Utilization of Inkjet Technology for Primary Imaging of Printed Circuit Boards

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Abstract

The rules of the game in PCB production are changing with new disruptive technologies. At the company there has been the implementation of a "primary image inkjet-resist" printer for both inner-layer print and etch and outer layer pattern plating processes in full production. Inkjet printing has become a crucial building block for the first zero emission, fully automated PCB factory.

Ink jetting resist eliminates standard lithography processes while still providing a fully digital solution in a very small footprint. This technology combined with an intelligent nozzle conditioning routine, and real-time ink channel acoustic monitoring with double channel redundancy, gives full process control during production. To ensure higher yields and continuous feedback, the print is also fully inline scanned by integrated AOI at full process speed to check the print result before etching (Image Quality Inspection).

The fully automated panel logistics, the clean machine, and reduction of processes enables CAM to etch processing within minutes. The short overall process pipe line and digital imaging gives flexibility to the flow and facilitates easy mixing of jobs. With "jet-resist", production becomes a straight forward process, greatly reducing process steps and complexity compared to traditional production.

Furthermore, since the resist is based upon a hot melt wax, the use of next generation etching and stripping process techniques have been employed that have resulted in 100% closed loop rinsing, stripping, and etching processes that consume no chemicals, and require no waste treatment whatsoever. The only by-products are solid resist and pure copper metal, which may be reused in the copper plater. Additionally, the precision of the ink placement on the substrate, further allows for a 5-10% increase in panel utilization compared with standard dry film and liquid resist application processes. The overall solution represents the next generation in PCB Fabrication, and a formula for manufacturing in North America and Europe at equal to or lower cost than current Asia-Pacific sources, in much shorter cycle times.

Process Description

Ink jetting resist eliminates standard lithography processes while still providing a fully digital solution in a very small footprint. Digital UV imaging (LDI) and other direct imaging techniques have been introduced, but this only replaces the analog artwork through a direct exposure. There is still the need for film lamination and developing, and dealing with the associated failure modes from these processes. A basic comparison of each of these process methodologies is illustrated below:

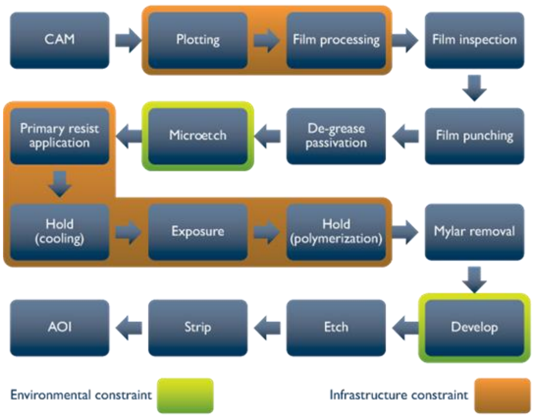
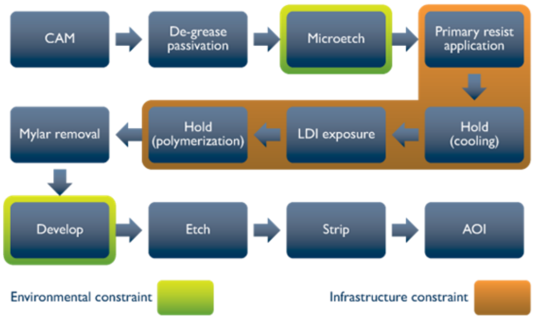


Figure 1: Lithography Process

Lithography Process

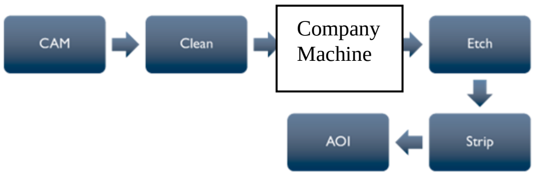
- Costly and complex
- Registration constraints
- Yield constraints
- Environmental constraint – process waste handling
- Infrastructure constraint – clean room etc.
- From data to print in days



Direct Imaging Process

- Typically more costly than conventional lithography
- Complexity remains
- Registration constraints eliminated
- Eliminates artwork process
- Can be detrimental to yield (dependent on other processes)
- Environmental constraints – process waste handling
- Increased infrastructure constraints – special clean room etc.
- From data to print in hours

Figure 2; Direct Imaging Process



Inkjet

- The inkjet process is almost as simple as it can get.
- The image is directly jetted onto the substrate with a "jet-resist", only needing a cleaning process.
- An inline scan inspects the printed image and can detect errors before etching. No first article inspection is needed.

Figure 3: Inkjet process

The short overall process pipe line and digital imaging gives flexibility to the flow and facilitates easy mixing of jobs. With "jet-resist", production becomes a straight forward process, greatly reducing process steps and complexity compared to traditional production.

Figure 4.

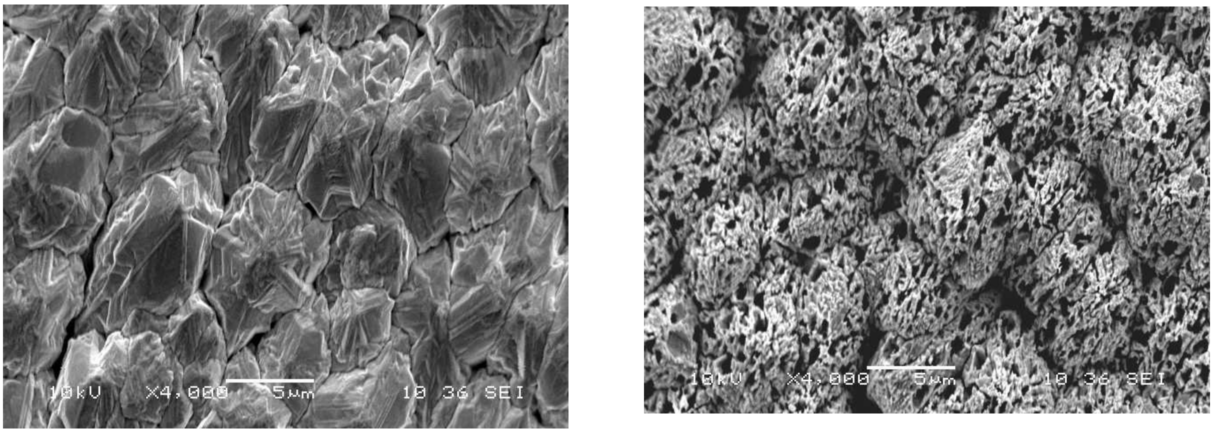
Pre-clean and Surface Treatment Considerations

In a standard dry film or liquid resist process the resist is applied by transposition using a type of roller. This process often requires the use of mechanical and/or chemical pretreatment steps in order to roughen the surface sufficiently to raise adhesive strength, due to the poor wetting characteristics of these highly viscous transposed resists. With ink jetting, the resist does not rely on roller transposition, and jetted ink is able to wet out the surface to a much higher level. This is due to both its inherently lower viscosity at the active jetting temperature, and the subsequent force of droplet impact on the surface. As a result, panel plated and shiny copper surfaces are able to be imaged without the need for any surface roughening or annealing of any kind.

Table 1 – Pretreatment Comparison of Traditional Resists to Jet-Resist

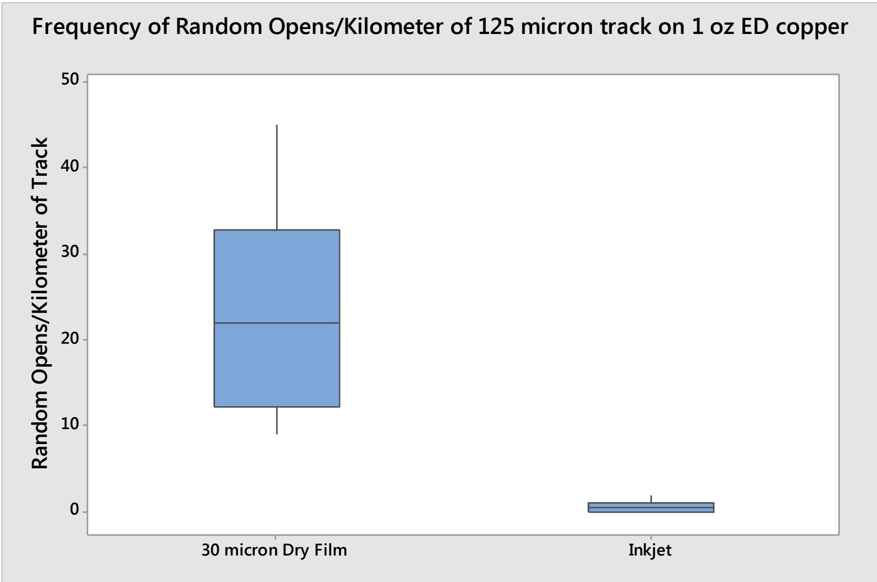
Surface Copper Type	DRY FILM/Pretreatment	INKJET Pretreatment
Panel Plated - Production PPR	Microetch, Pumice, or Mech Scrub	None or Degrease Only
HVLP Copper - Print & Etch	Microetch or Degrease Only	None or Degrease Only
ED Copper - Print & Etch	Microetch or Degrease Only	None or Degrease Only
RTF Copper - Print & Etch	Degrease only	None or Degrease Only

Standard resists are formulated to rely on a pure copper(0) metal surface to achieve the consistent chemical bonding required to maintain adhesion thru subsequent etching and plating steps. For this reason, pre-clean of some type is generally required to eliminate oxides and any other contaminants. With the low viscosity inkjet ink, the wetting is so thorough that adhesion/conformation-type opens are not a concern (ie. it fills all pits in the laminate surface easily). Also, since there is no developer process as in conventional photolithography, there is no chance for cu spots and shorts caused by lock-in of resist to a salt spot after drying, or redeposit of debris in the developer prior to etch, etc.. Consequently, a good anti-tarnish on the surface (ie. like the conversion coating on an as-received core), is all that is needed. In 20,000 panels of production processing there has never been a cu spot or an open caused by adhesion loss or lock-in of the ink. Conformation to the surface easily exceeds that which is achieved by conventional wet lamination of dry film.



4000x ED Cu untreated out of box 4000x ED Cu treated with micro etch

Figure 5 – Cu Topography Comparison of Untreated versus treated surfaces



Random Open Frequency on Shiny Copper

Figure 6 – Shiny Copper Defect Frequency

Registration Performance

Design

Registration accuracy demands very rigid design constraints. A jet-resist machine must use several techniques to tackle registration challenges. The following were the key techniques employed in our example:

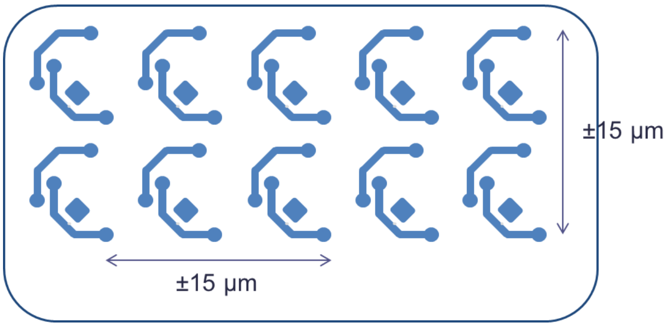
1. <u>Clean machine design.</u>
   The machine has a temperature controlled down flow to prevent pollution, but also to ensure a stable temperature environment.

2. <u>Substrate temperature control</u>
   The chuck temperatures in the machine are all controlled within ± 0.5 ºC. Prior to printing, during alignment, the substrate is conditioned to the printing process temperature. While printing, this temperature is maintained, and even during curing the substrate is cooled.

3. <u>High resolution encoders</u>
   The motion control of the stage uses eight high precision encoders to ensure accurate positioning

4. <u>Beam and scanner</u>
   The print beam and scanner are thermally the most sensitive. To ensure stability, both of these beams are made from state of the art carbon fiber with thermal elongation < 1 µm/ºC/m.

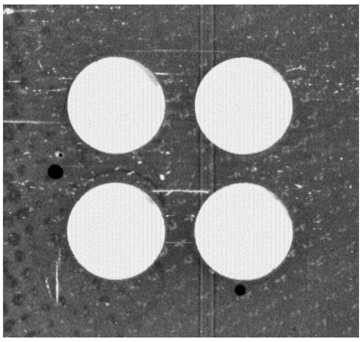
5. <u>Scanner calibration in the machine</u>
   The scanner is used to calibrate both head-positioning, and nozzle timing. To ensure accuracy, the scanner is calibrated in the machine with a high precision ruler positioned on the printing chuck.

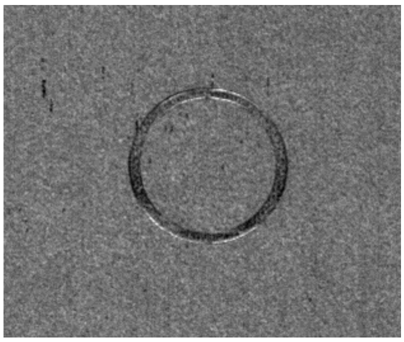


These measures ensure that the print is extremely accurate under all conditions.

