Volume Repeatability for Non-Contact Jet Printing of Solder Paste

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Abstract
Solder paste is one of the most common materials used in surface mount technology (SMT) processes. Typical methods for applying solder paste to devices are needle dispensing or screen printing, each one has specific benefits and drawbacks. The process of jet printing of solder pastes and other functional materials enable higher throughput than needle dispensing while eliminating the material waste generated by screen printing. Volumetric repeatability of the jetted solder paste is a critical property that must be ensured for any deposition technology to be considered as mature for real SMT production. According to the 2016 iNEMI roadmap placement accuracy for these kinds of components will reach 6 sigma placement accuracy in X and Y of 30 um by 2023 [1]. This level of placement accuracy for components must be accompanied by a related accuracy for the deposit of solder paste and related fluids in order to fulfill the related increasing demands on interconnect reliability in increasingly demanding environments with respect to temperature extremes, mechanical stresses and/or production limitations. Data will be presented demonstrating equipment accuracy for jet printing solder paste, jetted process capability for a given output and jet printing process capability for varying outputs within a single board. Throughput comparisons will be presented to understand how jet printing fares against both needle dispensing and screen printing.

Keywords: solder paste, jet printing, piezo, non-contact, ejector, printing

Introduction

Jet printing solder paste is a technique whose mechanics differ greatly from traditional solder paste deposition methods, such as screen printing and capillary dispensing. Each technology has its place in the production line and understanding the mechanics of their operation will enable better paste selection and maximize productivity. The three major deposition methods we will review are solder paste screen printing, solder paste needle dispensing and solder paste jet printing.

Screen printing

Screen printing is the most commonly used method for the deposition of solder paste onto substrates in a majority of surface mounting manufacturing environments. The technology allows for the rapid transfer of printed solder paste patterns onto flat surfaces with high yields. The principal of operation is fundamentally very simple, but process control introduces a level of complexity. A stencil or screen is made with laser or chemically etched orifices that align to the pattern to be deposited onto the substrate. After the board and stencil are aligned and placed in contact with each other, a squeegee moves solder paste across the stencil. The paste enters the stencil orifices and fills them with material that is transferred from the stencil orifice to the boards when the stencil is removed from the substrate thereafter.

Screen printing allows for many printed features to be produced in a single pass. The stencil thickness will limit the feature size and material volume that can be applied by this method. Although stepped stencils exist allowing both large and small dot depositions with a single stencil, there are design rules that limit its capability. Per IPC 7525 stencil guidelines for every 25 µm of height (step down) you must allow a distance (slope) of 900 µm. For a 100 µm step you need to allow 3.6 mm slope. Due to this limitation, cavity printing is difficult for highly populated boards. Another factor that must be taken into consideration is changeovers and total cost of ownership as stencils require cleaning, storing and replacement over time. In situations where board changes are frequent, these costs can become considerable.

Solder Paste Needle Dispensing

Solder paste needle dispensing has been used for decades and is, at its core, the extrusion of solder paste in a controlled manner over a unit of time. The simplest form of solder paste dispensing utilises a time-pressure valve, where the air pressure at the top of the syringe is controlled and with it the average volume flux of material out of the tube and the connected orifice. In this case, the air pressure and the nozzle orifice determine the amount of material that exits per unit of time. Balancing the air pressure to the nozzle diameter is key for accurate dispensing. If the pressure level is too high, the system may not have time to equalize at the same rate as the future changes in the control pressure causing a back-pressure that will result in a flow of material out of the nozzle even after the air pressure is removed from the syringe.

Another more widely used method of solder paste dispensing uses an auger valve, also known as an Archimedes screw. The auger valve offers both precise and rapid material deposition, depending on its specific design, compared to time-pressure valves. The dispensing of solder paste is very flexible and enables the deposition of material into cavities and on top of mounted components, as well as producing small and large dots, with a single setup. Lines and irregular dispense paths are also possible. The main drawback of this technology is the relatively slow speed at which solder paste can be dispensed when compared to screen printing and jet dispensing. The auger valve is used in conjunction with screen printing for add-on and/or cavity dispense applications to maximize line flexibility.

Jet Printing Solder Paste
Jet printing in general is the non-contact deposition of a functional material through the transfer of momentum from a piston to the material, in this case solder paste. Jet printing on the fly is the capability of jet printing material while in motion. Jet printing on the fly enables the highest possible throughput. The most common form of jet printing requires the use of a valve which during the jet printing process is in direct contact with a seat to maximize the transfer of momentum. Due to the softness of the solder particles in the paste, this method introduces problems because it leads to flattening of the spheres (referred to as "coining") and eventually clogging the nozzle orifice.

To jet solder paste reliably the transfer of momentum must be made while minimizing opportunities to deform the metal alloy particles to eliminate the coining effect, thus resulting in continuous jet printing over time. A possible method of transferring momentum without contact is through very high accelerations. Coupling high accelerations with precise volumetric control enables the jet printing of a wide range of dot sizes with a single hardware setup, see Figure 1.

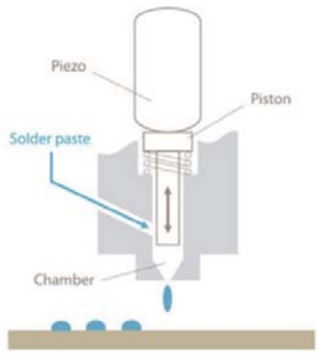
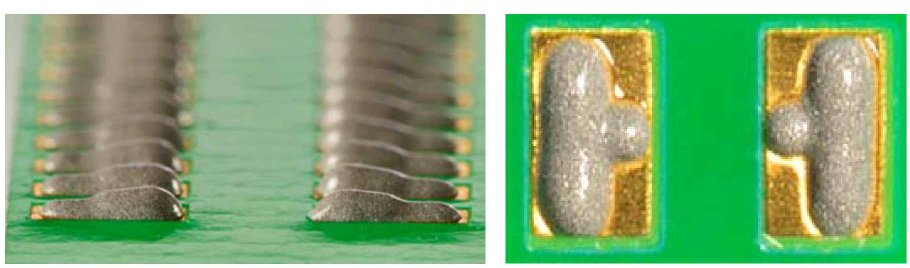


Figure 1 : A schematic of a solder paste jet with an auger that feeds solder paste to the jet printing chamber and a piston that transfers momentum to the solder paste.

By controlling the material fed into a jet printing chamber, you create a fixed volume that is the basis of the jet printing process. The volume that has been transferred into the chamber is forced through the nozzle in a single shot by the volumetric displacement provided by the piezo unit. The chamber is then refilled before the next ejection. Using this principle you can create variable volume of material depositions without changing the frequency of the jet because the solder paste volume is precisely controlled through the feed of material into the chamber [Svensson et al. 2016][2]. There are physical limitations of the mechanics which define the functional range of this apparatus, but these are well defined and enable a wide range of outputs with a single setup at a constant speed of up to 300Hz, i.e. in excess of 1,000,000 deposits per hour.

Jet printing solder paste not only allows for single dot variation, but also enables multiple pass possibilities to customize solder paste deposits. Customization can be done with respect to volume, paste height, shape, position and pad coverage which can be seen in Figure 2.



a) b)

Figure 2 : Examples of the control of a) paste height (2.5 D printing) and b) pad coverage and volume.

The jet printing of solder paste enables solder paste deposition on flexible substrates that stretch, print within cavities and on top of components within the same program, as well as add-on solder paste post screen-printing at very fast speeds with little material waste.

Current jet printing technologies offer depositions with diameters down to 250 µm ($V_{250\mu m} \approx 2$ nl). Smaller deposits that would enable 0.35 mm and 0.3 mm pitch are requested by the industry, see Figure 3.

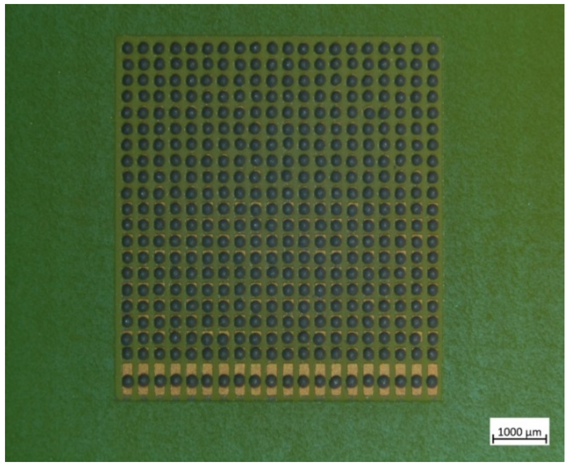


Figure 3 : Example of testing of fine pitch capability of jet printing with a 0.3 mm pitch BGA.

Production Jet printing

To understand the process capability of jet printing in a production setting, a study was initiated with a SMT production company. A summary of the production methodology and results will be presented below.

Methodology

The test series encompassed approximately 400 printed circuit board (PCB) panels, distributed over two different PCB layouts. All boards were produced using one of two production jet printers with two production ejectors for the actual deposition of solder paste. The production jet solder paste used was a commercial SAC305 type 5 variant. A total of 45 cm^3 of solder paste was consumed during the test. After each case of jet printing of any PCB, each panel was scanned by a production inspection machine (3D AOI) in order to obtain images of the jetted paste deposits to detect deposit quality on each pad pattern.

The PCB was then mounted with a production pick-and-place system. Thereafter, the PCB was transferred to a production vapour phase vacuum reflow oven for reflow. The flow chart of the service stations is presented below, see Figure 4.

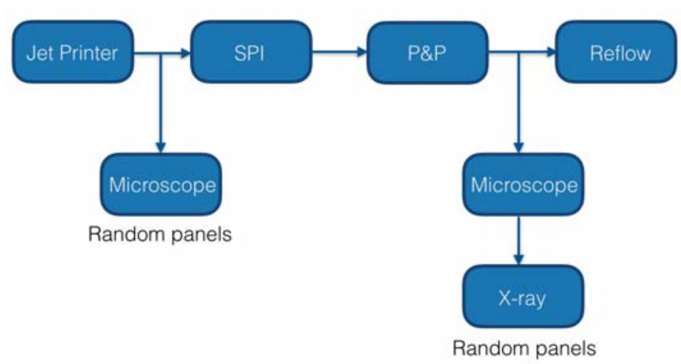


Figure 4 : Beta test flow chart diagram.

While two layouts were produced, Layout D and Layout A, only the results from PCB Layout D will be presented in this paper. The layout used for testing, namely PCB Layout D, see Figure 5, contained several components of 0603, 0805, 1206, 1210, Aluminum Electrolytic Capacitors, SOT23, SO14, SO16, SO20, Transistor Output Optocoupler (PC357T), R-MELF, DIP4, DIP12, D-pak.

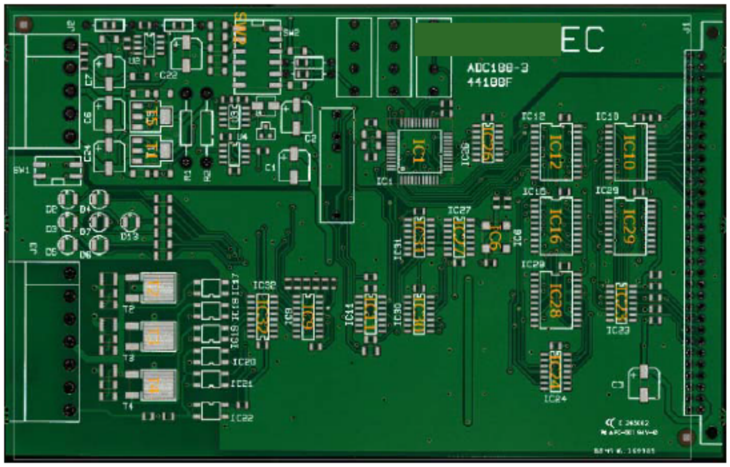


Figure 5 : Layout D with the smallest pitch of 0.8mm.

