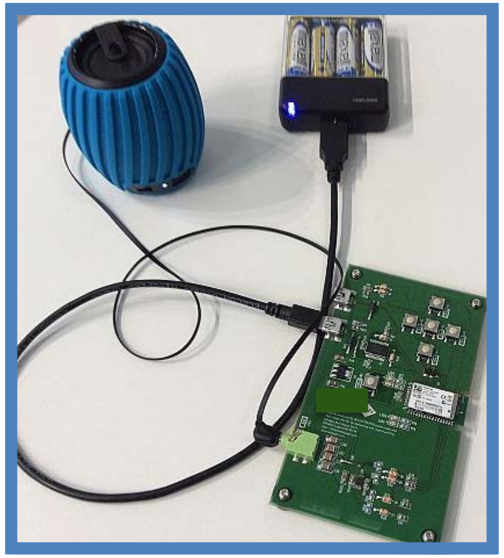


Scanning electron microscope recordings:



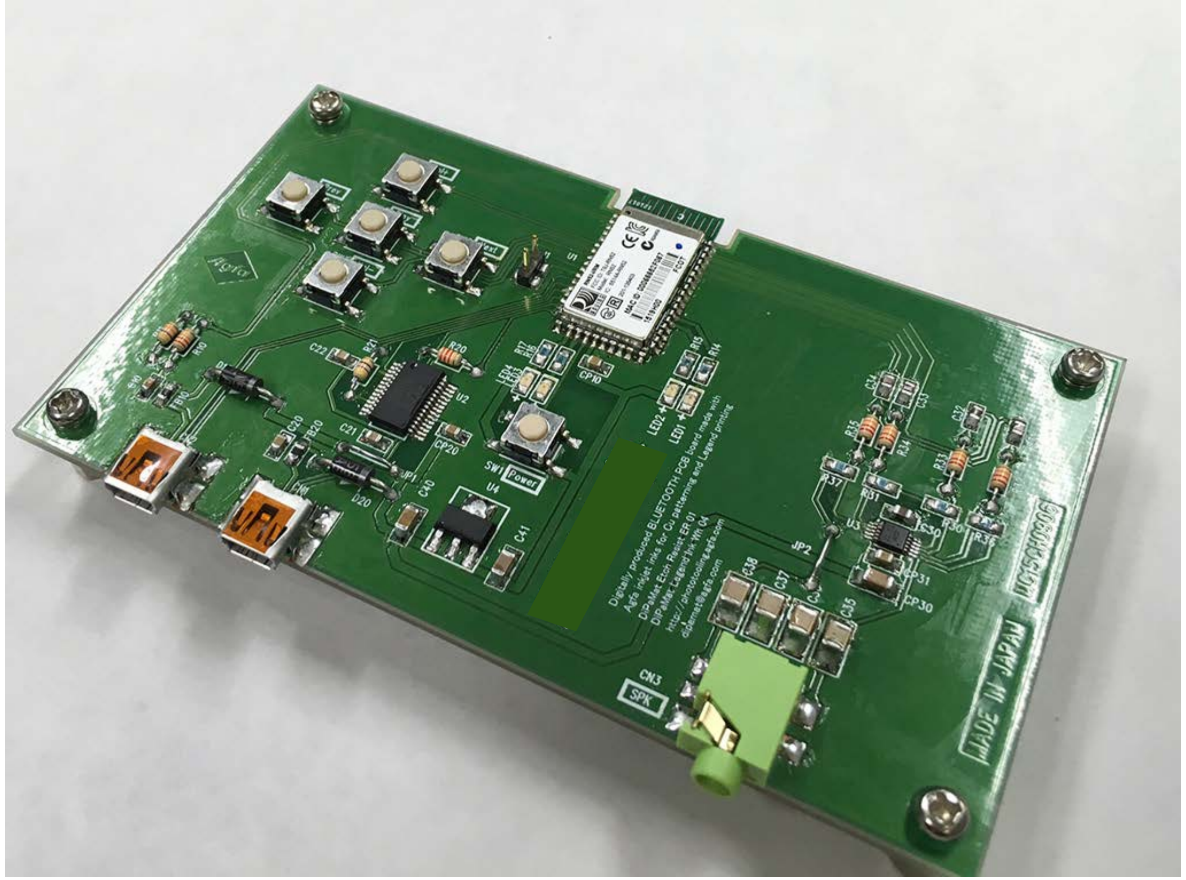


Case study:
When digital legend inks meet digital etch resist inks

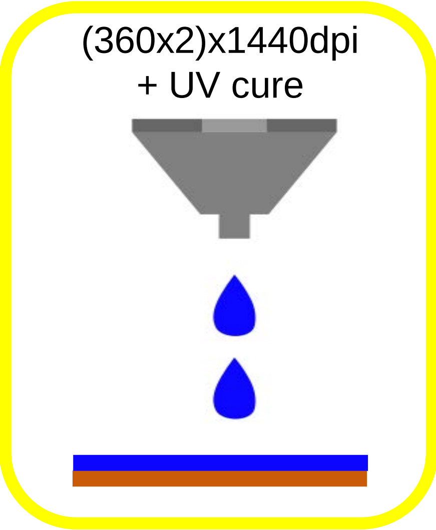


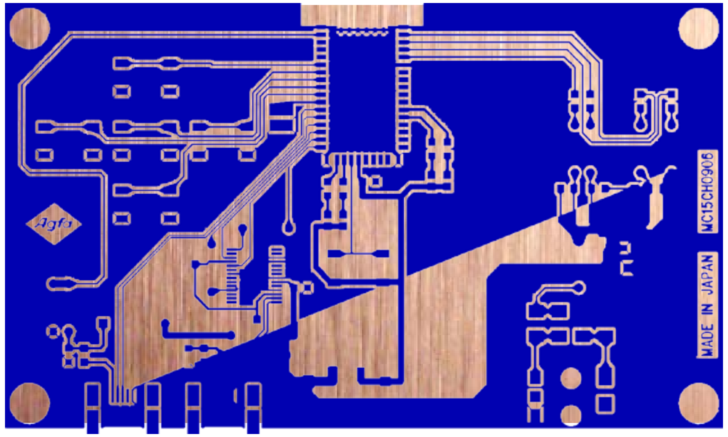