Figure 7

Fiducials
For top to bottom registration internally made markers or pre-drilled fiducials can be used. The accuracy of the stage and scanner ensure high accuracy positioning. The markers are stamped in the pre-alignment marker unit in the input module and are used for inner layers. The quad holes can be used with pre-drilled panels.


Quad hole


Internal marker

Figures 8a and 8b

The fiducial information is used to position the printing chuck prior to printing in the print plane, with displacement as well as rotation compensated for mechanically. There is no digital rotation needed, thereby preventing stair-casing effects on the print.

The registration methodology, coupled with the fact that each panel is individually compensated this way during the input cycle, means that ink can be precision placed within 1 mm of the panel edge, to maximize utilization of the substrate to a level not previously achieved. The 12-25 mm borders required for a conventional dry film process do not limit the panels processed thru inkjet. If CNC and multilayer tooling is properly optimized to take advantage of this reduced keep-out space, 5-10% average panel utilization improvements can be realized using inkjet compared to a standard process. This has now been demonstrated in production at the beta-site factory.

Print strategy
High accuracy printing for PCB manufacturing is not comparable in demands to graphical applications. The drop target position is ± 10 µm (at 3 sigma) for all drops on the panel (on average 2 billion drops).

This demands high control of jet speed (dot firing), timing, head positioning and stage movement. Let us call this the “mechanics’ of drop positioning.

Within a traditional data path, a model is used based upon a raster and dot size which does not yield a well-defined image due to uncontrolled flow behavior.

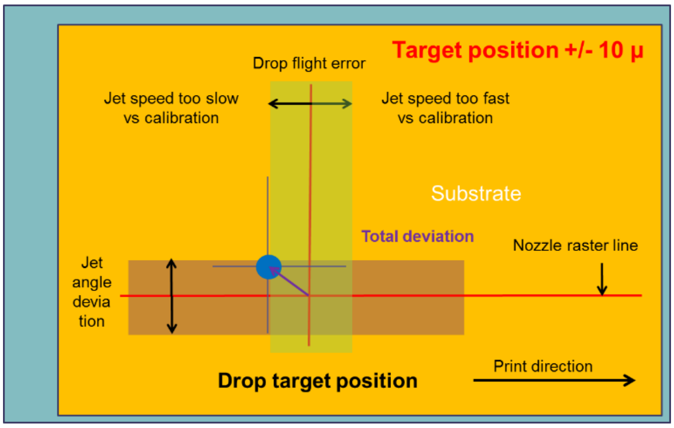


Figure 9

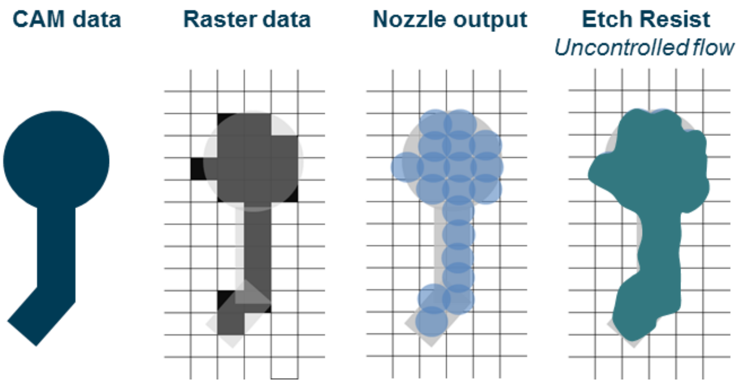


Figure 10

Within our data path an extensive model is used to determine the dot pattern to be printed which incorporates the flow characteristics of the ink.

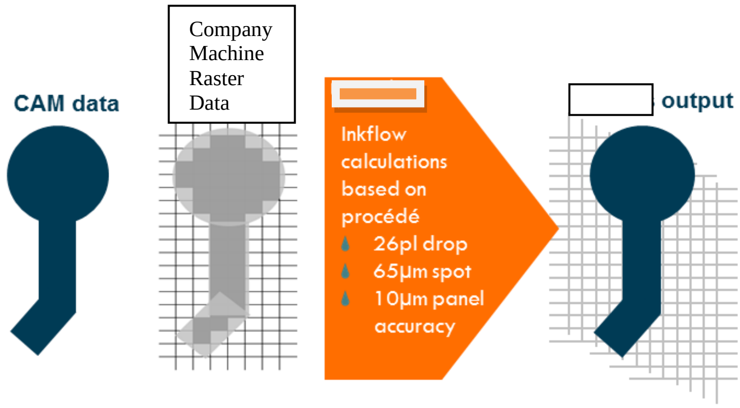


Figure 11

To ensure a good print, an acoustic measurement is continuously performed against predetermined spec limits during the printing process on each nozzle, with out of spec nozzles being subsequently disabled until they achieve a passing measurement. Based upon study of these disabling rates, the system was designed to have three print heads per raster line to provide sufficient redundancy to assure high confidence that there will always be sufficient nozzles available for jetting.

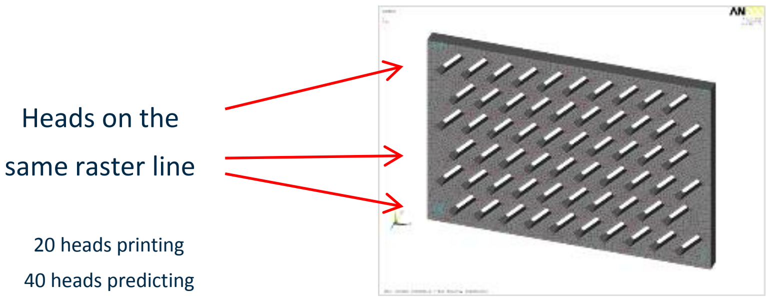


Figure 13

As a further control, on a daily basis prior to operation, the print heads are conditioned, and an additional nozzle disabling takes place based upon actual jetting performance. This test utilizes the inline AOI scanner to check the jetting performance in positioning and within a frequency range. Any nozzles that show deviations or non-stable jetting performance are disabled, and easily replaced by the redundancy in the system. If during the life time of a head too many nozzles are disabled, the head can be replaced by a trained operator during regular maintenance.

Y-direction Performance Variables/Controls

Y lines are by definition smooth. The drops are jet at a high frequency after each other and flow into one mass before crystallization. The lines displayed next to this text are lines on the raster distance of the heads. In the company machine this separation is 120 µm.

So how are lines positioned at random places on the print, and how are different line widths made?

For this, the machine makes use of several mechanisms. During every swath of the print, the stage makes a displacement perpendicular to the Y-line, which introduces a raster shift on the panel. This is done in variable increments (depending on the number of swaths). In the example below 4 steps of 30 micron are shown.

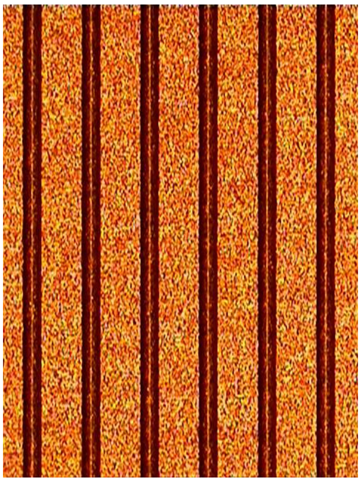


Figure 14

This would still not give enough positioning resolution.

To achieve a 10 micron positioning of the line (or feature) edge we use variable line widths as illustrated. The combination of the raster, stage positioning and variable line widths is pre-calculated in a mathematical model, also taking in account the flow characteristics of the ink to realize the required line positioning

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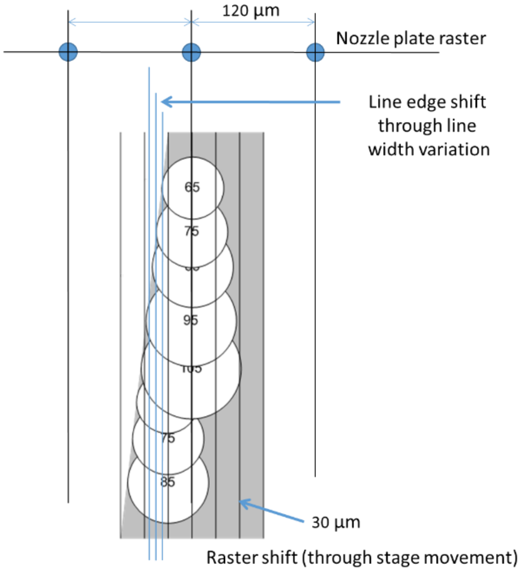


Figure 15

X-direction Performance Variables/Controls

Lines perpendicular to the stage movement are built up with drops fired in subsequent printing swaths. Due to the time between jetting drops, there is a propensity for the drops to crystalize before the next drop is placed, giving a less smooth edge than those seen with Y lines.

Within the machine, the nozzle firing trigger is coupled to the absolute position in the stage through the encoders.

The dot positioning is ensured through calibrations, perfect print head positioning calibration (with mechatronic actuators the print head is physically moved in the print beam), jet-speed firing calibration, and positioning timing calibration.

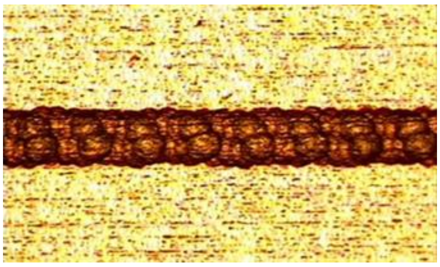
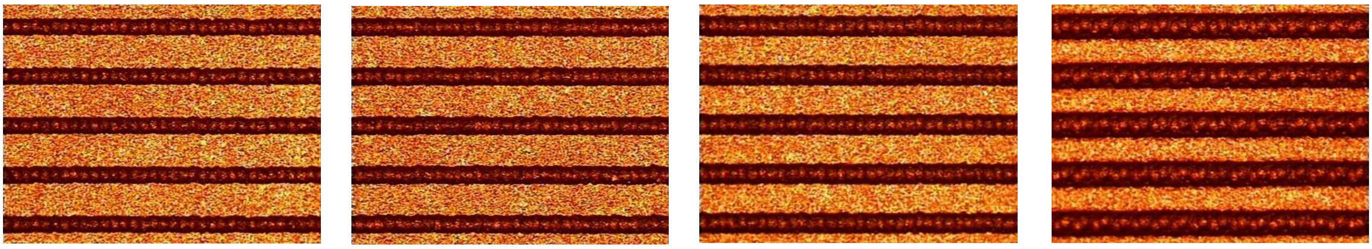


Figure 16

The printing of the lines is done in several print swaths in which the stage is moved. Choosing the number and position of drops within the edge of the line is dependent on the required line width.

The result of the model is different for every line width target to get an optimal position, taking into account the flow and the neighboring drops that already have been fired.



90 µm 100 µm 125 µm 150 µm

Figure 17

AOI Methodology: Image Quality Inspection

Inkjet application of resist is an additive one step process. The "jet resist" is WYSIWYE "what you see is what you etch". This characteristic is unique. There are no hidden failure mechanisms due to adhesion or substrate topography problems of film or issues with developing.

This process lends itself perfectly for an inline quality inspection.

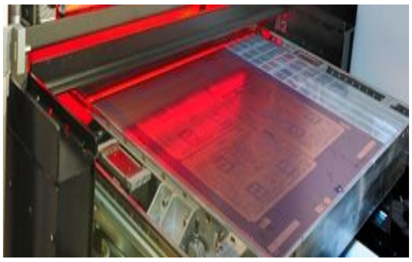


Figure 18

The scan is made with a fully integrated high resolution scanner. There is no loss of cycle time because the image is captured at process speed. Thresholding and interpolation of a gray level pixel (of 8 µm) is done through hardware in seconds giving a high resolution (2.8 micron B/W) image which is compared with the CAM input file.

The captured file is of high optical quality because the thresholding and exposure levels are tuned to the substrate and resist combo being used through an automated calibration.

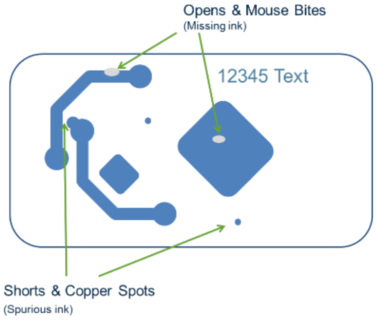


Figure 19

The areas of non interest are blanked prior to further analysis (defined in the CAM process). The output is de-speckled and intelligently inspected on possible opens and shorts. If errors are flagged, the substrate can be diverted out/stripped, and corrective actions performed in print head conditioning and maintenance.