After input of the CAD data and compilation of the jet printing path using the jet printing compilation software, a jet printing plan is obtained. An example of a jet printing path for the PCB used has been visualized using production software and is shown in Figure 6. The blue circles represent deposits, while the purple lines represent the path followed by the head. The choice of deposit volumes to populate a given pad is provided by the job compiler to minimize jet printing time for the entire PCB. For example, according to Figure 10, the pad coverage of the 0603 component contains 3 dots, while for 0805 components the pad is covered by 4 dots of size 585µm (33nL).

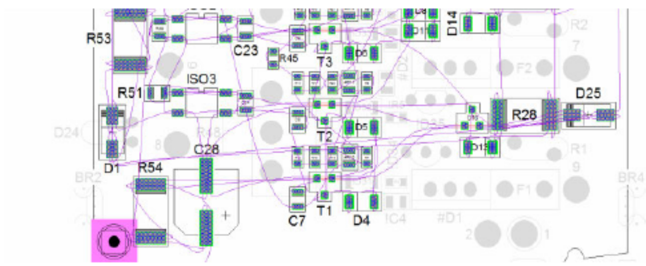


Figure 6 : A portion of the jet printing path for layout A.

It should be noted that each jet printing segment is a straight line. Each jet printing segment is reached via a travel segment that is limited by the mechanical machine specifications concerning available range of speed and acceleration.

Production Results

The overall jet printing results for the tested PCB were good and, in general, there were no discontinuities concerning deposit volume or positioning that introduced production disturbances. An example of the overall results can be observed in Figure 7 below.

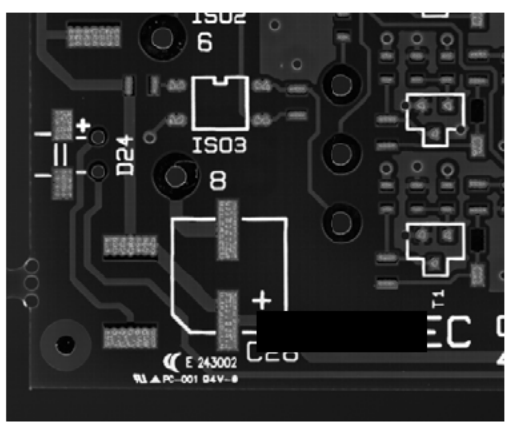
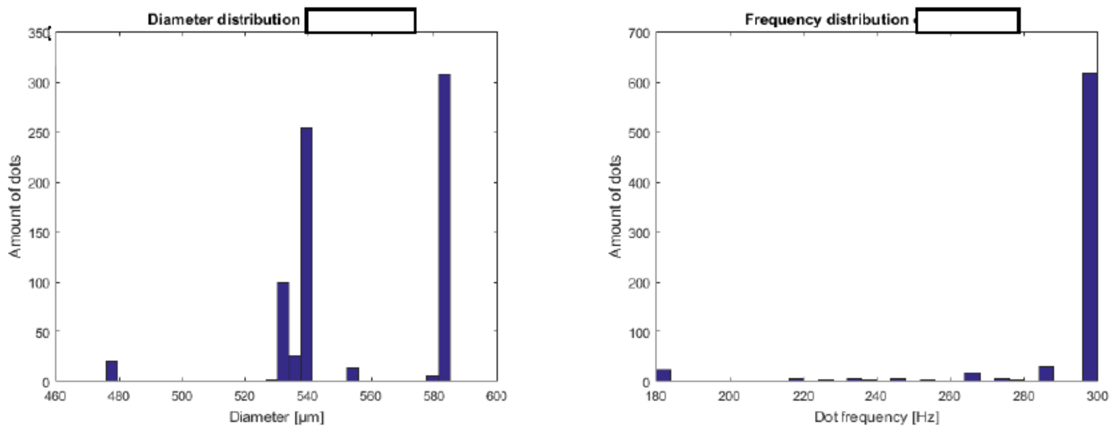


Figure 7 : Characteristic jet printing results on layout A.

The distributions of deposit sizes and frequencies for the layout D are provided in Figure 8. There are distinct peaks in the deposit size distribution that correlate with the characteristic lengths of the pad sizes on the PCB.



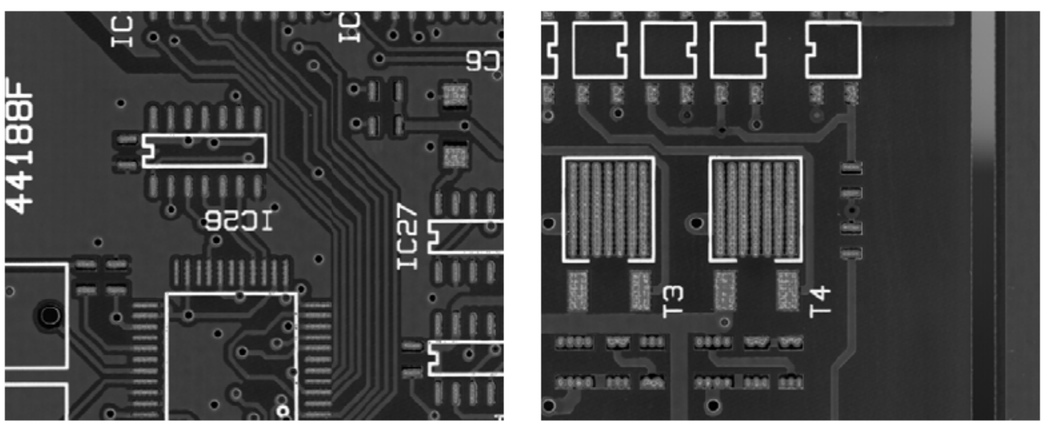
a) b)

Figure 8 : Histograms the number of deposits as a function of a) deposit size and b) jet printing frequency distribution for PCB Layout D.

In Figure 8 b), the distribution of jet printing frequencies for the given PCB is shown. The most common jet printing frequency is 300 Hz.

Jet printing results

The jet printing results of the production ejector with the production jetting solder paste were good in comparison to the volumetric and positioning guidelines that were provided. After a performance review, the SMT production company had no major comments with respect to improvements. The smallest pitch for the chosen PCB was 0.8 mm, which means that the ejector does not utilize the entire available volumetric span. An example of jet printing for the 0.8 mm pitch is provided in Figure 9 for the PQFP10X10-44 and the largest D-pak components.



a) b)

Figure 9 : Results after jet printing using for a) PQFP10X10-44 and b) the largest D-pak.

The first volumetric deposits to be studied are the Transistor Output Optocoupler and C1206 with volumes around 0.2 mm^3. The deposits for these components show stable volume distribution results even if the expected volume defined by the compiler were slightly higher than the actual volumes measured with the available SPI. The repeatability was approved according to the SMT production company requirements and is shown in Figure 10. It is clear from the plots that the repeatability of each individual deposit is very high. If combining repeatability of all the components, the volume distribution will be larger, but well within the specification.

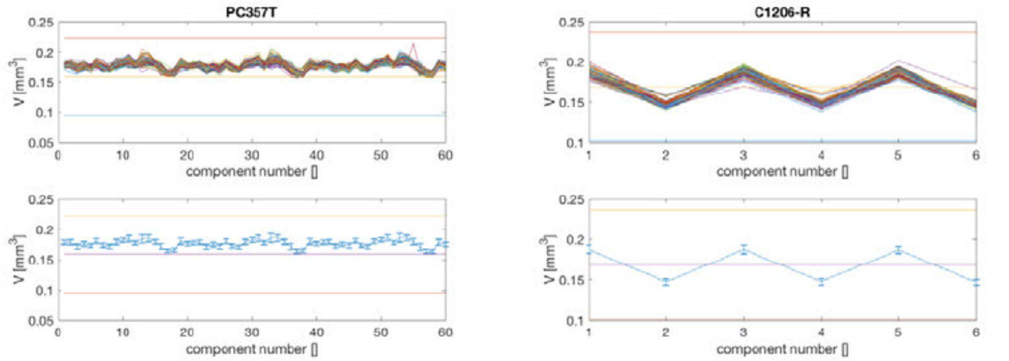


Figure 10 : Pad coverage of Transistor Output Optocoupler (PC357T) and C1206 components

For the larger pads of the C1206 components, an interesting oscillation in volume between individual components is observed. This variation can occur due to the compiler optimization which proposes different deposition strategies for different component instances. The strategies for the individual deposits that will produce the final total volume on the pad are produced by a 'travelling salesman'-like algorithm that attempts to find the optimal positioning of individual droplets with specific droplets on the pad to obtain the goal volume as specified by the operator. These strategies can also be modified by the operator to override the method obtained by the algorithm. Jet printing results for the C1206 pads for different jet printing strategies may be seen in Figure 11.

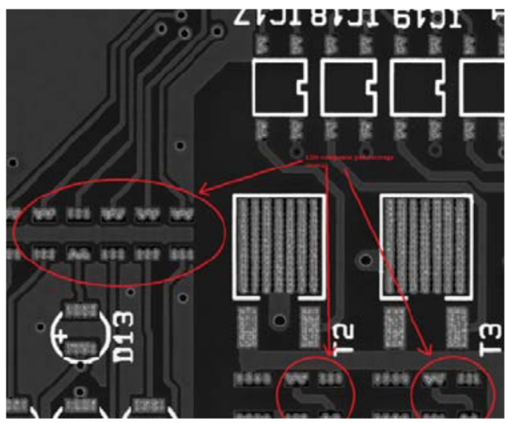


Figure 11 : Different jet printing strategies for C1206 component.

In Figure 12, volumetric deposit results are shown for SOD80-R and the Aluminum Electrolytic Capacitor component pads. All of these component pads show low volumetric deviation in delivered solder paste volume. The distribution of volumes is smaller for identical component positions between boards than between components on the same board, even though the distribution of volumes is still small in both cases.

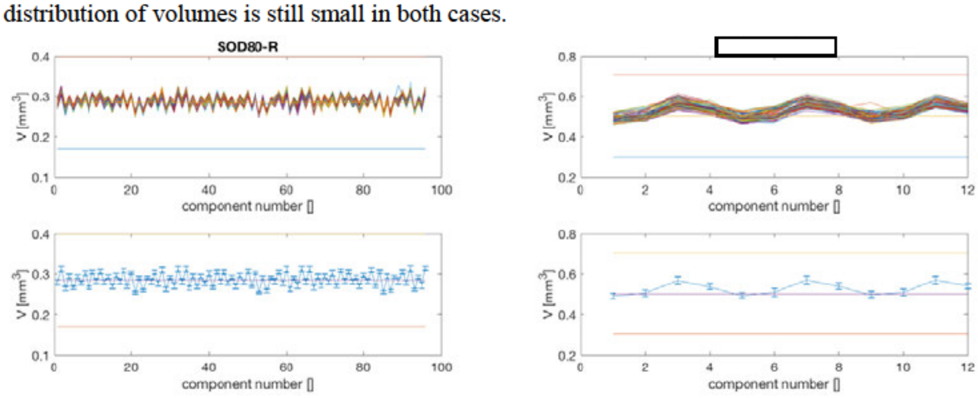


Figure 12 : Pad coverage of SOD80 (left) and Aluminum Electrolytic Capacitor components (Right).

Reflow

The results of the solder joints after reflow in the vapour phase oven are good and were approved according to the specification of the SMT production company. An x-ray inspection of D-pak components showed issues of voids, see

Figure 13. The issue of voiding for this specific component was present for previous production batches and is therefore not aggravated by the process of jet printing. Voiding was not an issue for the other utilized component types.

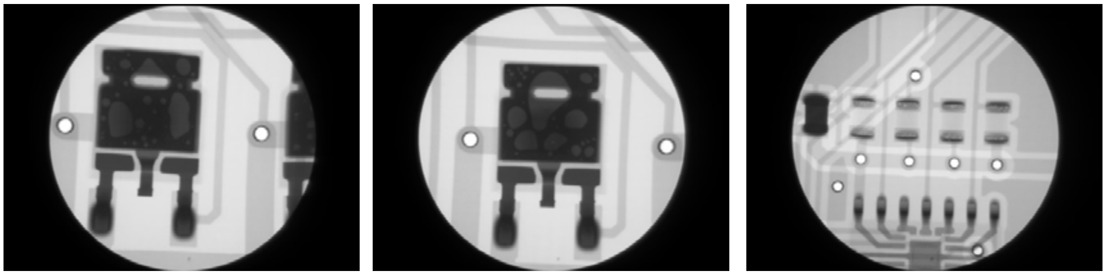


Figure 13 : X-ray images after reflow on D-pak and smaller components.