Fully functional Bluetooth module produced using White Legend inkjet ink and Etch Resist inkjet ink.

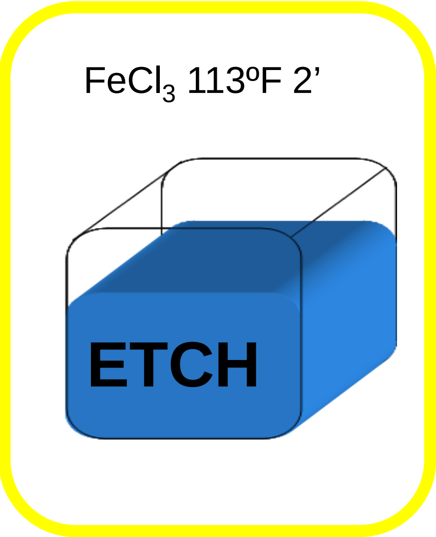
Demonstrator enables Bluetooth connection between smartphone and speaker

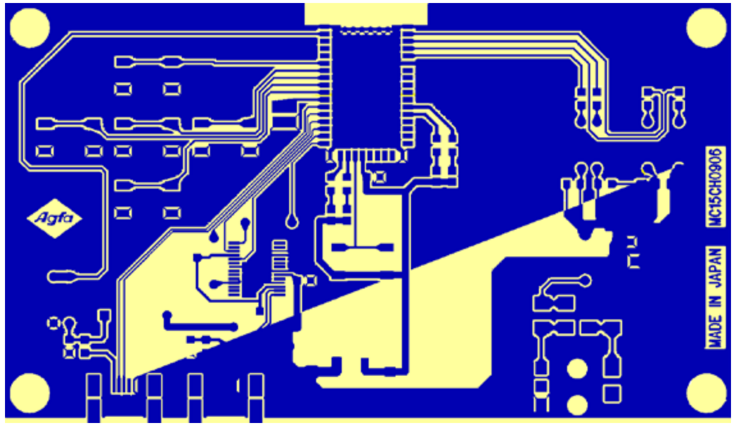


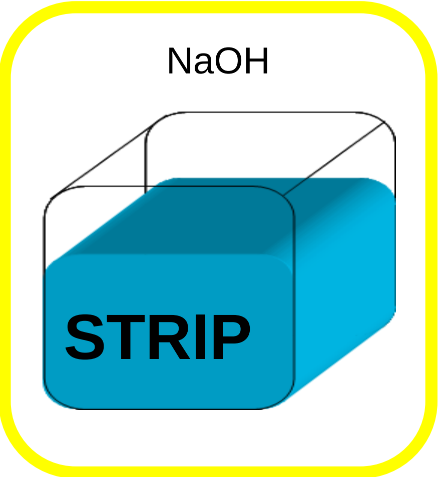
Digital demonstrator PCB production with Inkjet