Etching / Circuitisation Capability and Implications for Zero Discharge

The use of a hydrophobic wax based etch resist results in the ink being completely insoluble in either acid or alkaline etch. This subsequently enables the ability to recycle the etchant in a closed loop mode without risk of long-term contaminant build-up which can inhibit the etching reactions, and decrease the purity of the Cu extracted from the system. In our production site, a closed loop ammonium sulfate based alkaline etch formulation was developed which has been operating for over one year already per the below general model:

Electro-chemical explanation of etching and plating of copper.

Chemical reaction in the etching machine;

$$[Cu(NH_3)_4]^{2+} + Cu \longrightarrow 2[Cu(NH_3)_2]^{+}$$

$$[Cu(NH_3)_4]SO4 + Cu \longrightarrow [Cu(NH_3)_2]_2SO4$$

Chemical reaction of the regeneration in the oxidizer/complexer

$$2[Cu(NH_3)_2]^{+} + 1/2\ O_2 + 2NH_3 + 2NH_4^{+} \longrightarrow 2[Cu(NH_3)_4]^{2+} + H_2O$$

$$[Cu(NH_3)_2]_2SO4 + 1/2\ O_2 + 2NH_3 + (NH_4)_2SO4 \longrightarrow 2[Cu(NH_3)_4]SO4 + H_2O$$

Reaction balance etching and regeneration

$$Cu + 1/2O_2 + 2NH_3 + (NH_4)_2SO4 \longrightarrow [Cu(NH_3)_4]SO4 + H_2O$$

Figure 20

Additionally, [Cu] is held constant by use of an electrolysis cell to extract the pure cu metal for recycling, and Cu-laden rinse water is metered back to the electrolysis cell based upon amp-hours plated (which directly correlates to drag-out rate). The copper metal removed from the system in this way is of sufficient purity (thanks to the insolubility of the ink jet resist), that the copper can actually be reused in the PCB metallization cu plating bath (>99.99% pure). In the USA, this can be a good way to lower your reportable quantities for SARA 313 reporting of copper, while also lowering your costs, since the circuit pattern can be plated with the otherwise discarded copper being etched away from the laminate.

The rinse water replenishment is balanced to the moisture loss per panel and to the drag out rate, resulting in a zero discharge rinse system in addition to the zero discharge chemical system.

Also, the regeneration reaction is performed in a hermetically sealed tank with venturi pumps that reuse the gas byproducts from electrolysis (ammonia and oxygen), thus avoiding the need for ventilation of the etchant to the atmosphere to draw oxygen into the etch chamber, as occurs in every other alkaline etch installation in the world.

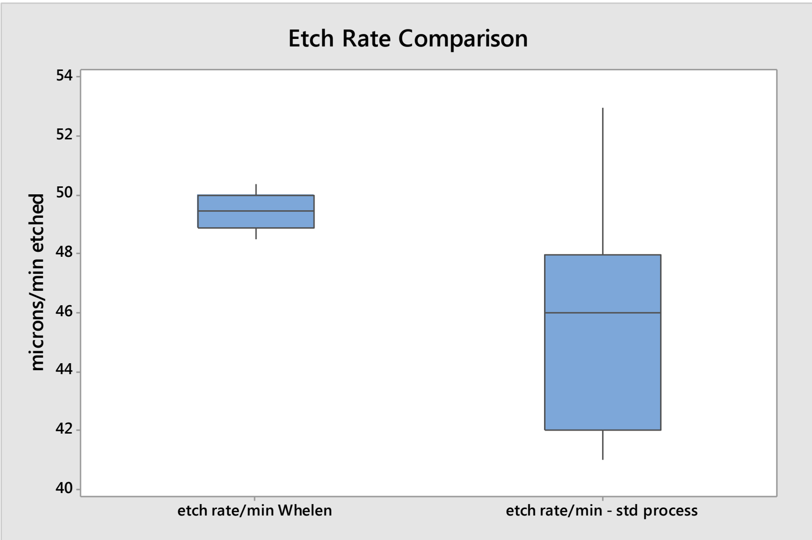


Figure 21 – Etch Rate Comparison (Recycled versus Traditional Alkaline Etch)

Figure 22 – Etch Recycling System

Resist Stripping Capability and Implications for Zero Discharge

The wax ink formulation contains many of the adhesion promotors that are commonly found in dry film and liquid resists. Since they are part of the insoluble wax matrix, however, they dissolve at less than 1% of the level commonly seen with aqueous-based dry films, so there are in fact no resist chips generated. Instead the stripper only attacks the periphery of the crystallized drops, and the resist is removed in strings of Y lines (since Y-lines crystallize together unlike X-lines). Due to the subsequent long-life of the chemistry stemming from the basic insolubility of the resist, if a solvent-based stripper chemical is used (we use an unregulated green solvent in our production site), recovery of the solvent by distillation at operating temperature is able to keep up with demand of stripper per panel.

The small amount of contaminants can then be isolated and solidified in a high surface area shallow tank heated by a jacket of the active solution. Consequently, the chemistry is made to last forever by a simple packed distillation column in the scrubber duct. Water lost due to humidity and drag out is compensated via the rinse water replenishment at a matched flow similar to what is done in the etcher. The net result is a zero liquid discharge system for both stripper chemical and water.

The only solid by-products are the resist itself which is separated by a drum filter, as well as 1-2 kg per week of soluble resist components separated by the distillation process.

Due to the fact that the resist strips in strings as opposed to chips, ink jetting is a very good process for selective cu plating for epoxy fill applications as well as protection of butt-lines (high topography 3D features) between selective images on circuitized patterns. The strings are too large to possibly plug a hole that might then need to be inspected and poked out with a conventional process prior to epoxy via fill. Also, for selective protect processes, the ink conforms to any circuit pattern so well, that it leaves no potential for adhesion loss as is commonly seen with thick circuit features on outer layers.

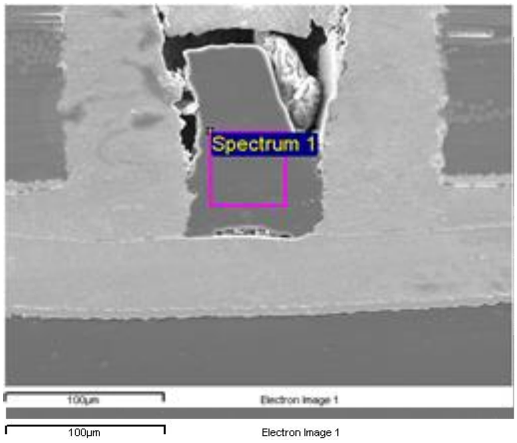


Figure 23: Example of dry film chip plugging a via filled hole.

Post-etch Results
Half ounce ED copper 150 micron cores with two CAT test patterns were studied for variation in net resistance thru the jet resist printer and alkaline etching. The resistance values were then inserted into a calculator to calculate the average width of each net across the entire pattern. Etch loss values on half ounce copper were equal to or better than established industry standards using dry film (even wet lam), as were defect rates per net. This may be attributable to the high adhesion level as well as the sloped profile of the resist (compared to the familiar rectangle associated with dry film) resulting in a thinner diffusion layer during etching.

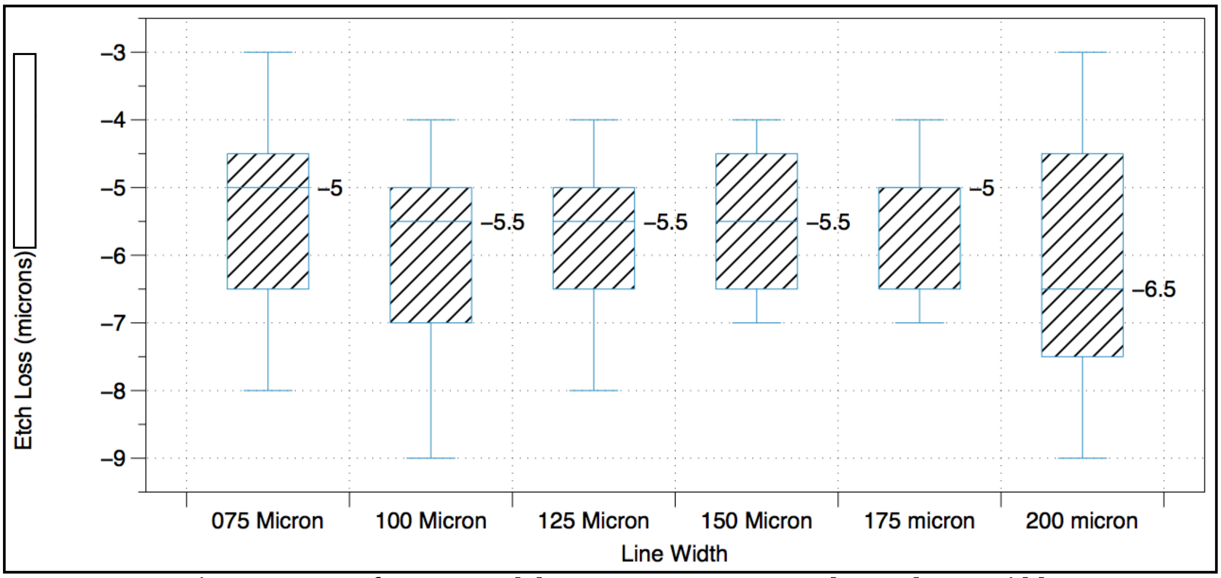


Fig 25 – Range of average etch loss on CAT test patterns by conductor width

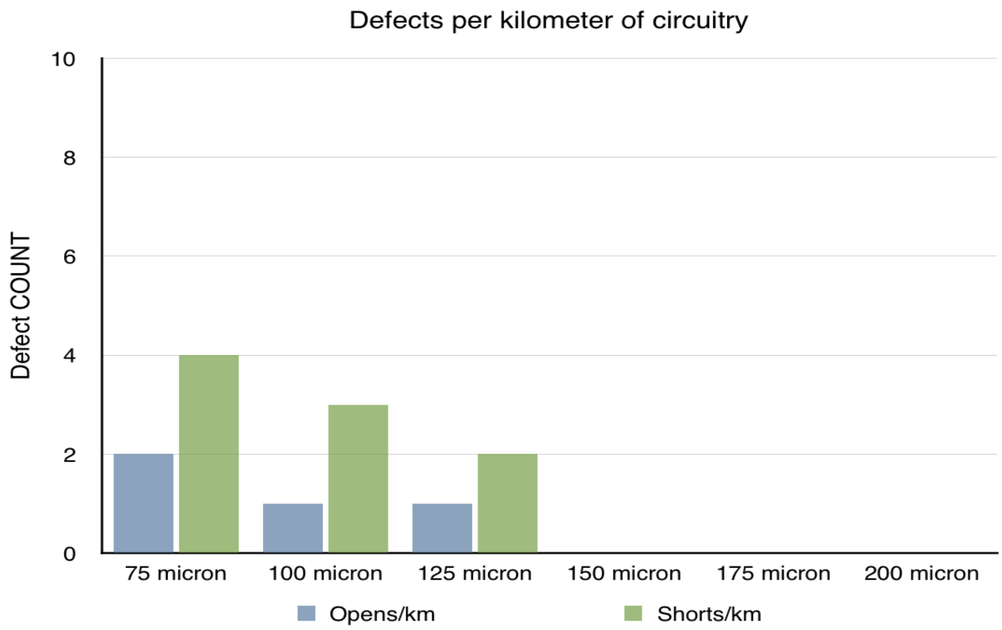


Fig 26 – Defect per kilometer of circuitry on CAT test patterns

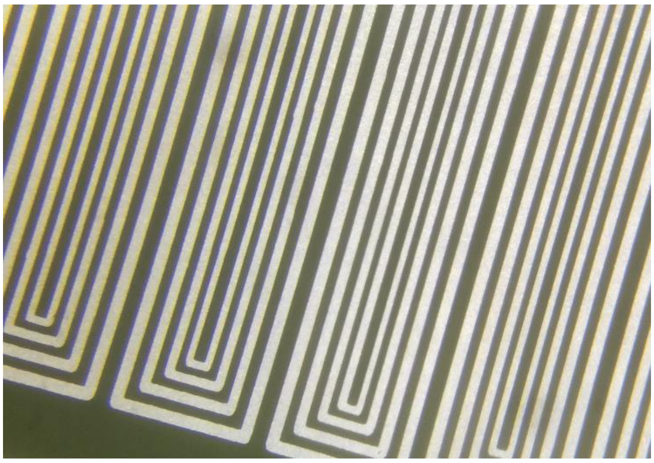


Fig 27 – Example of Etched CAT test vehicle

Facility Requirements and Costs

The R&D work performed on this joint project has resulted in a green line concept that allows for the placement of a print and etch process in any factory without the need for any water or chemical treatment. 100% recycling has been demonstrated and achieved in full production at the beta site without any central wastewater system. All water, chemicals and air can be recycled using a well-engineered line. Total processing costs inclusive of labor for a 50 panel per hour double-sided print and etch line are < $3/panel using this type of system, with a portion of this further off-set by the reclaim of pure cu metal (based upon the cu weight and the image area used). For heavy cu applications with a properly configured etcher, it is possible for Cu reclaim to off-set all of the processing costs.