Conclusions

Due to the nature of the material, jet printing of solder paste requires a novel approach to be able to transfer momentum without coining the material and enable actual high volume production. To be able to increase the throughput the software and machine must run at maximum possible rates given the arrangement of the dots on the board. SMT production company results demonstrate the capability of jet printing different material volumes with a single hardware configuration accurately and with repeatability. Further development has yielded advancements in smaller dot sizes for this jet printing technology. It is clear based on these results that solder paste jet printing can now be considered a viable option when compared to legacy solder paste deposition methods, while at the same time increasing flexibility of a single production system.

Acknowledgements

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References

1. iNEMI Roadmap 2016 Advanced Manufacturing Technology, January 2016, iNEMI.
2. Svensson, M., Mark, A., Edelvik, F., Karawajczyk, A. and Mårtensson, G.E. 2016 “Simulation of Droplet Jet printing of a Non-Newtonian Mixed Suspension”, ICMF-2016 – 9th International Conference on Multiphase Flow, Firenze, Italy.

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Gustaf Mårtensson[1,2] Jeff Leal[1] and Nerijus Augustis[1]

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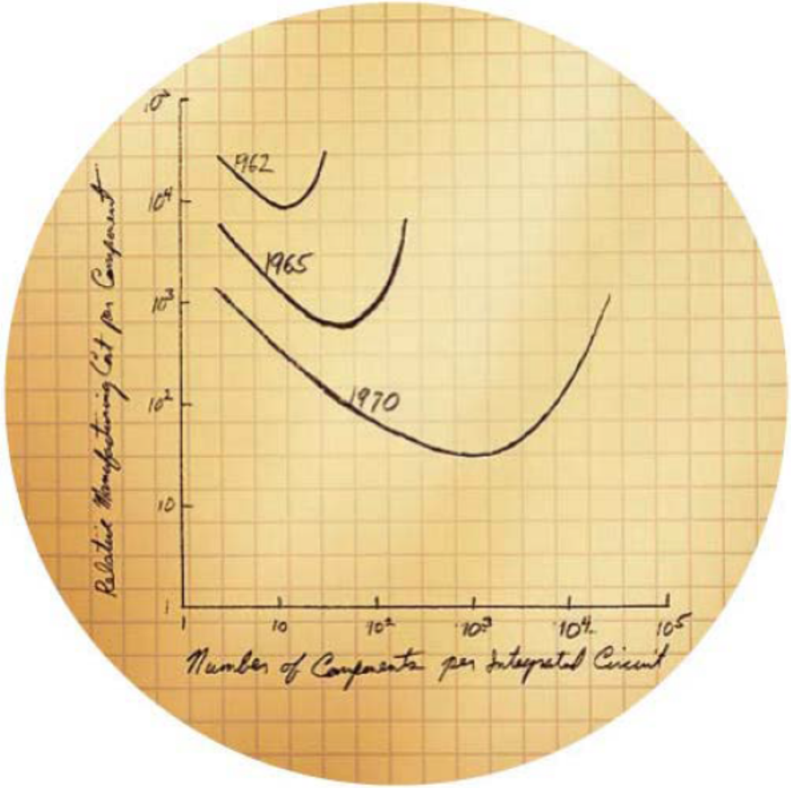
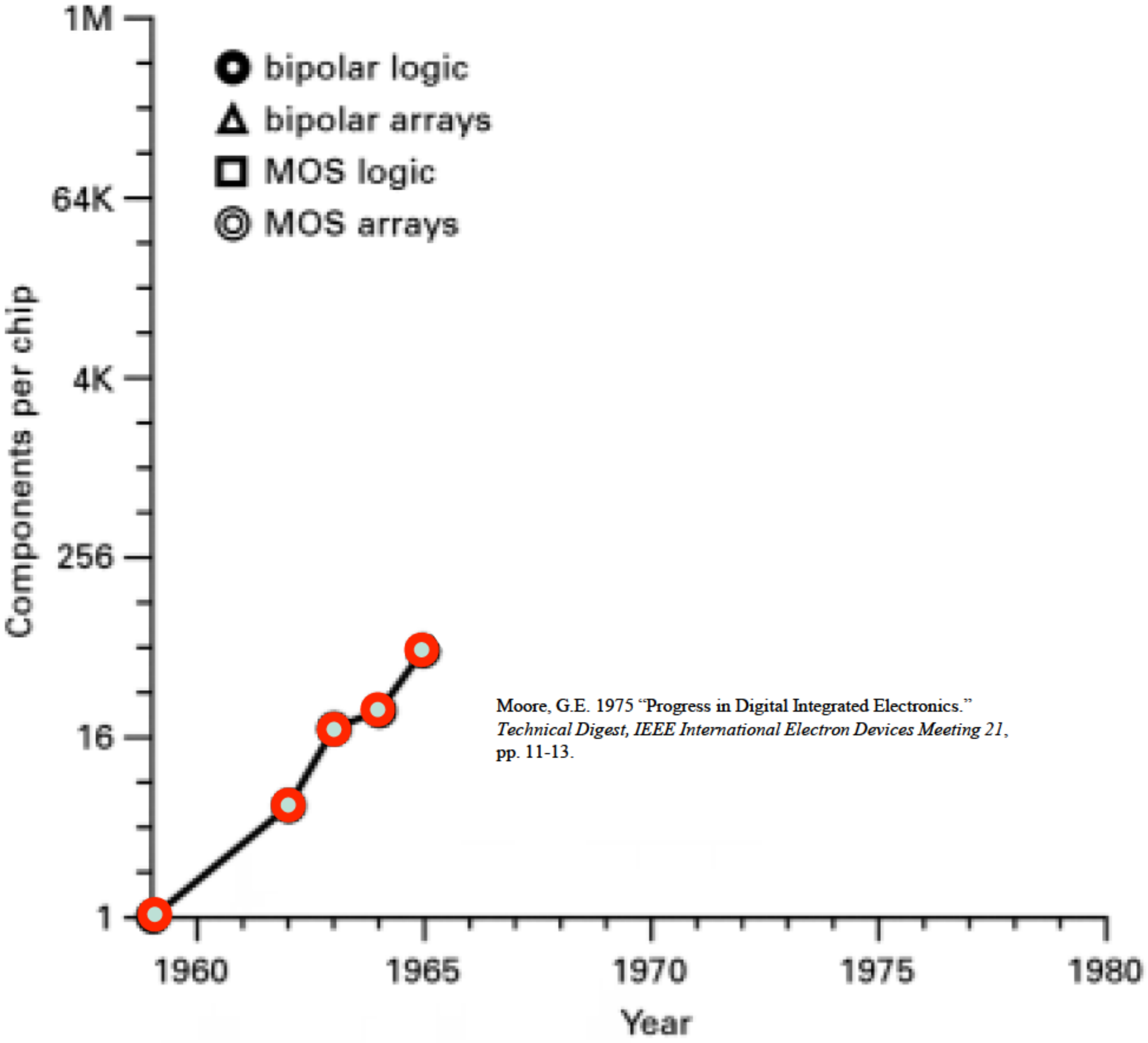
Technology

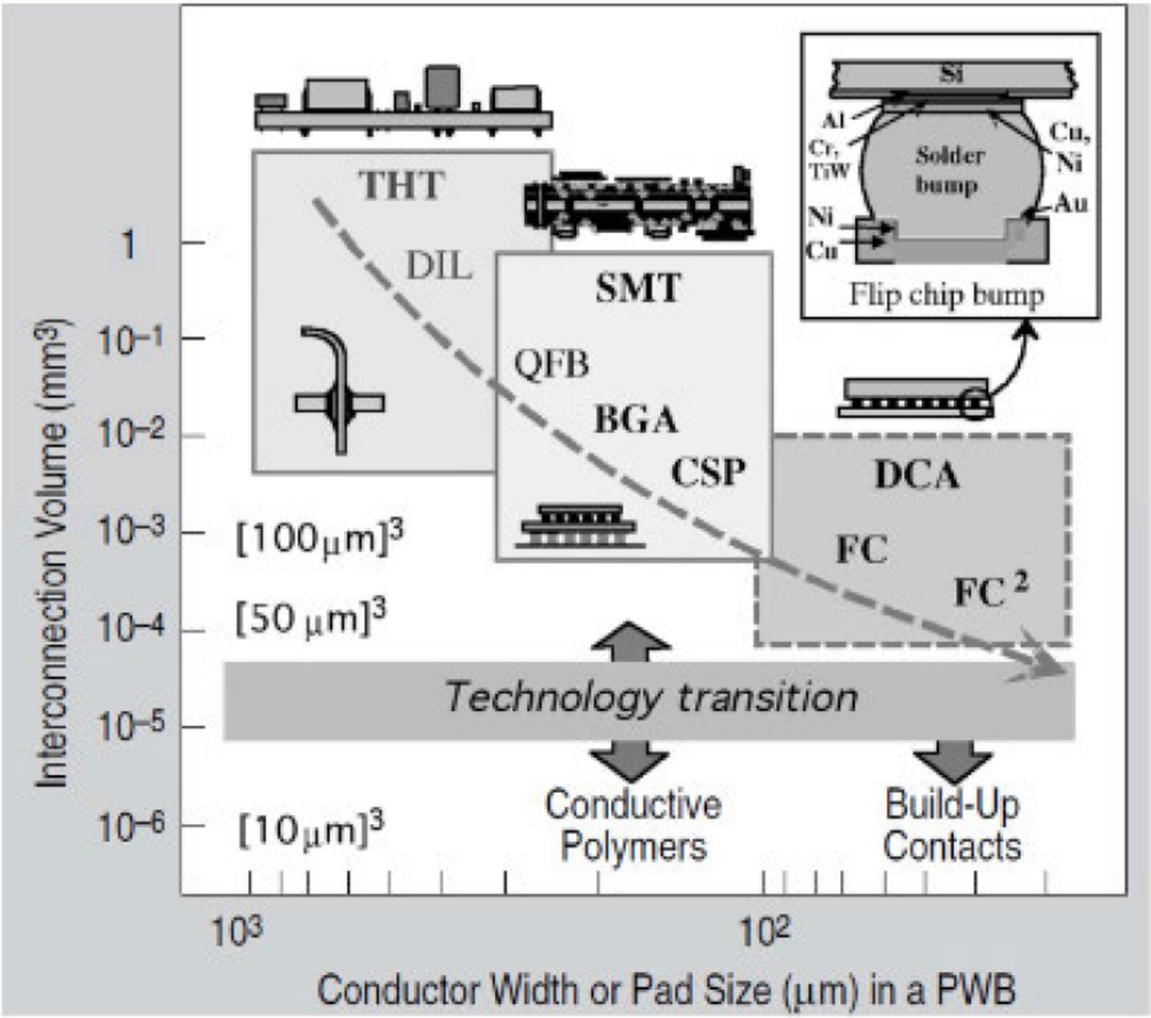

1962
1965
1970
10
1
10
10^2
10^3
10^4
10^5
Number of Components per Integrated Circuit
Relative Manufacturing Cost per Component

Moore



Moore, G.E. 1975 "Progress in Digital Integrated Electronics." *Technical Digest, IEEE International Electron Devices Meeting 21*, pp. 11-13.