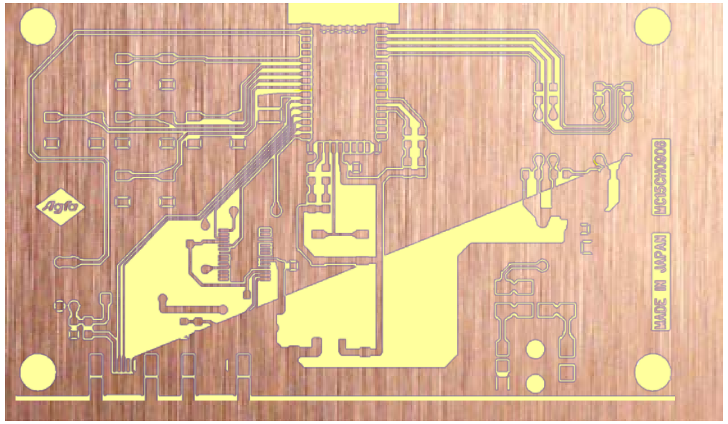












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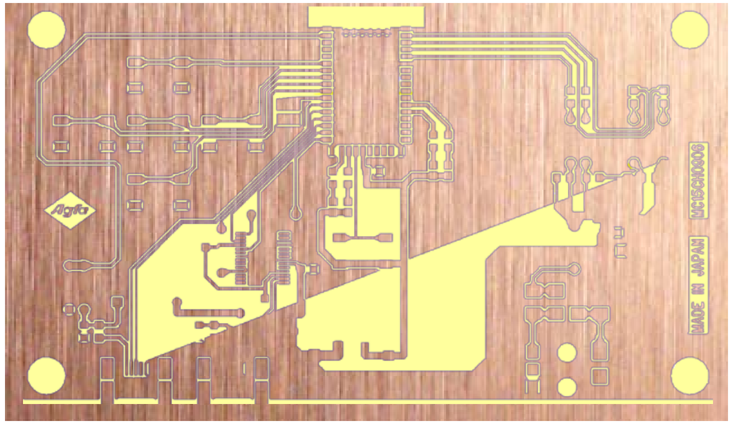
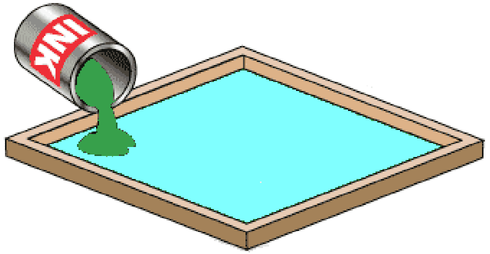
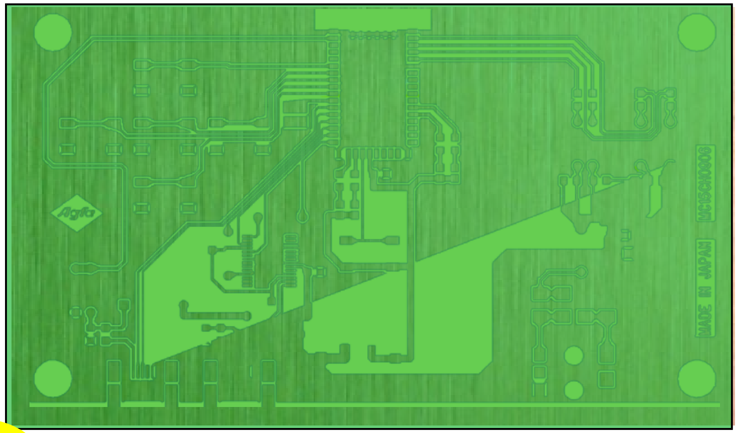
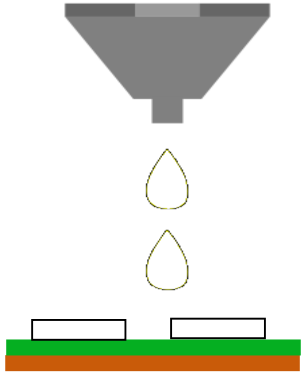
Digital demonstrator PCB production with Inkjet