Conclusions

Based upon our collaborative work, we have now demonstrated in full production that jet-resist for primary imaging can be an enabling technology to drive out tremendous cost and cycle time from the PCB manufacturing process, through the elimination of a variety of traditional wastes. These advantages are leveraged in the beta site factory to achieve print and etch cycle times of only a few minutes, and outerlayer cycle times from production release to shipping of <8 hours. Use of this technology as part of an overall well engineered factory solution has the potential to eliminate PCB manufacturing cost advantages in the Far East for a wide variety of technologies, and also provide substantial cycle time advantages.

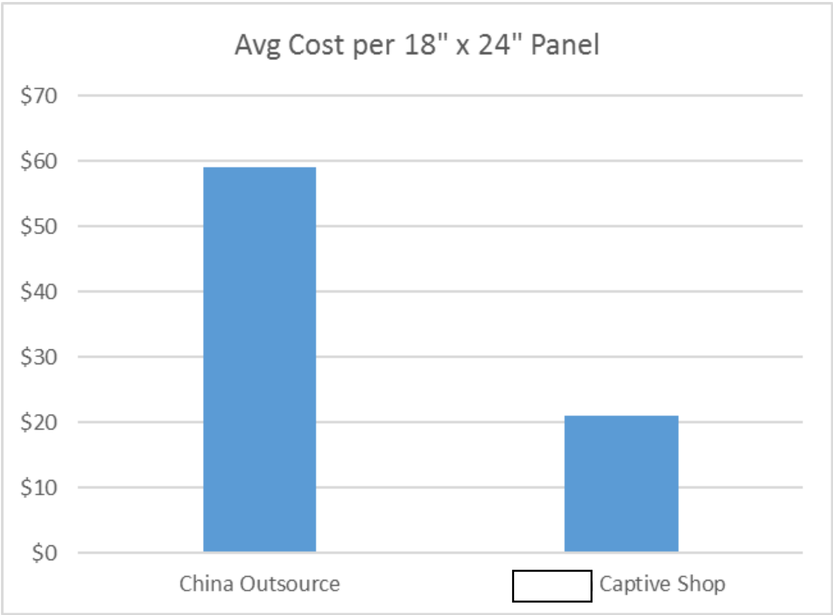


Fig 28 – Beta Site Average Cost per Panel versus Previous China Source

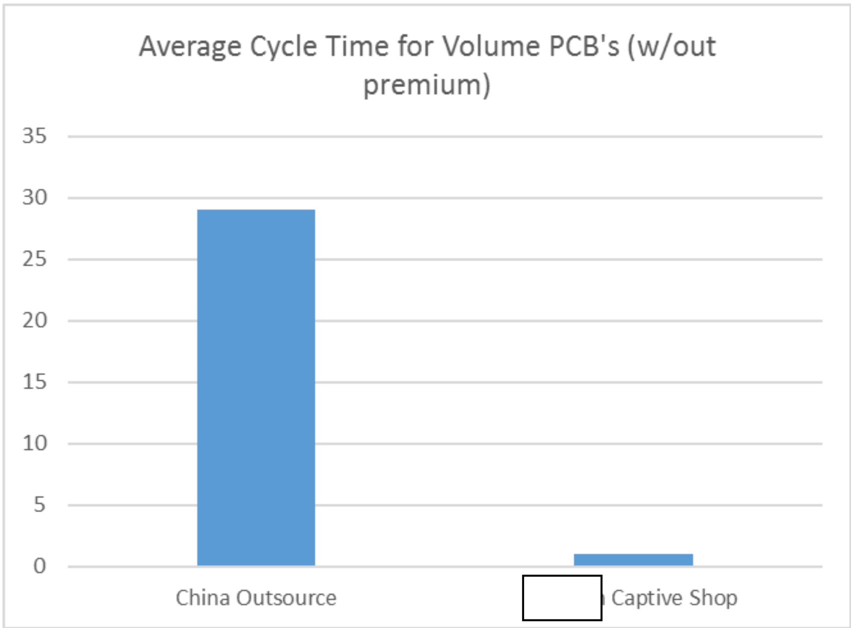


Fig 29 – Beta Site Average Cycle Time per Panel versus Previous China Source

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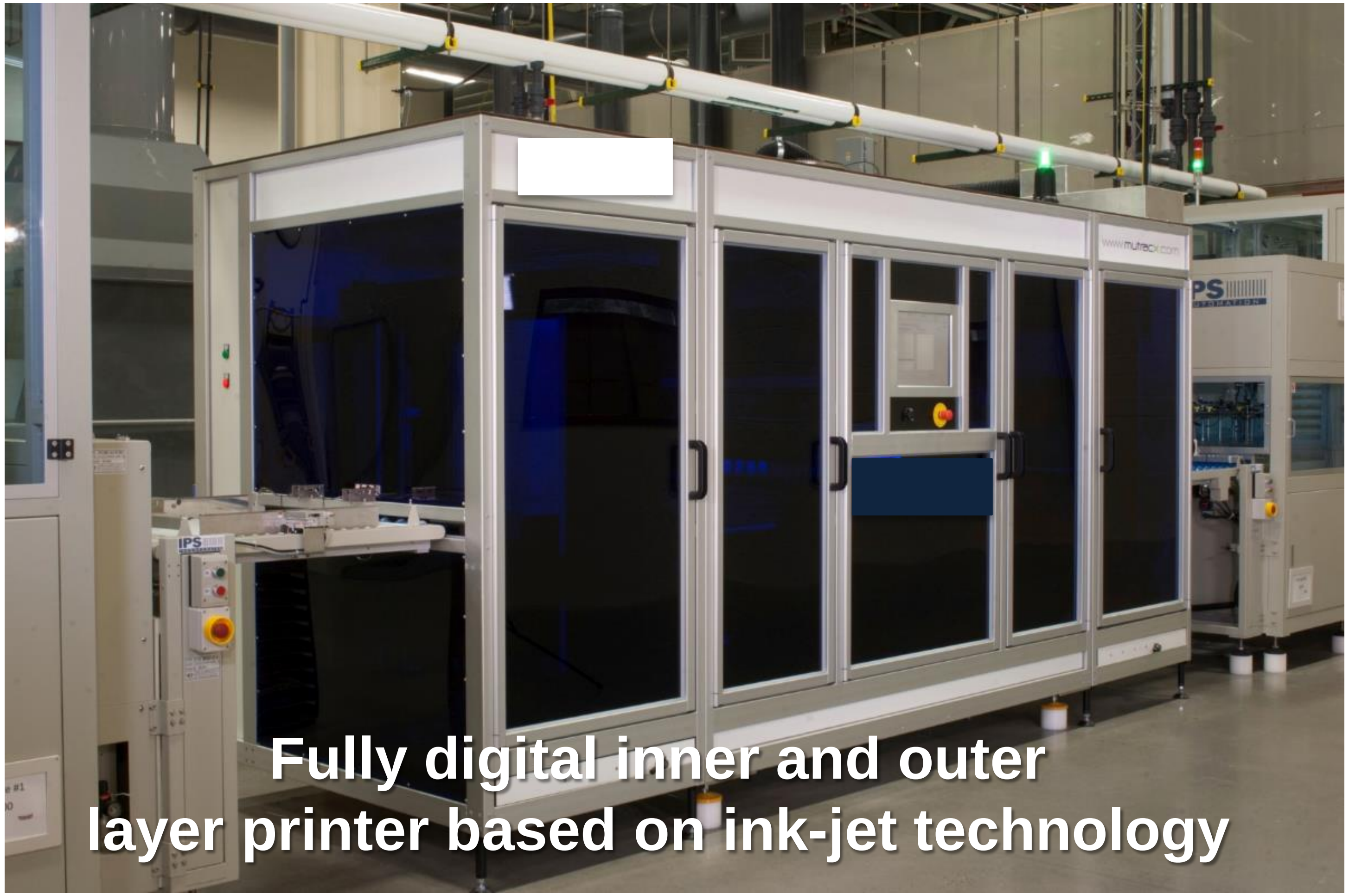
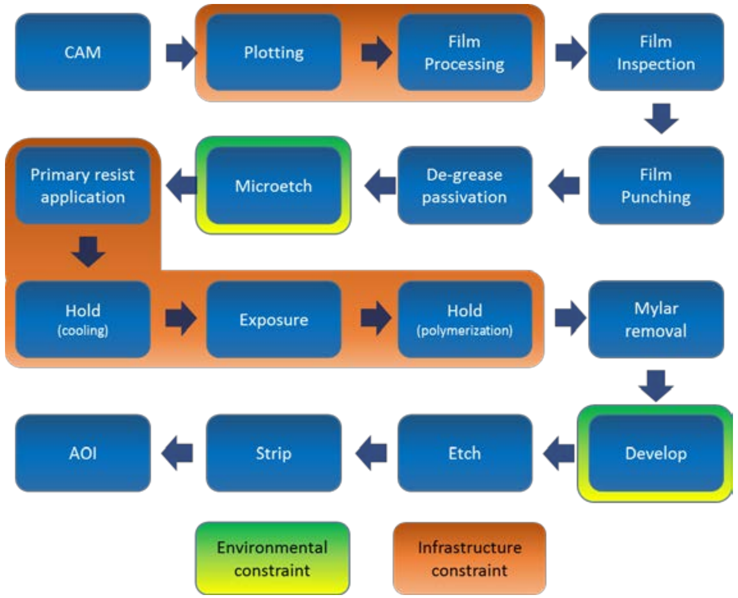
Printing with Jet-resist

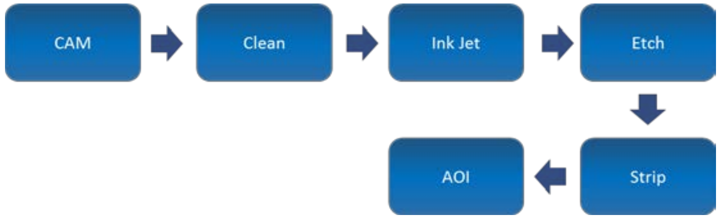


Artwork vs Jet Resist

- Lithography Process



- Inkjet Process

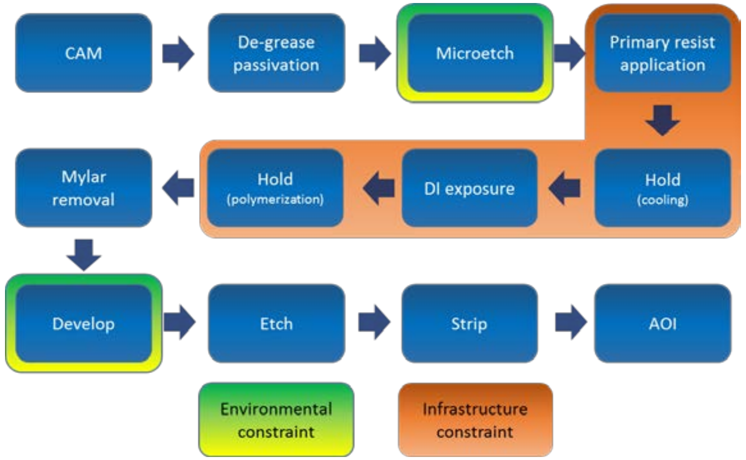


Lithography Process

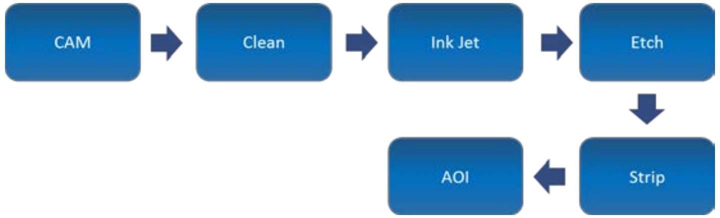
- Costly and complex
- Registration constraints
- Yield constraints
- Environmental constraint – process waste handling
- Infrastructure constraint– clean room etc.
- Long Cycle Times