Technology

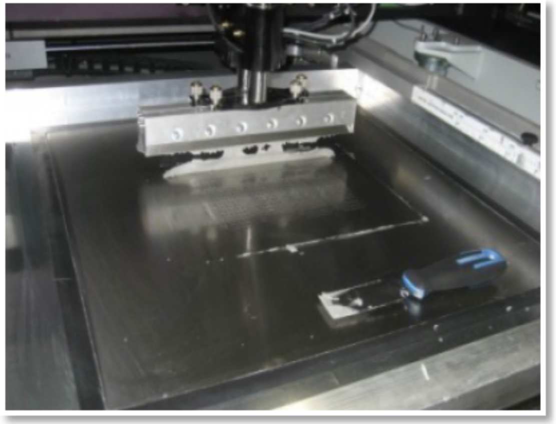

THT
DIL
SMT
QFB
BGA
CSP
Si
Al
Cr, TiW
Solder bump
Cu, Ni
Au
Ni
Cu
Flip chip bump
DCA
FC
FC 2
1
10−1
10−2
10−3
10−4
10−5
10−6
[100 µm]3
[50 µm]3
[10 µm]3
Interconnection Volume (mm3)
Technology transition
Conductive Polymers
Build-Up Contacts
103
102
Conductor Width or Pad Size (µm) in a PWB

Technology

Technology drivers

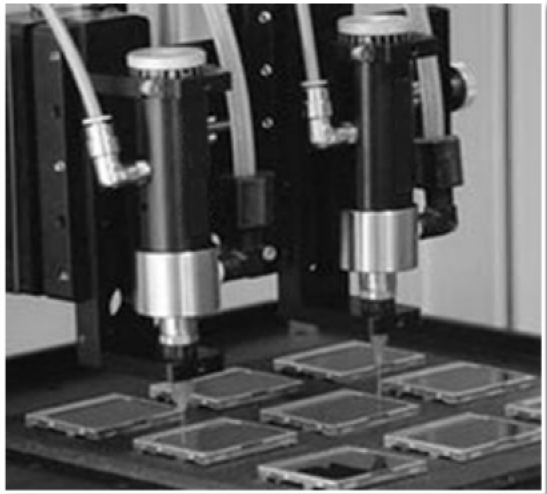
- miniaturization
- mixing large and small components
- higher density boards
- 3D electronics and boards
- new semiconductor packaging
- new LED technology
- hybrid packaging/devices
- flexible boards

Stencil printers



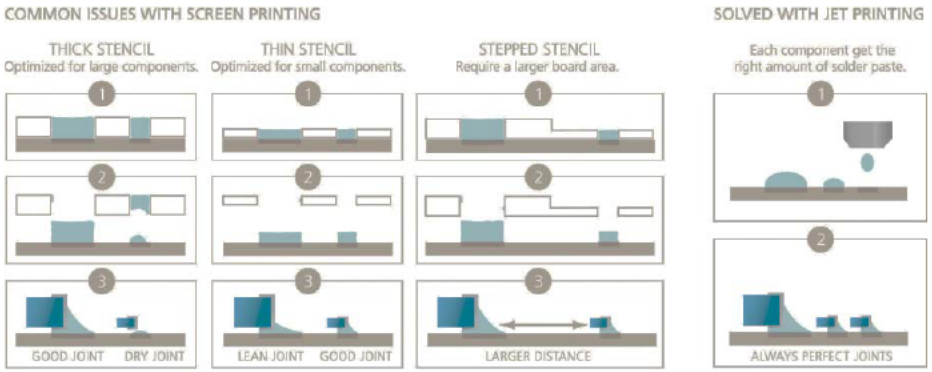
- can be difficult to do everything on the board

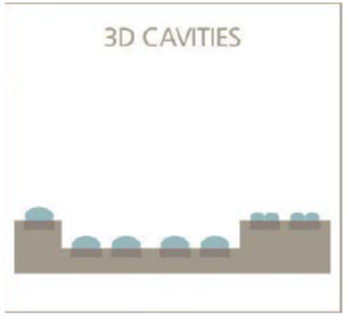
Dispensers

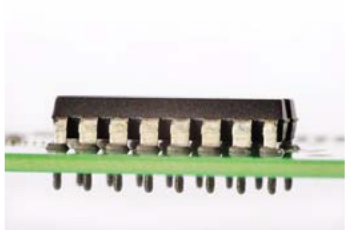


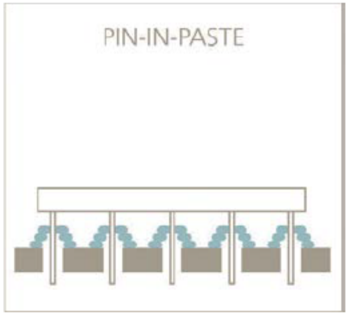
- very slow, not cost effective
- accuracy is challenging

Opportunities

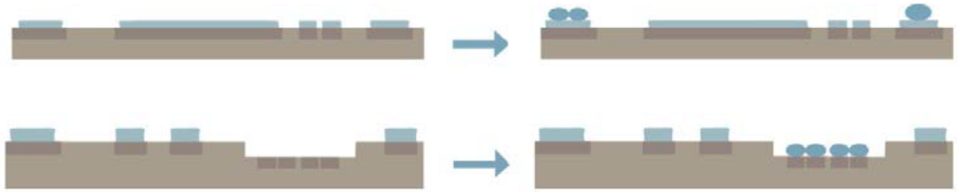


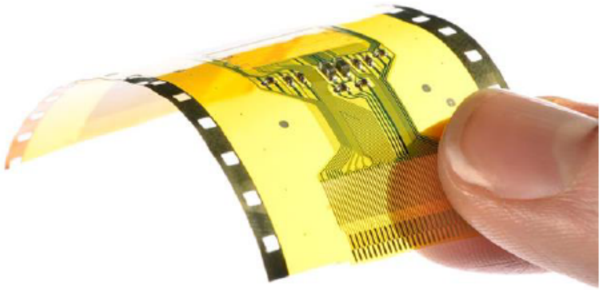






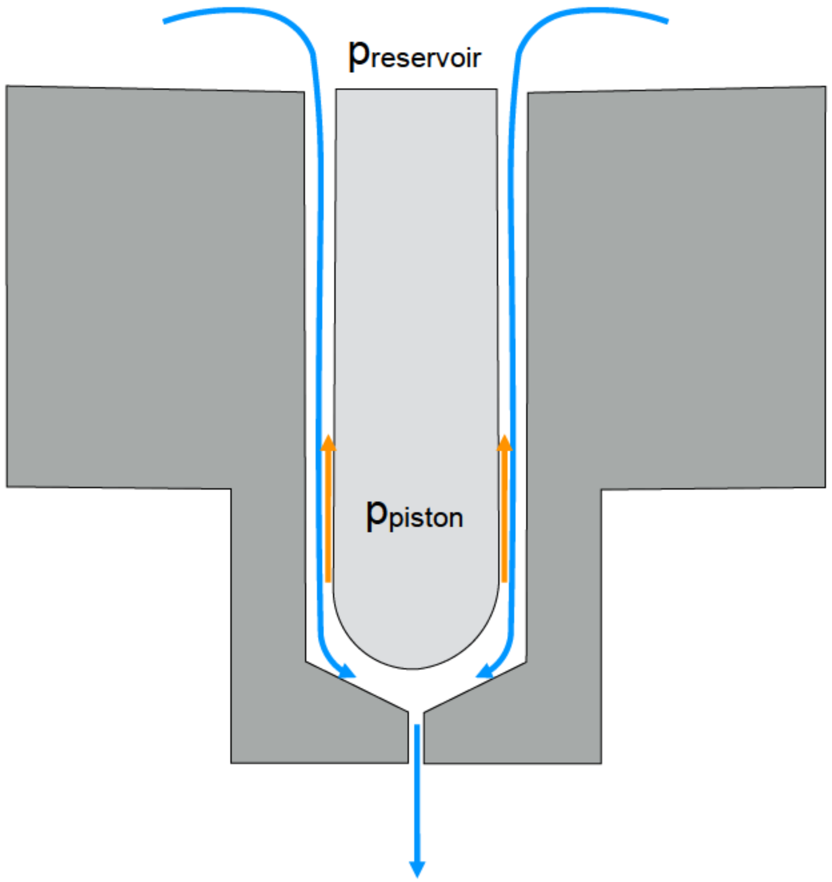
Add-on strategies





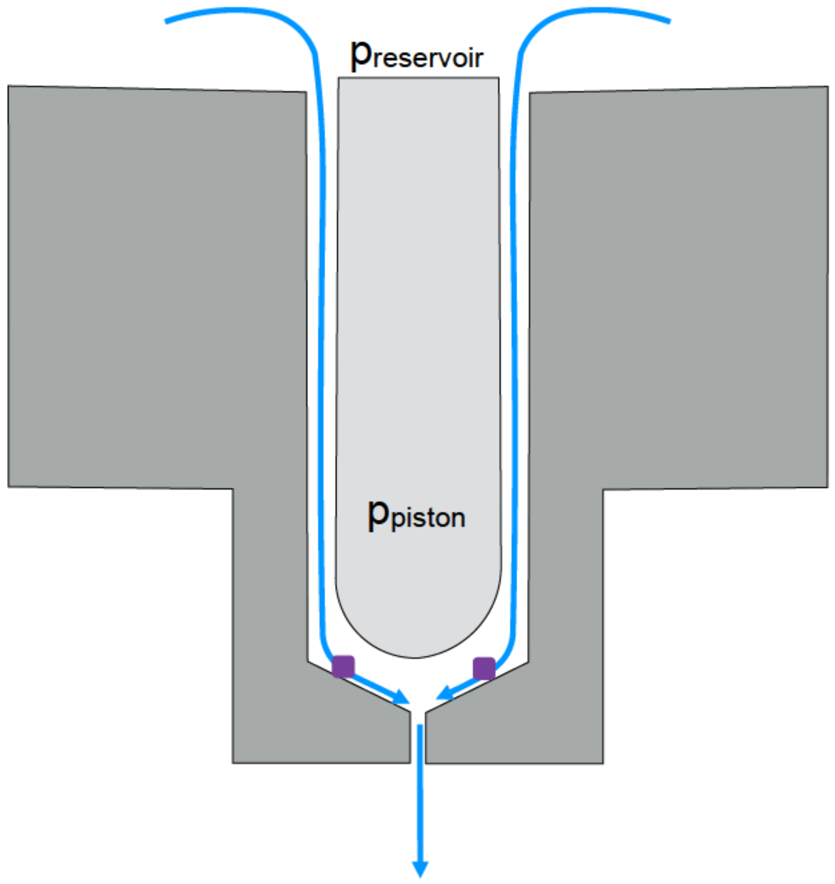
Jetting - I

- High reservoir pressure
- Small piston movement creates higher pressure pulse
- No valve causes considerable backflow