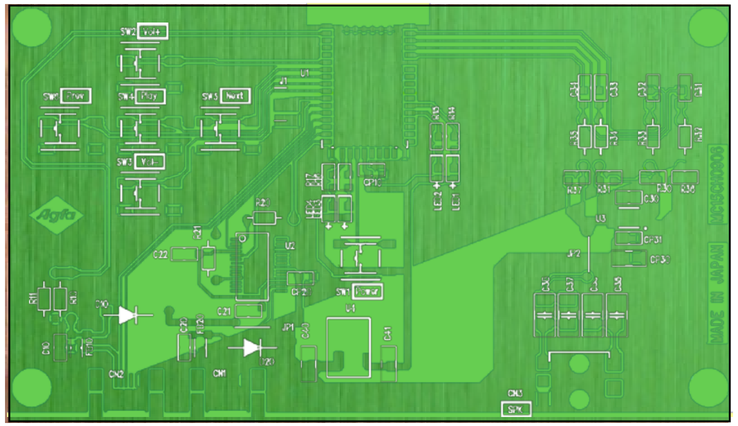




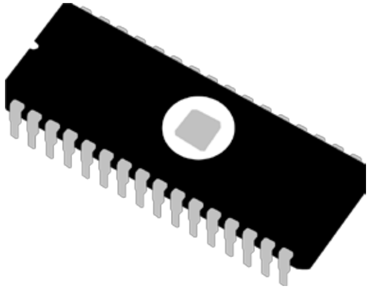


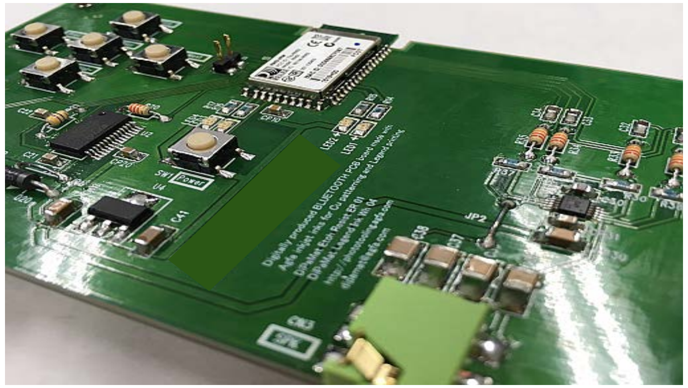
(360x2)x1440dpi
+ UV cure





PCB assembly

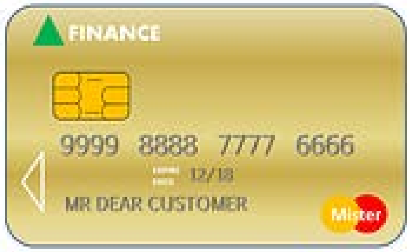




FORWARD THINKING
FOR TOMORROW'S TECHNOLOGY

Non PCB applications of ER inkjet

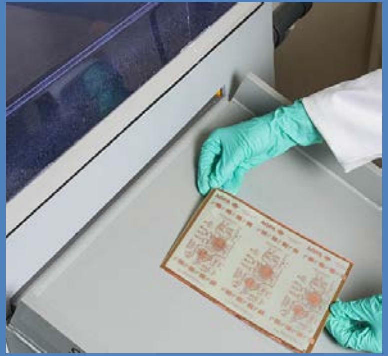
- Chemical milling (PCM), name plating and decorative applications
- Steel Rule Die: cutting dies for the packaging industry (self-adhesive labels, graphic and flexible packages)
- Leadframe: IC packaging: 2nd level of interconnection between the integrated circuit in the package and the circuit board
- Smart card connectors: connecting microprocessor chips to cards for Banking, Telecom and I.D.



Conclusions

- Inkjet printing for PCB production is happening now because:
  - Technology is ready and mature
  - Easy variable data printing + short start-up → economical short runs
  - Variable data print → unique identification, mass customization
  - No films, no development chemicals, less ER waste → cost saving
  - Inkjet allows for Just-in-time production
- Inkjet printing for a high end application such as PCB production required a dedicated strategy: etch resist inkjet inks are part of a portfolio of functional inkjet inks.
- Research has led to the identification of key functional molecular moieties allowing industrially reliable digital PCB production: Some compounds synthesised from scratch: no commercial sources
- Same technology in non-PCB applications using acidic etching and caustic stripping
  - nameplates
  - flexible dies
  - chemically milled objects in general

  → these applications require mass customization necessitating a digital technology



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