DI vs Jet Resist

- LDI Process



- Inkjet Process

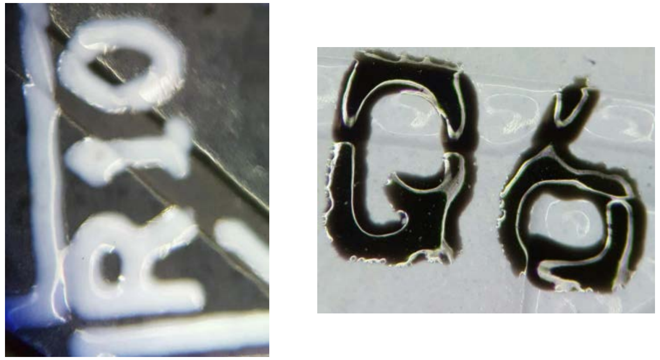


DI Process

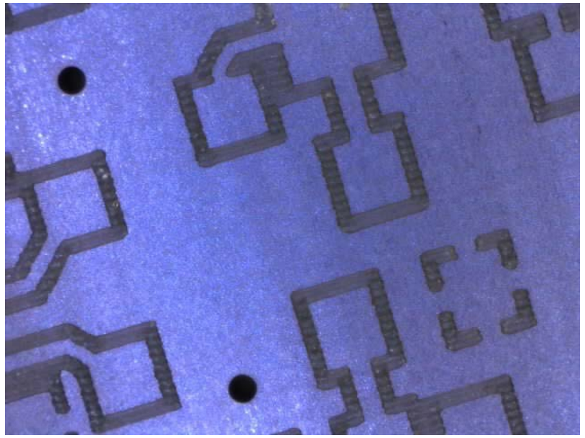
- More costly than conventional lithography
- Complexity remains
- Registration constraints eliminated
- Eliminates film work
- Can be detrimental to yield (dependent on other processes)
- Environmental constraints – process waste handling
- Increased infrastructure constraints – clean room etc.
- From data to print in hours

Inkjet applications in PCB

- Legend: comparable to graphical applications
- Solder mask: Jetting functional material
- Inner / outer layer resist:
  - High accuracy demands
  - Jet resist not in end product



Traditional inkjet / legend (Too choppy for etch resist)



Inkjet Etch Resist (High Quality Required)

Key building blocks

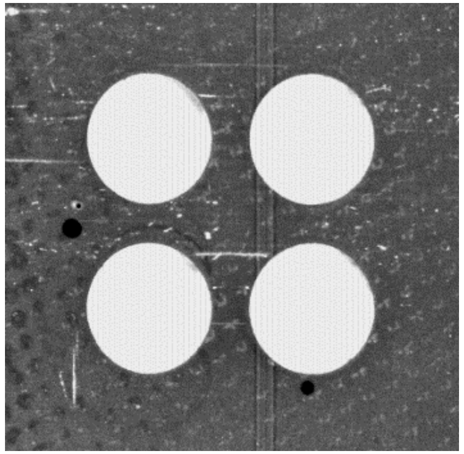
2015				2016
Mechatronics	3D calibration	Virtual plane	Panel logistics	2D fine
Jetting	Maintenance	Conditioning	Disabling	Jet Speed Angle deviations Jetting stability
Scanning	Lens distortion Stitching	Upscaling (thresholding)	IQI	Dynamic lens correction
100 micron post etch achieved				75 micron

Registration – Key building blocks

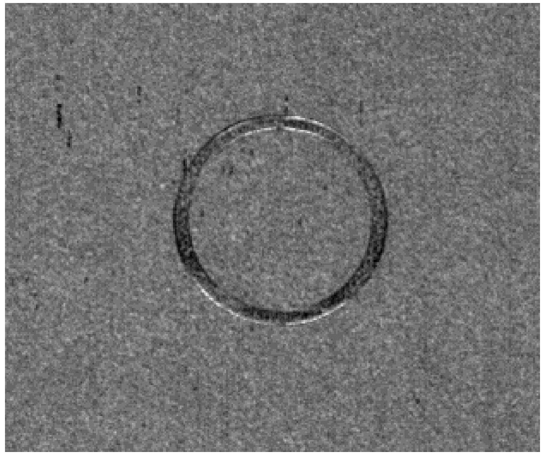
- Clean machine design.
  - The machine is temperature and humidity controlled
- Substrate temperature control
  - The chucks in the machine are all controlled ± 0.5 ºC
- High resolution encoders, 3D motion control
  - The motion control of the stage uses eight high precision encoders to ensure accurate positioning
- Beam and scanner
  - The print beam and scanner are made from state of the art carbon fiber with thermal elongation < 1 µm/ºC/m
- Scanner calibrated in the machine
  - To ensure accuracy the scanner is calibrated in the machine with a high precision ruler positioned on the printing chuck

Registration – Top to bottom

- Fiducials measured by the scanner



Quad hole drilled
panels

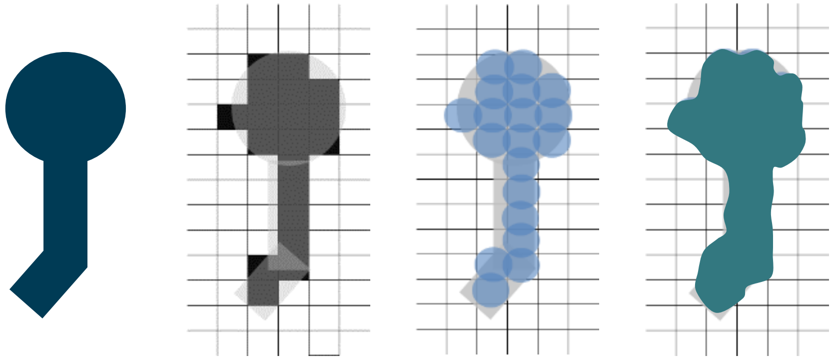


Internal fiducial
for inner layers

Patented Inkjet Technology

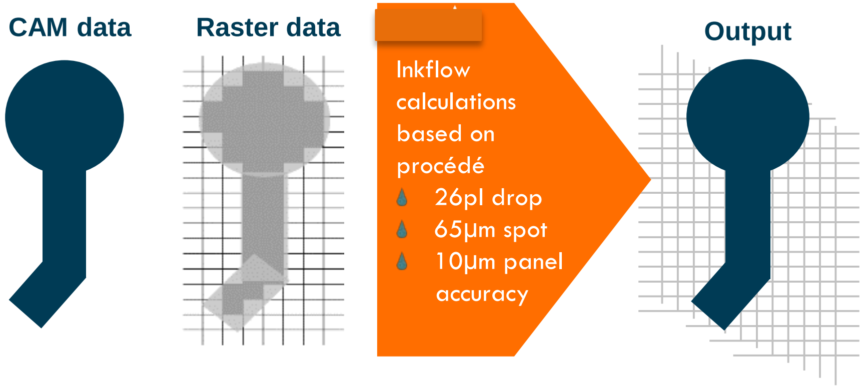
Without a Print Strategy…….

CAM data **Raster data** **Nozzle output** **Etch Resist** *Uncontrolled flow*

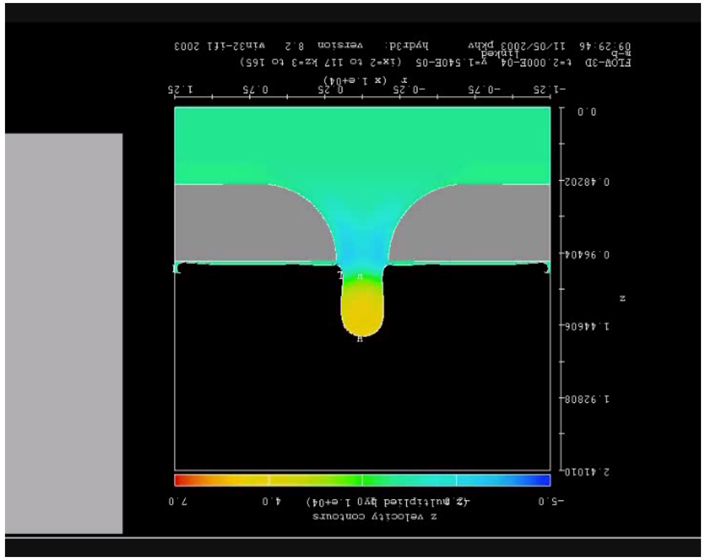


With Advanced Print Strategy …….

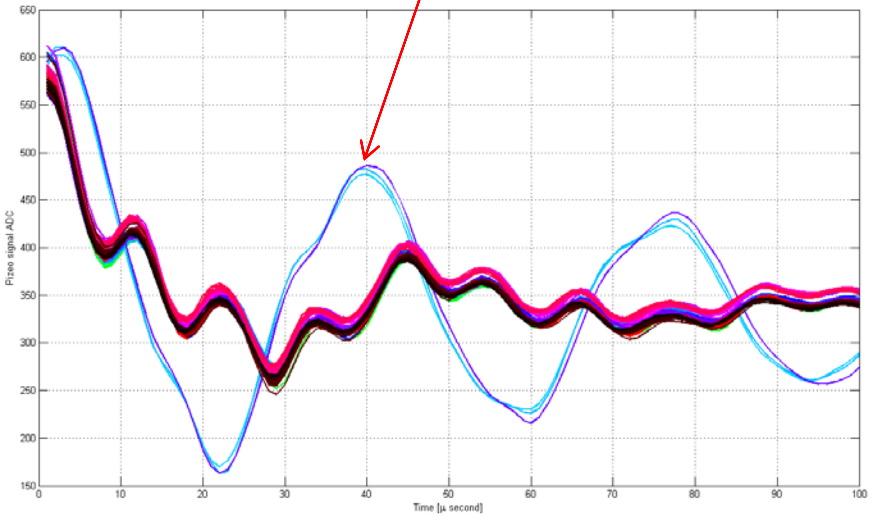
CAM data **Raster data** **Output**



All drops count

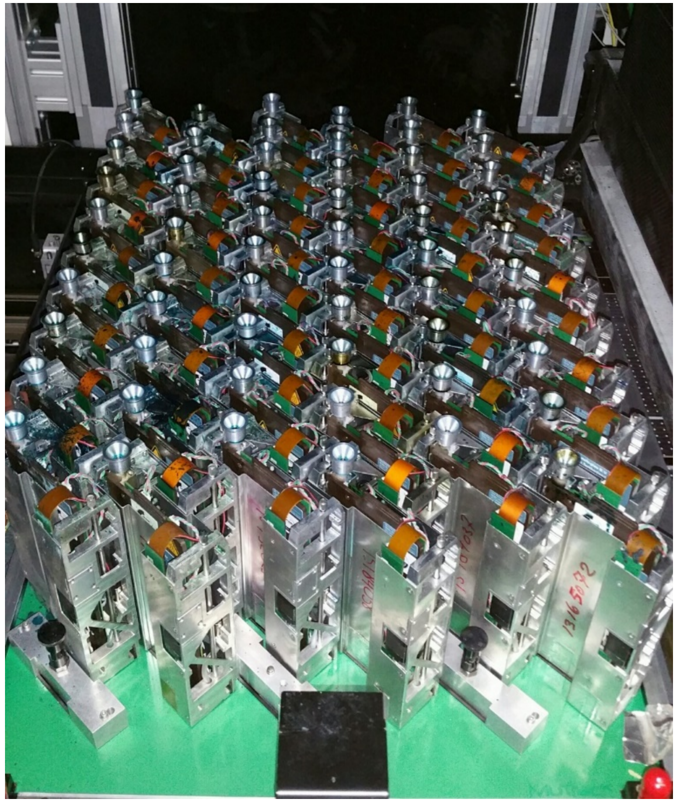


Typical defect



- Between 25 million – 50 million droplets of resist are fired per second
- Even with the best, most reliable heads in the world failure rate of 1 in 1 Billion droplets
- Even with this quality, <u>every 20 – 40 seconds</u> there is a potential problem
- With prediction software can look 10.000 drops forward