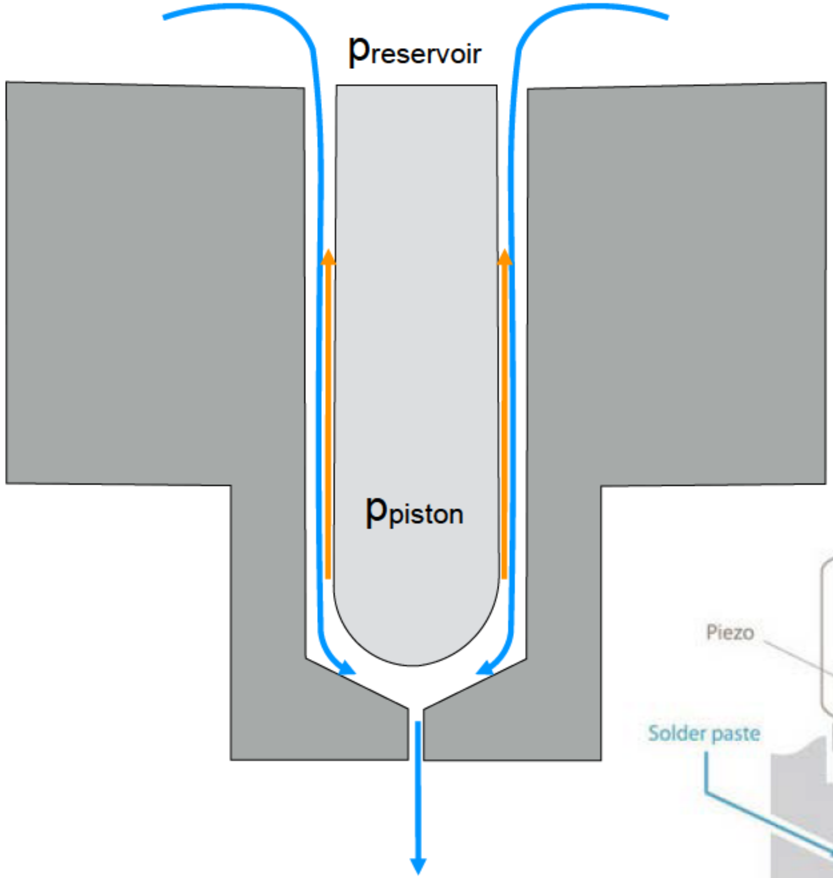
Jetting - II

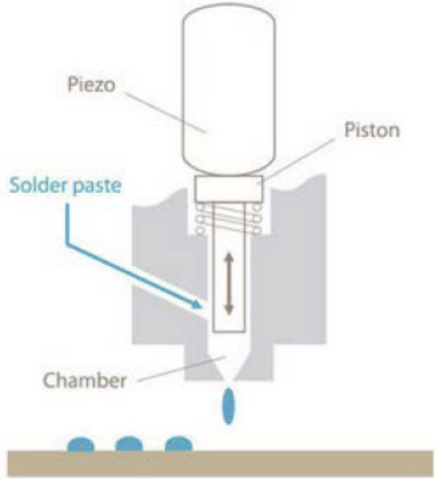
- Lower reservoir pressure
- Valve limits chamber volume
- Small piston movement creates higher pressure pulse
- Valve limits backflow



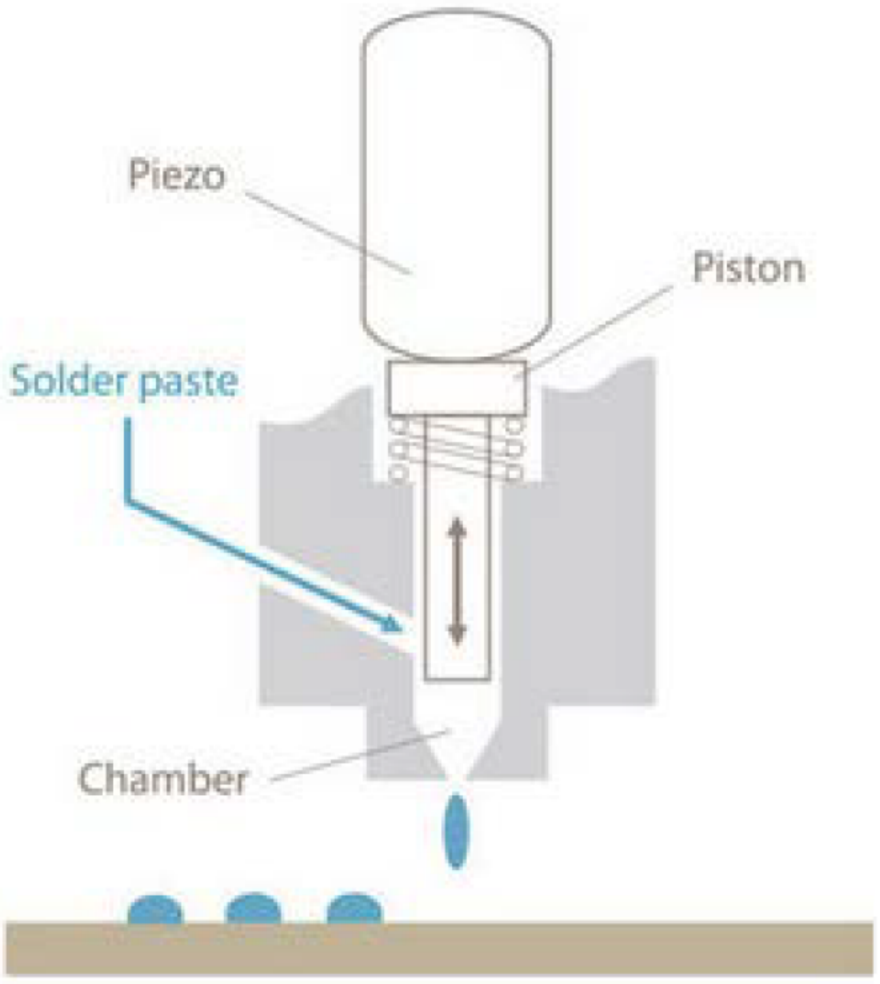
Jetting - III

- Low reservoir pressure
- Drastic piston movement creates higher pressure pulse
- No valve causes large backflow