Redundancy



20 heads printing

40 heads predicting

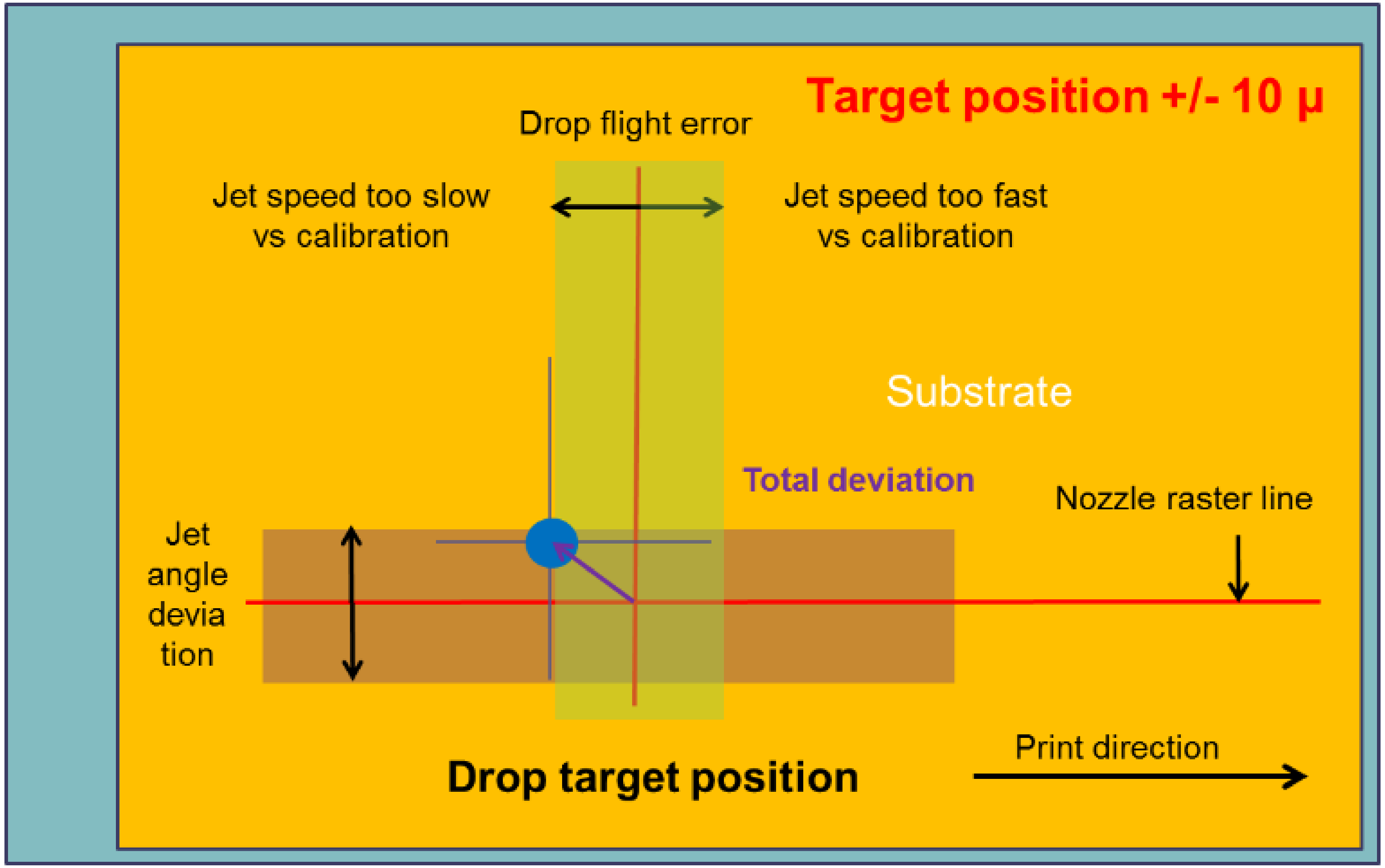
3 heads

positioned

same raster line

60 heads, 15360 nozzles in a “virtual beam”

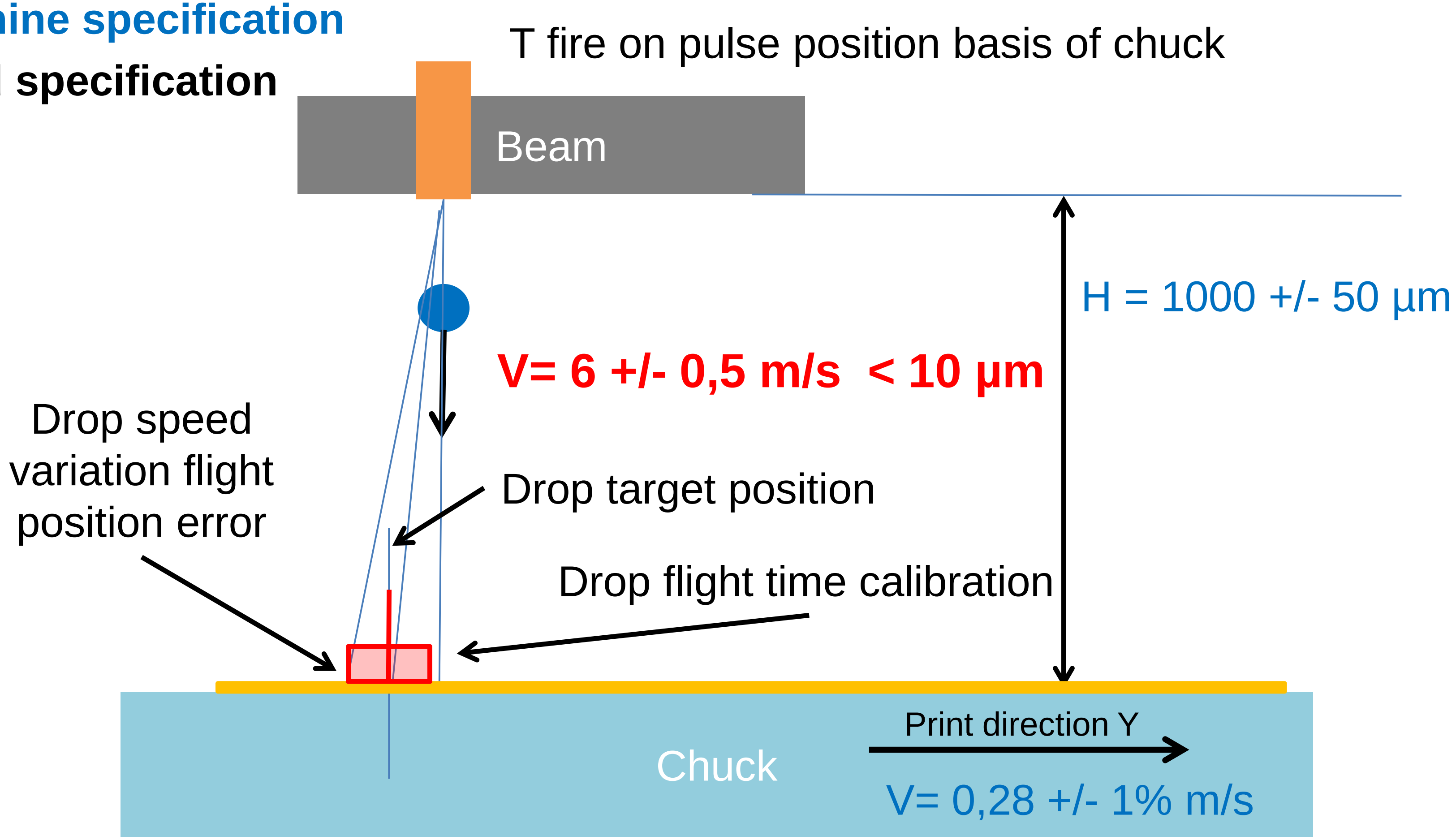
Drop target position



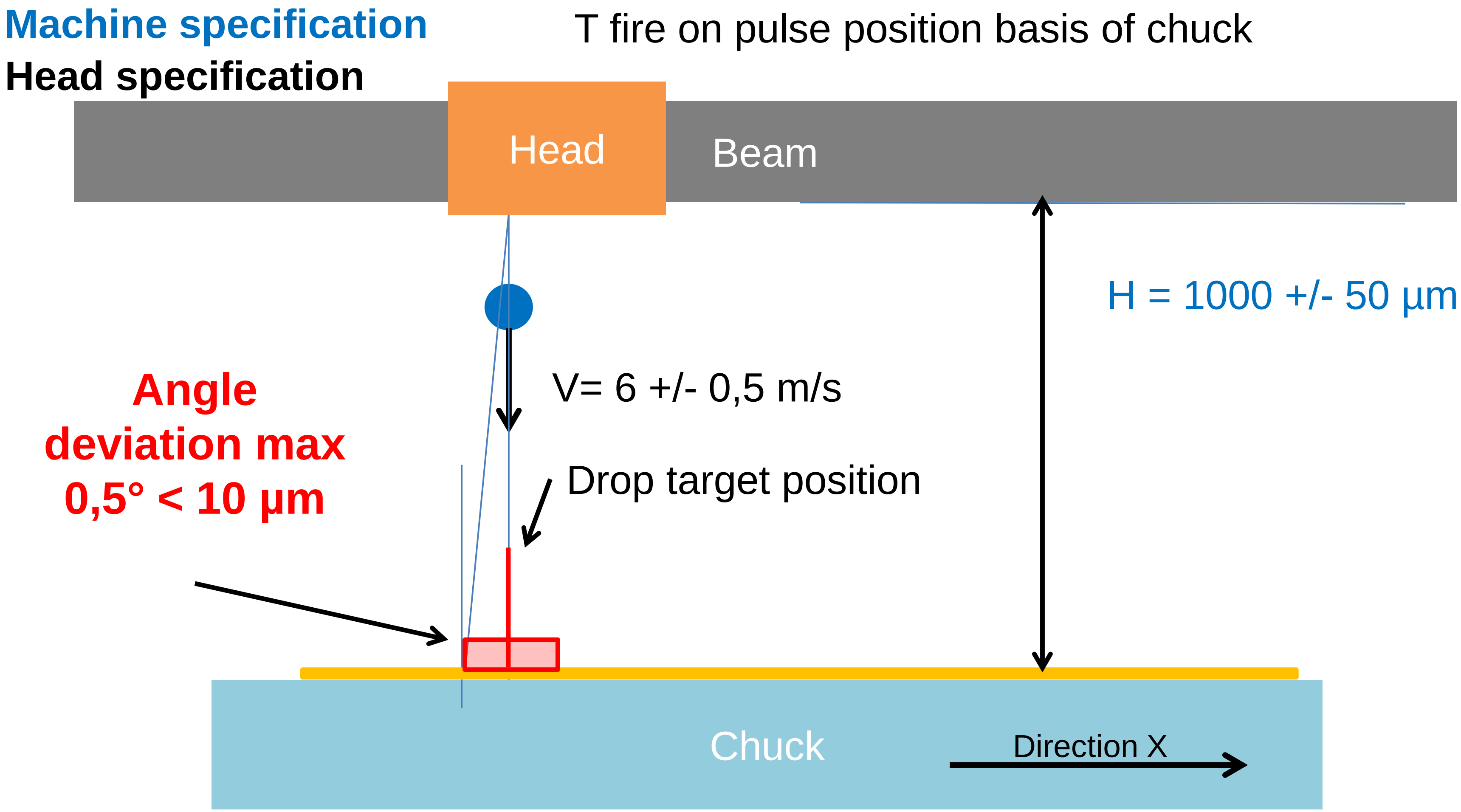
Drop position in X direction

Machine specification

Head specification

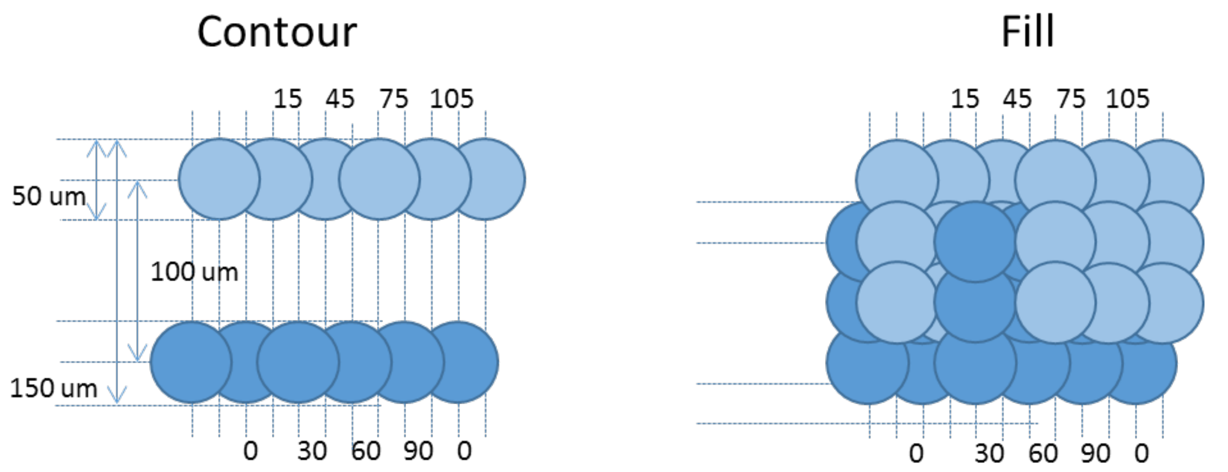


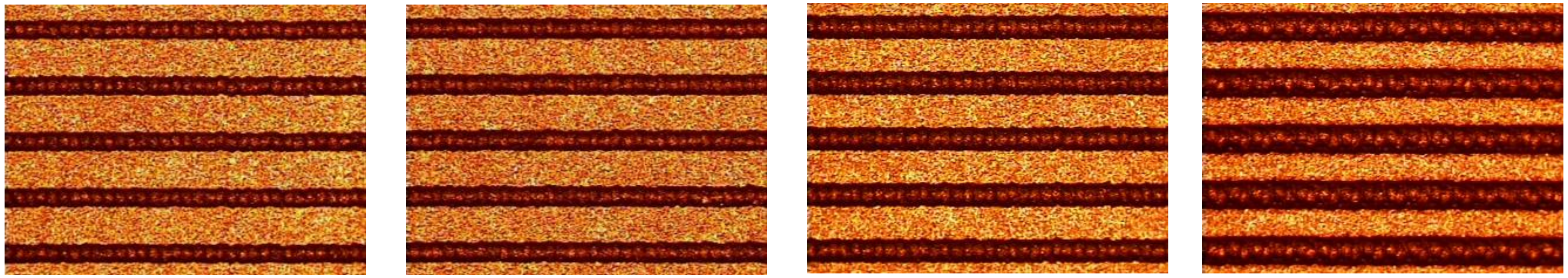
Drop position in Y direction



X - lines

X lines are built from dots put down in separate swaths.

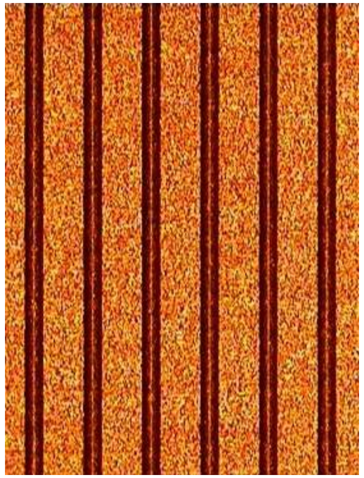




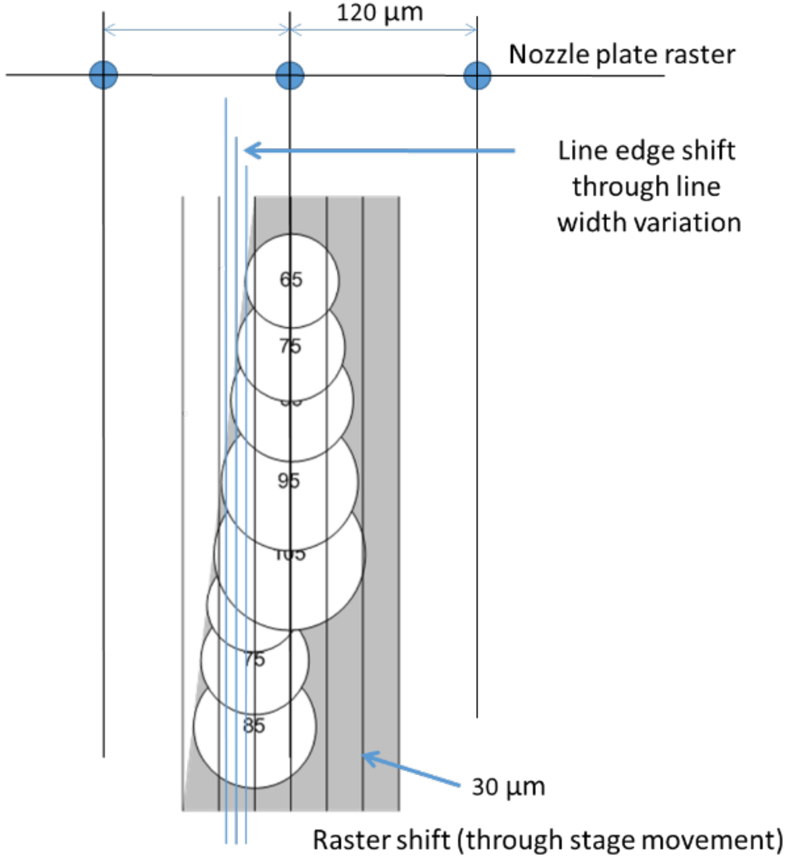
90 µm   100 µm   125 µm   150 µm

Y - lines

Y lines are built from dots put down sequentially in high frequency

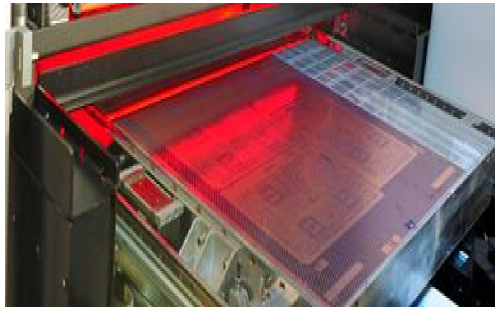


Positioning accuracy achieved with different line widths



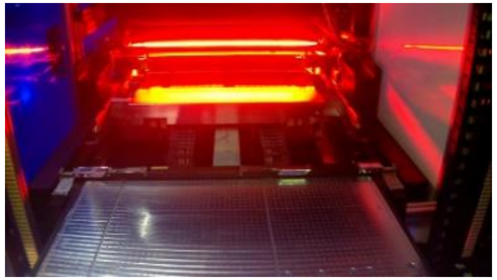
100% Image Quality Inspection

Inline-product AOI: IQI

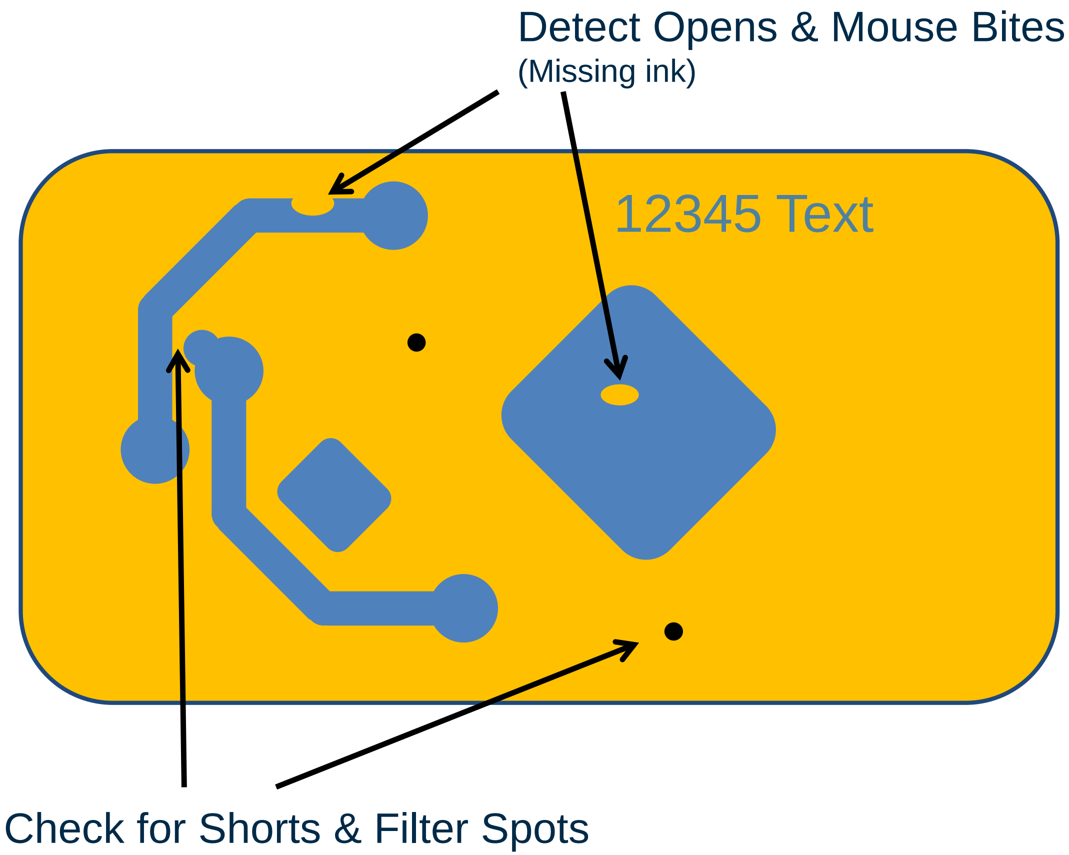


Used for

- Product Calibration
- Approval of every printed panel (prior to etching)



Check against CAM Info
Check at process speed for errors



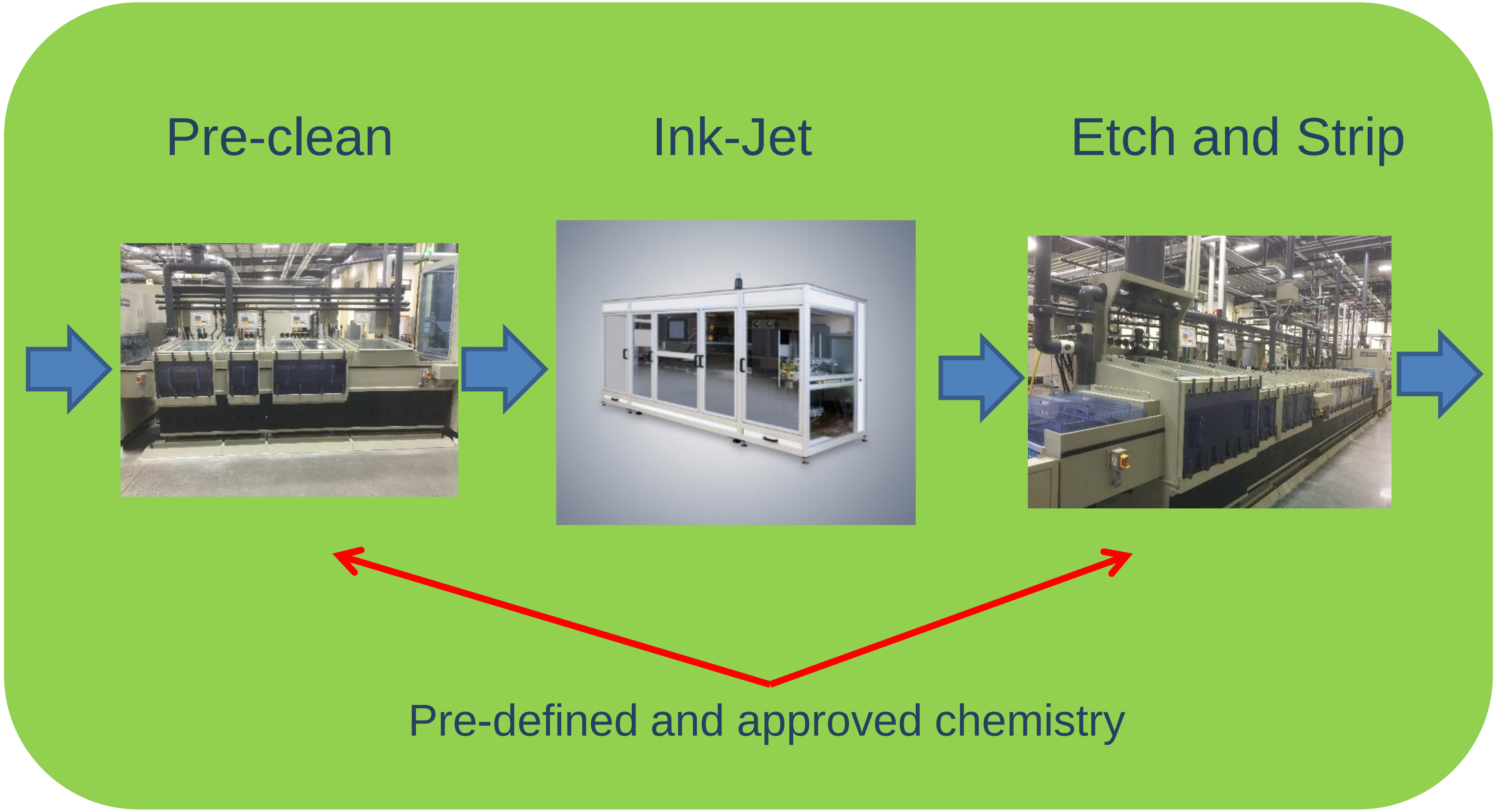
What You See is What You Etch

	Beta Site pre etch*	Beta Site post etch*
Resist line width (track)	125 µm	100 µm
Line width variation	3σ +/- 10 µm	3σ +/- 15 µm*
Space (gap)	75 µm	100 µm
Front-to-Back Alignment	+/- 25 µm	
Same-Side Alignment	+/- 15 µm	
Full IQI (AOI)	Yes	
Throughput cores/hour **	50	
Throughput sides/hour **	100	
Panel thickness	0,1 – 2,5 mm	

** Typical 2 ounce copper example from Beta Site. Lower cu weights will have better tolerances*

*** Panel size 610 x 533 mm*

Less Environmental Impact



Hot Melt Resist enables GREEN PROCESS LINE
Without ENVIRONMENTAL impact

TRADITIONAL PROCESS EXAMPLE WASTE OVERVIEW

Process Step	Liters/day of waste	Annual Cost of Chemicals & Waste Treat
Pre-clean	120	$14,300
Pre-clean Rinse	3,600	$4,100
Develop	310	$12,100
Developer Rinse	3,600	$3,500
Etcher	1,440	$182,400
Etcher Rinse	3,600	$4,900
Stripper	240	$17,700
Stripper Rinse	3,600	$4,050
TOTAL	**16,510**	**$243,050**