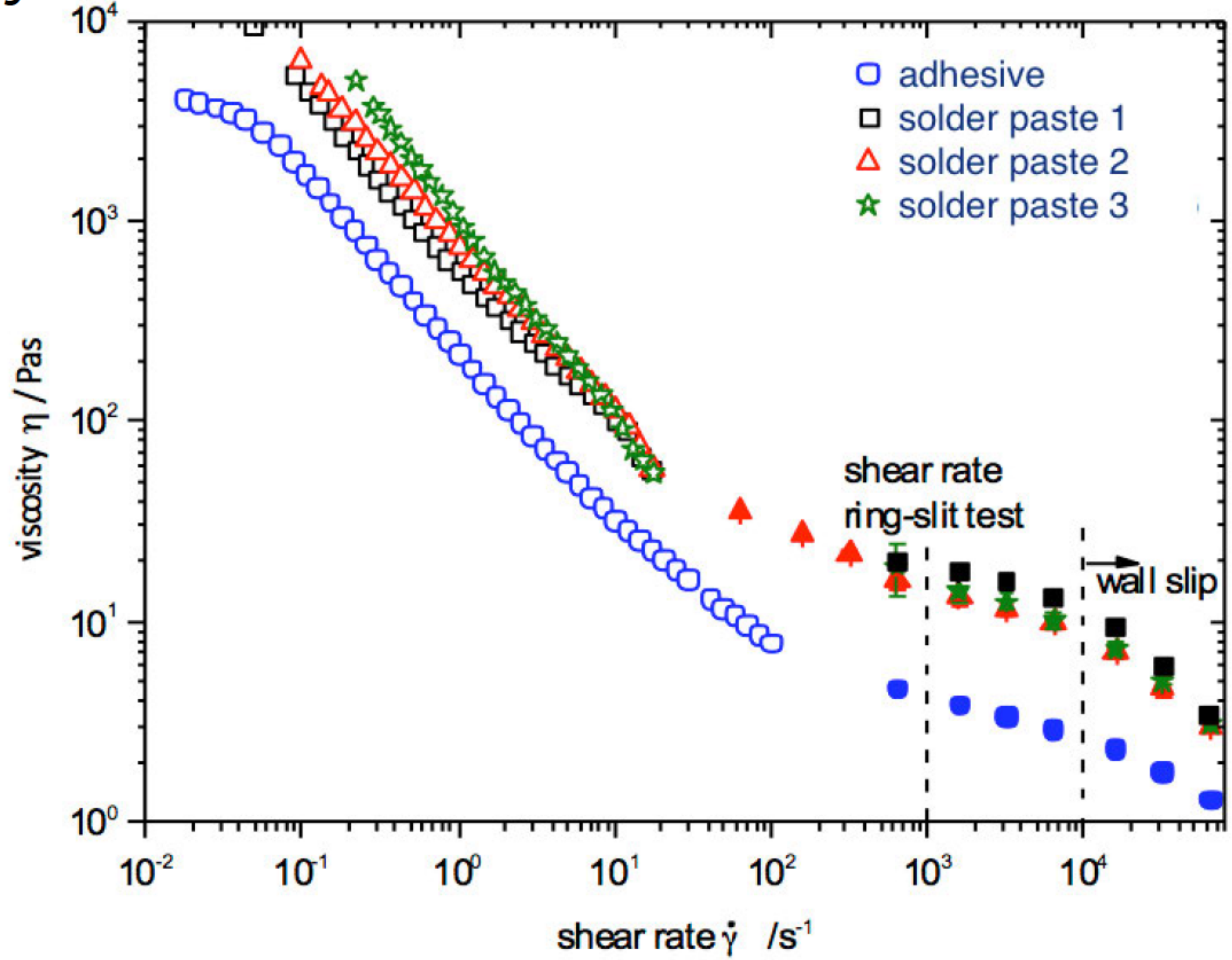




Jetting - III



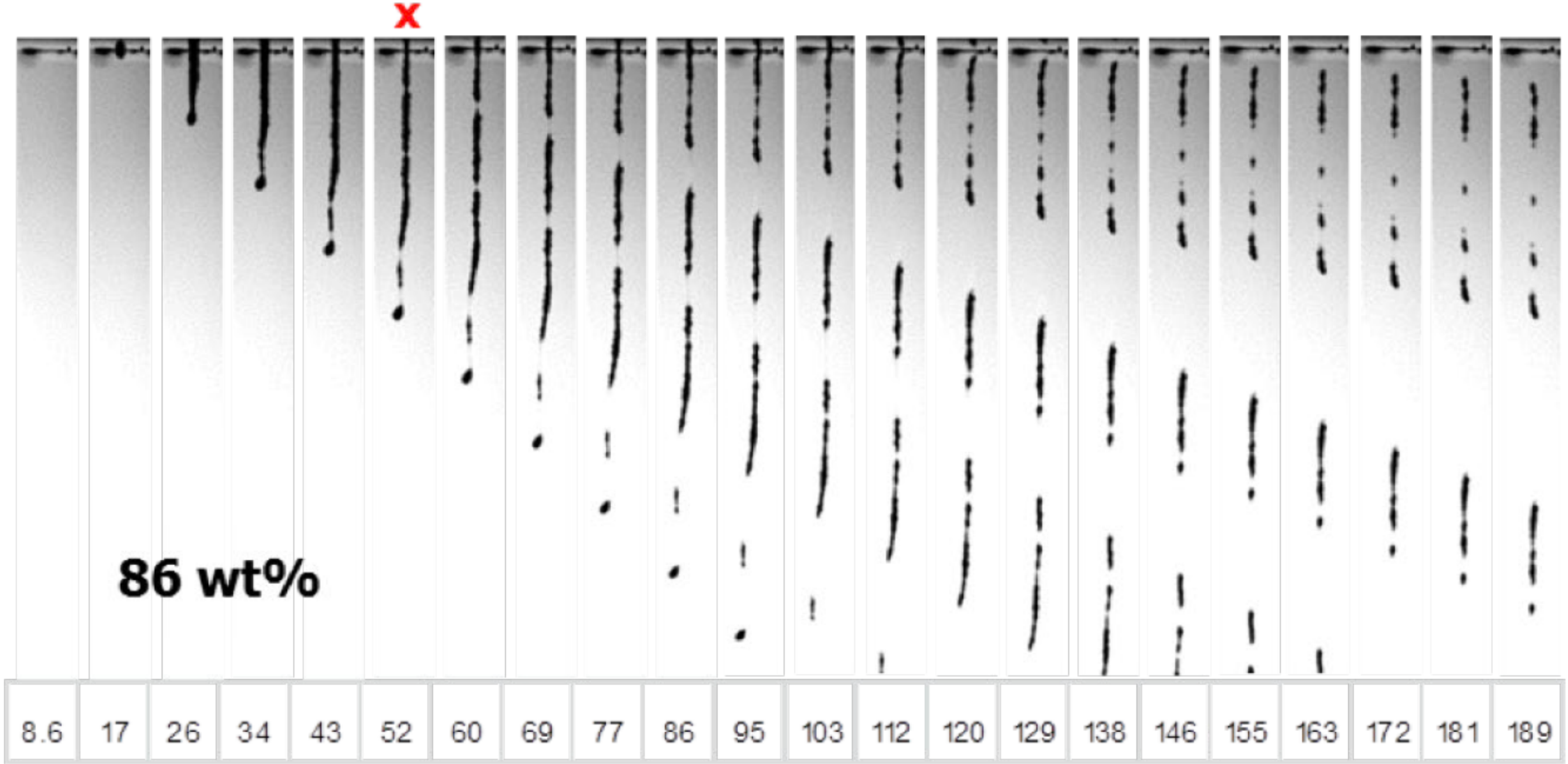
Rheology



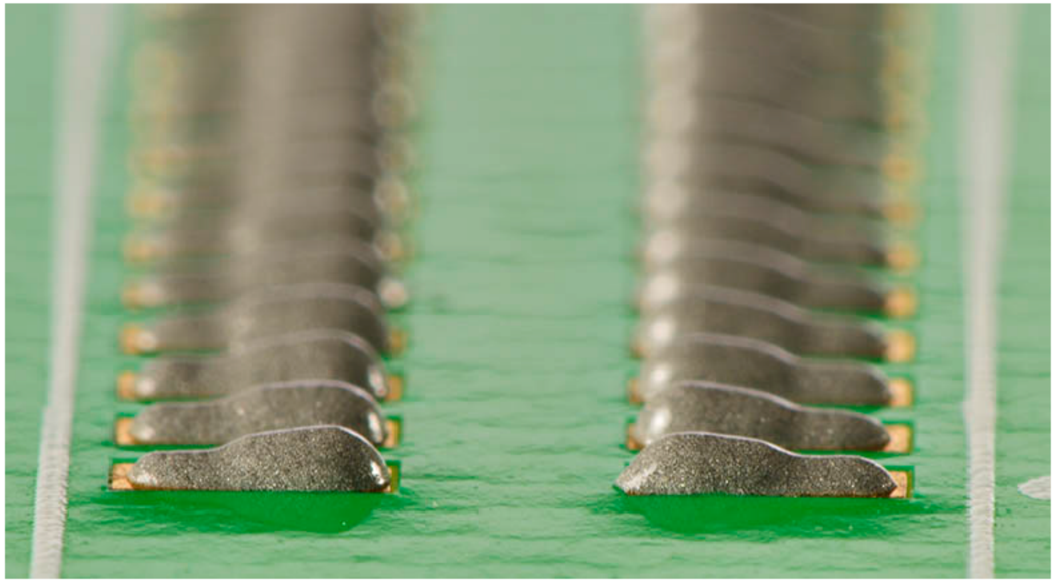
adhesive
solder paste 1
solder paste 2
solder paste 3
shear rate
ring-slit test
wall slip
viscosity η /Pas
shear rate $\dot{\gamma}$ /s^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{-2}
10^{-1}

Jetting

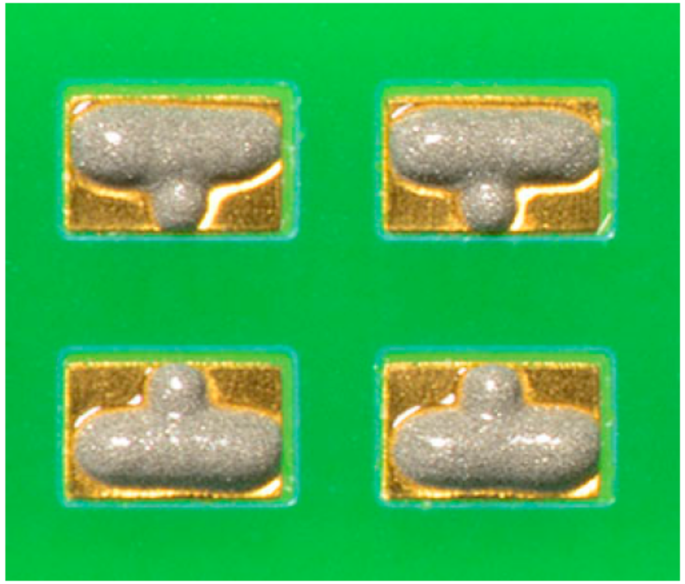
- Actual jetting process filmed at 330 000 Hz
- Substrate is at ca 1 mm



Customization

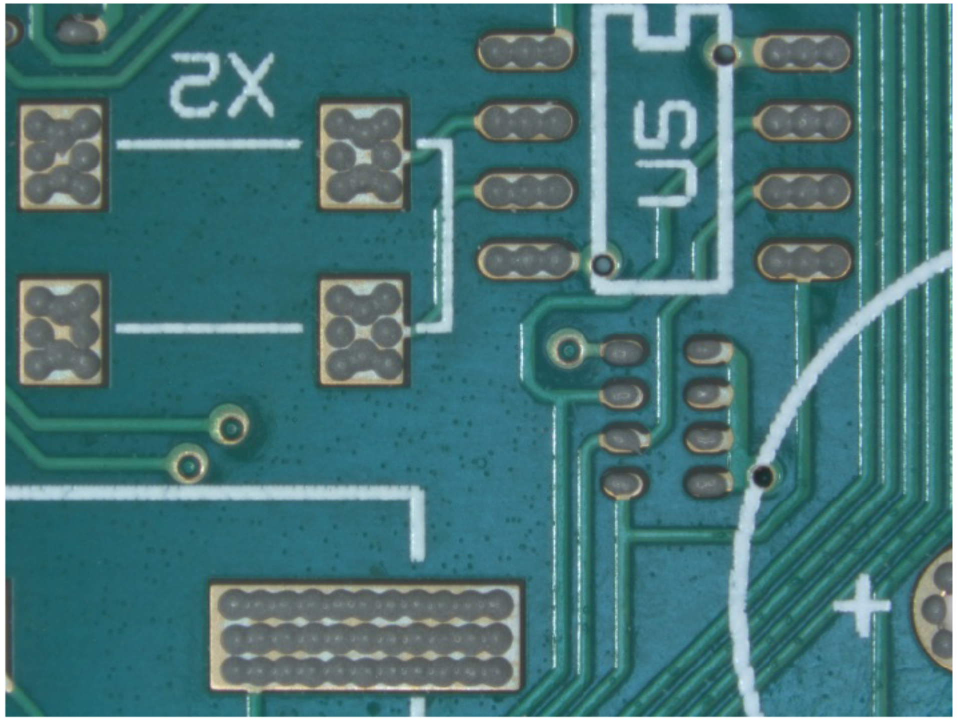


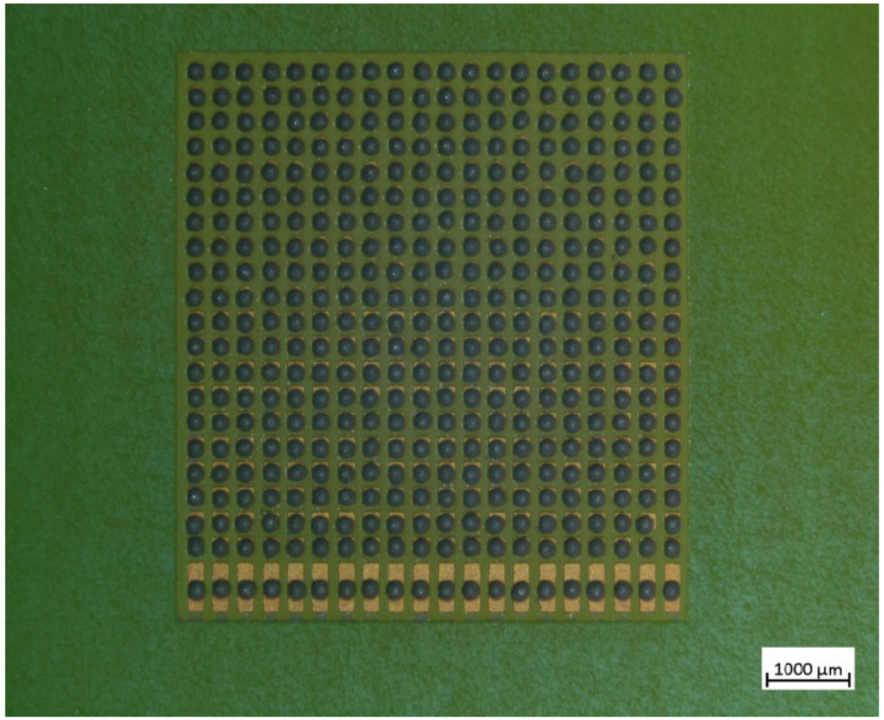
Heel strategy



T-strategy

Precision

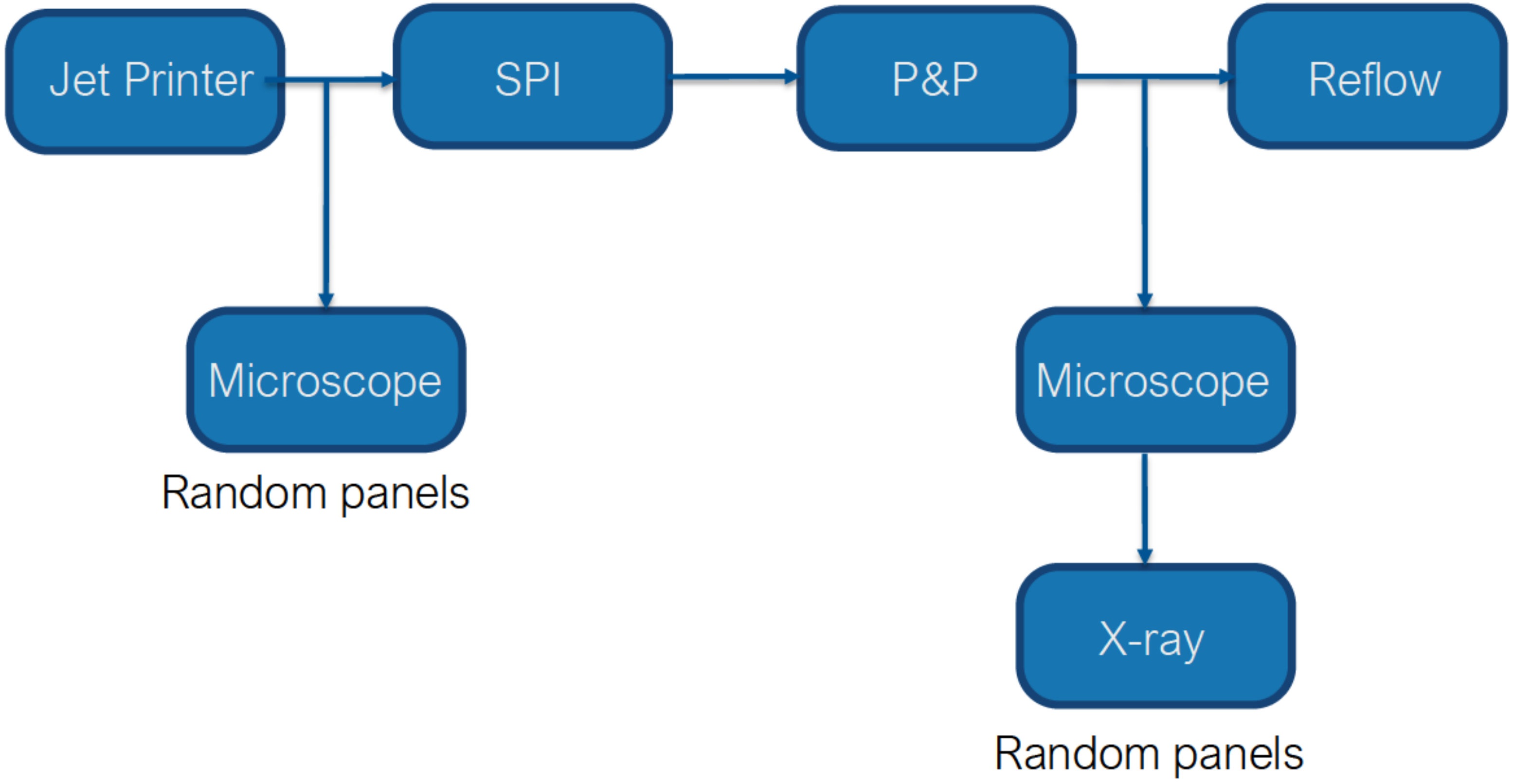




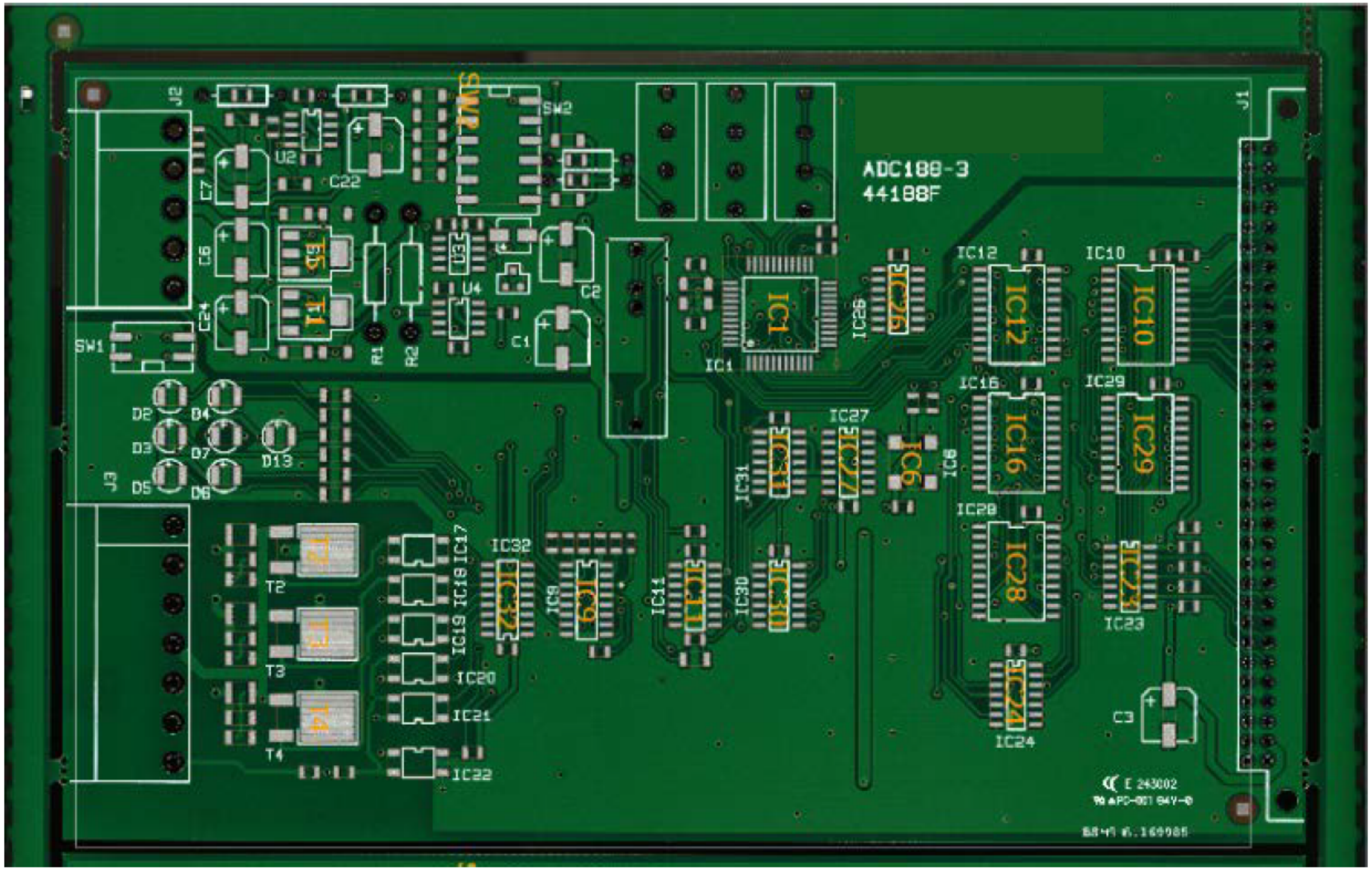
0.3 mm pitch

Beta test

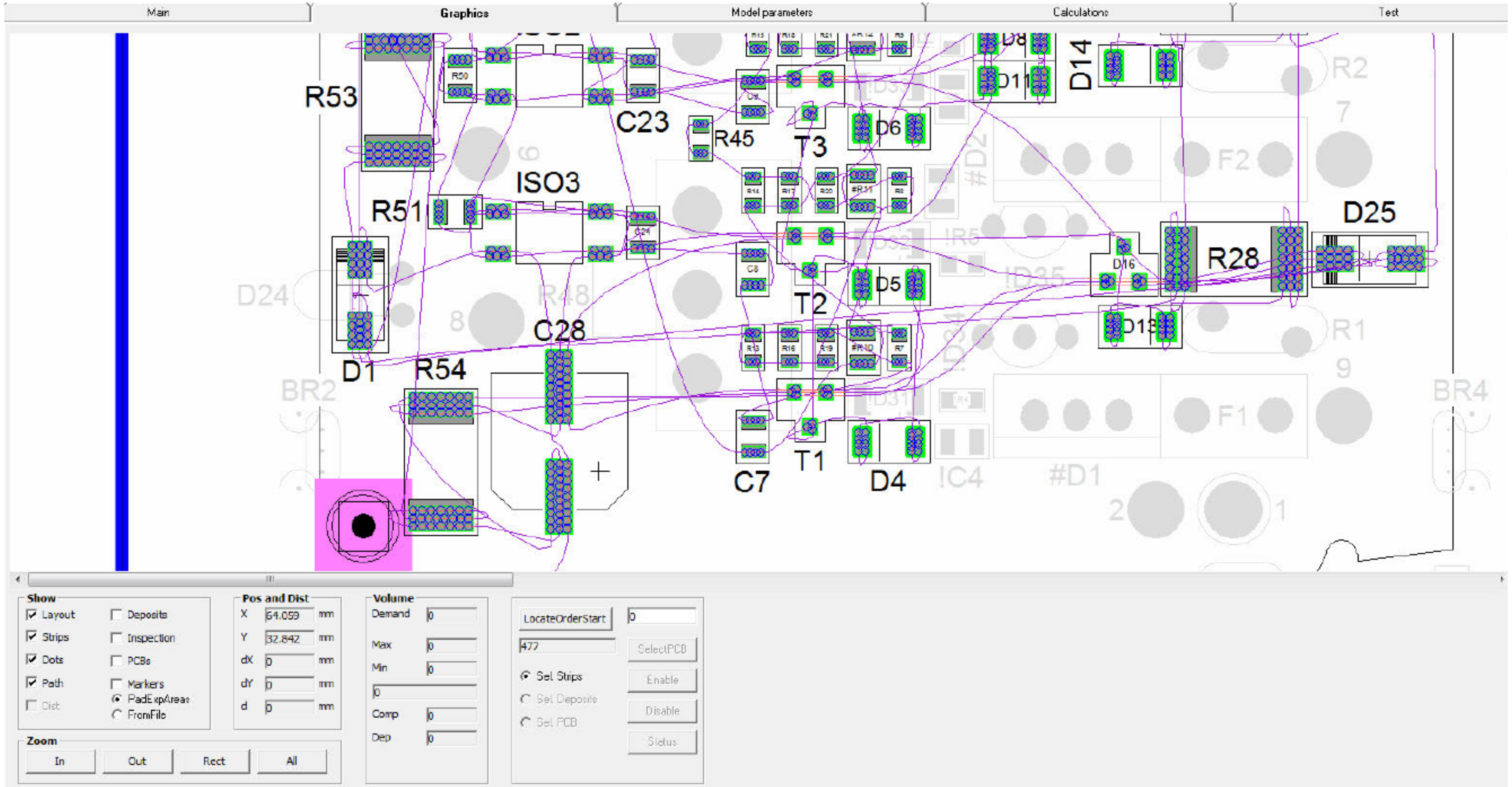
- At SMT production site



Board

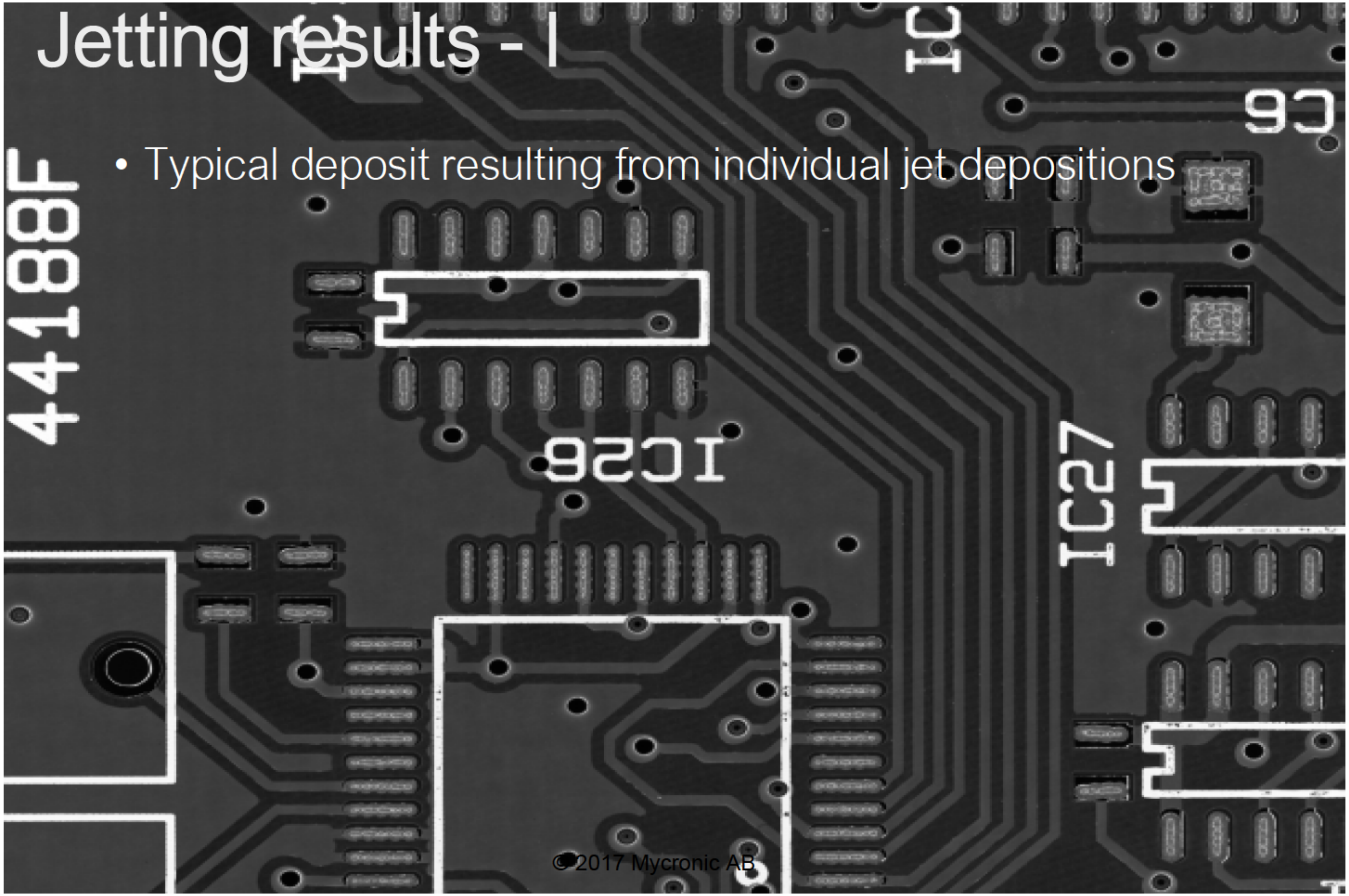

ADC188-3
44188F
J1
J2
J3
SW1
SW2
IC1
IC10
IC12
IC16
IC29
IC28
IC23
IC24
IC27
IC31
IC6
IC32
IC9
IC11
IC30
IC20
IC21
IC22
T1
T2
T3
T4
C1
C2
C3
C6
C7
C22
C24
R1
R2
U2
U3
U4
D2
D3
D4
D5
D6
D7
D13