1.0 m/min line speed @ 35 micron Cu per side and 18x24 panel dims

JET-RESIST GREEN LINE COUNTERMEASURES FOR TRADITIONAL PRINT & ETCH WASTE

Process Step	Liters/day of waste	How
Pre-clean	0	Special formulation with 100% regen cell
Pre-clean Rinse	0	Custom membrane system
Develop	0	No developer with inkjet…
Developer Rinse	0	No developer with inkjet…
Etcher	0	Custom recycling system developed that does not dissolve/leach jet-resist
Etcher Rinse	0	Integrated with custom recycling system
Stripper	0	Custom distillation system using non-regulated solvent
Stripper Rinse	0	Integrated with custom distillation system
TOTAL	**0**	

GREEN LINE OVERVIEW

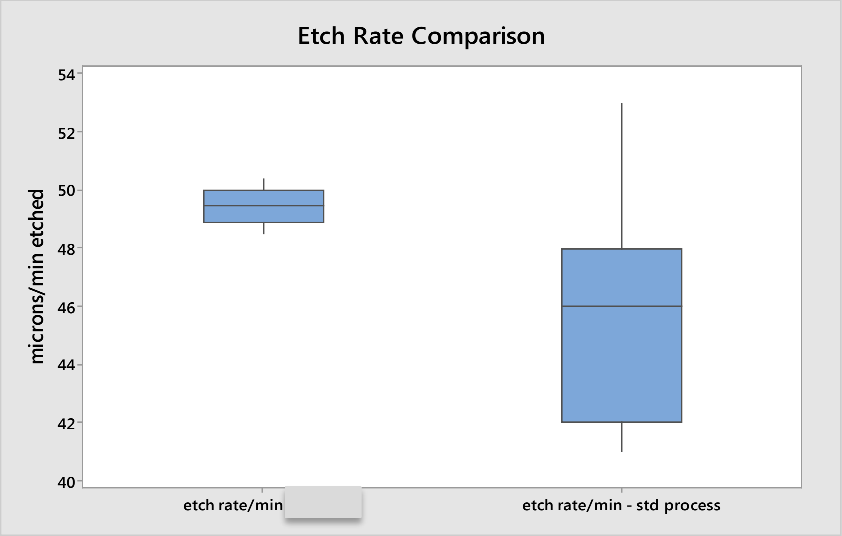
- Additional green process line capex, ROI through one year consumable savings
  - Zero chemical waste and zero chemical usage
  - Reclaim of copper results in very large annual savings
- Additional facilities savings:
  - No clean rooms
  - No wastewater transfer systems
  - Permit minimization/avoidance
- Green line Jet-Resist technology fit for both Brownfield and Greenfield
- Unique strategy to eliminate regulatory permits through Jet-Resist green line
  - Zero liquid discharge
  - Zero toxic emissions for the entire PCB factory.

CATEGORY	SAVINGS
Annual Savings from Elimination of Chemicals and Waste Treatment	$243,050
Annual Savings from Reclaim of Copper for Resale	$371,000
ANNUAL TOTAL	$614,050

1.0 m/min line speed @ 35 micron Cu per side and 18x24 panel dims

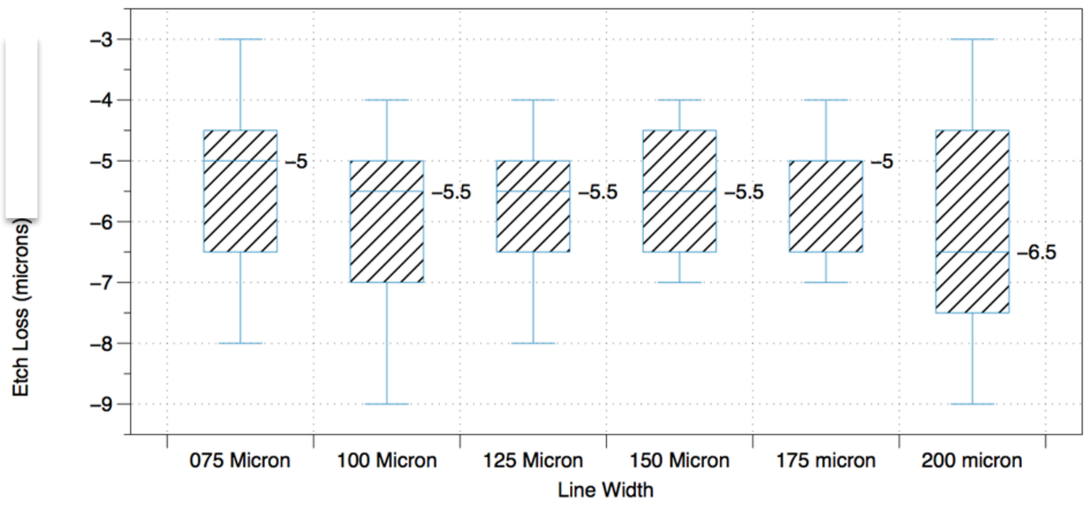
Closed Loop Etching with Ammonium Sulfate

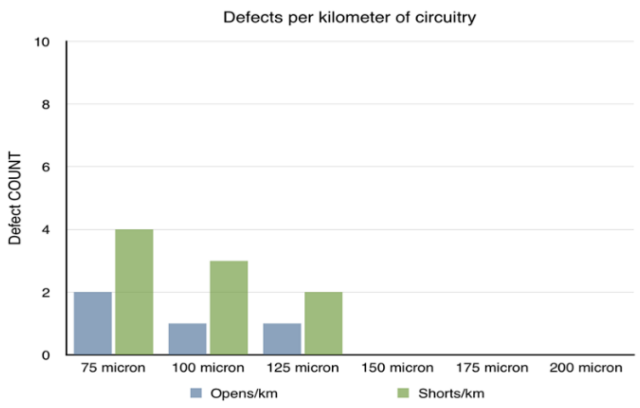
- Oxidative regeneration:
  - Sealed chamber off-line
  - No venting requirements
  - Fume scrubber is not required!
- System regenerates the etchant via oxidation using oxygen gas generated as a by-product of the electrolysis of excess cu metal from solution.
- Etch rate variation of recycled sulfate-based alkaline etchant is only 10% of traditional alkaline etchant systems:
  - Tight control of KPI achieved by a closed loop with an off-line regen reactor
  - No line recipe changes over 6 months!
- Etch rate variation is equal to or better than most acid etch installations.
- Bath has unlimited life: no resist leaching from hot melt jet-resist.
- System recycles all water and chemistry. Only by-product is >99.9% pure cu metal.

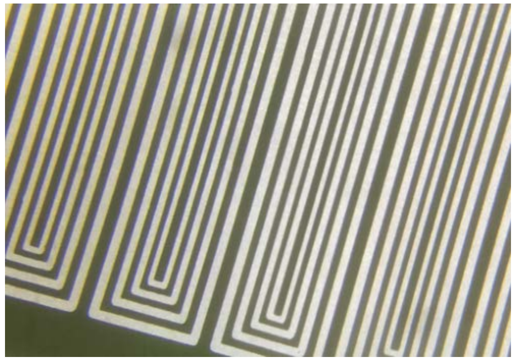


Post etch results

- Good results versus dry film
  - Good adhesion Jet resist to copper
  - Benefit of sloped etch resist edge profile
  - Beta Site was able to eliminate off-line AOI and ET due to the high yields achieved, thus enabling a fully in-line continuous factory.

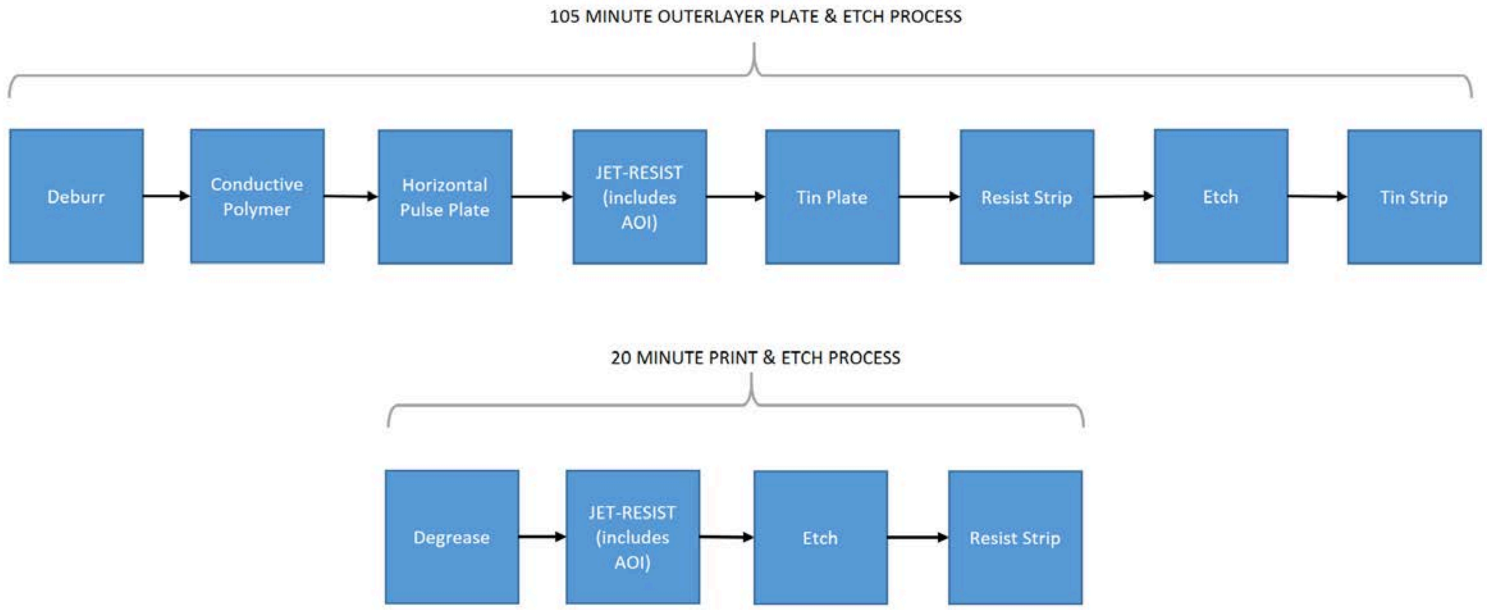






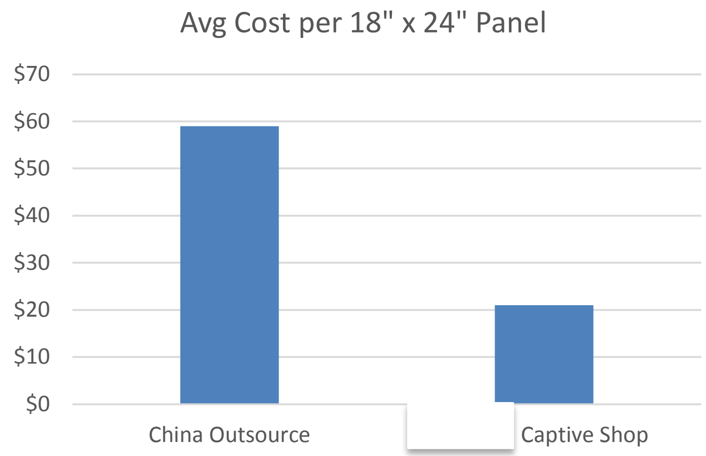
Labor Efficiency

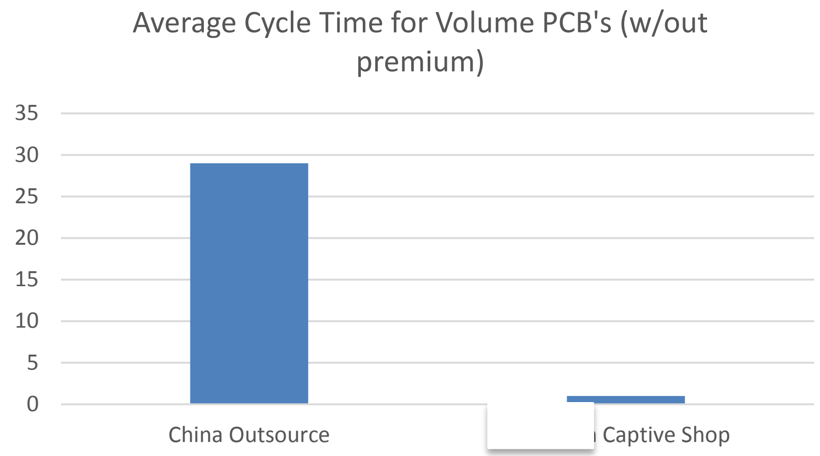
- Jet-Resist with Integrated AOI is a fully automated, integrated solution
- Producing 3,000 18x24 outer layer panels per week @ 50 panels/hour
- Line managed by only one direct labor employee per shift x 2 shifts/week
- Factor of 10 below established staffing norms!



Overall Savings of Jet-Resist Enabled PCB FAB Factory

- Fully digital, green, automated PCB factory
- 3-4 year ROI versus China Outsource at Company
- Factory install completed in 2015, and fully ramped up to 100% production in Q1-2016.





Questions

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