Job planning



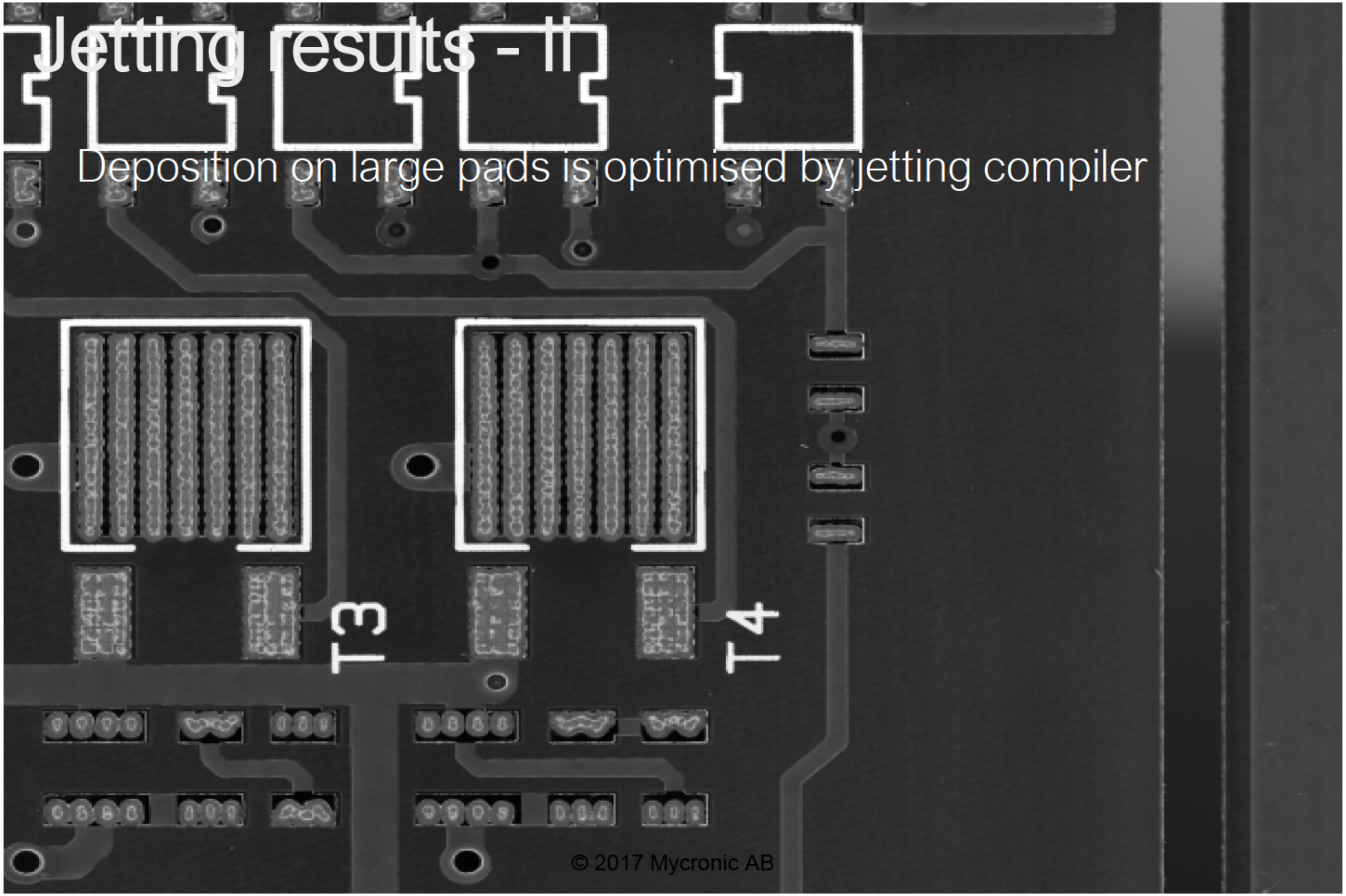
Jetting results - I

- Typical deposit resulting from individual jet depositions



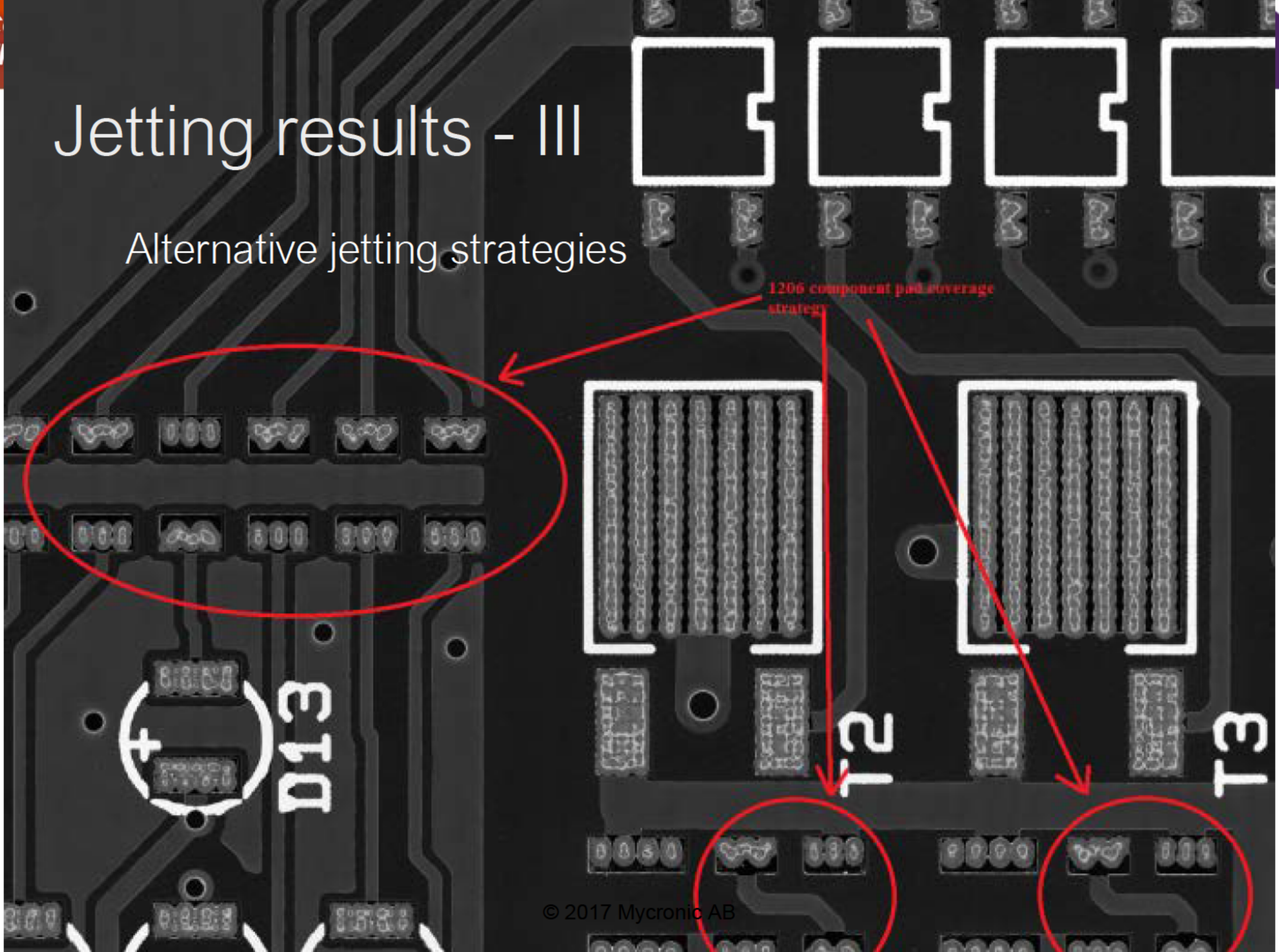
Jetting results - II

Deposition on large pads is optimised by jetting compiler



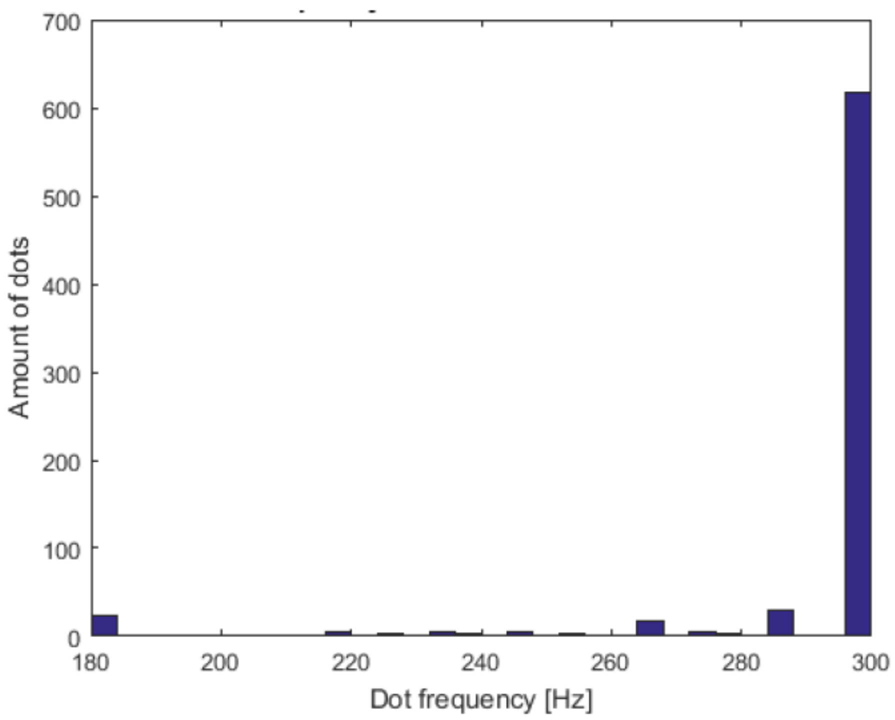
Jetting results - III

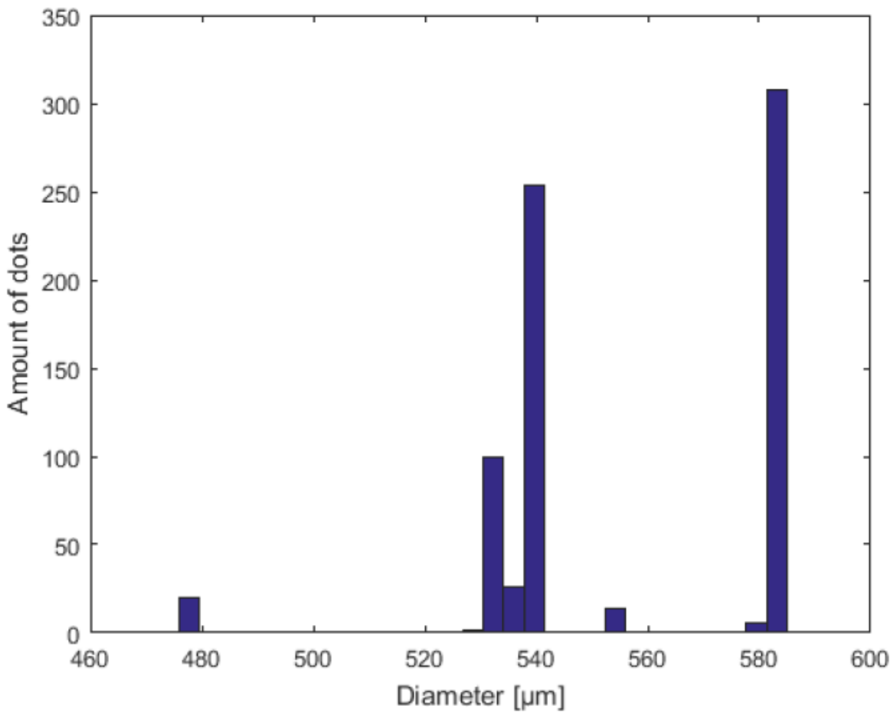
Alternative jetting strategies



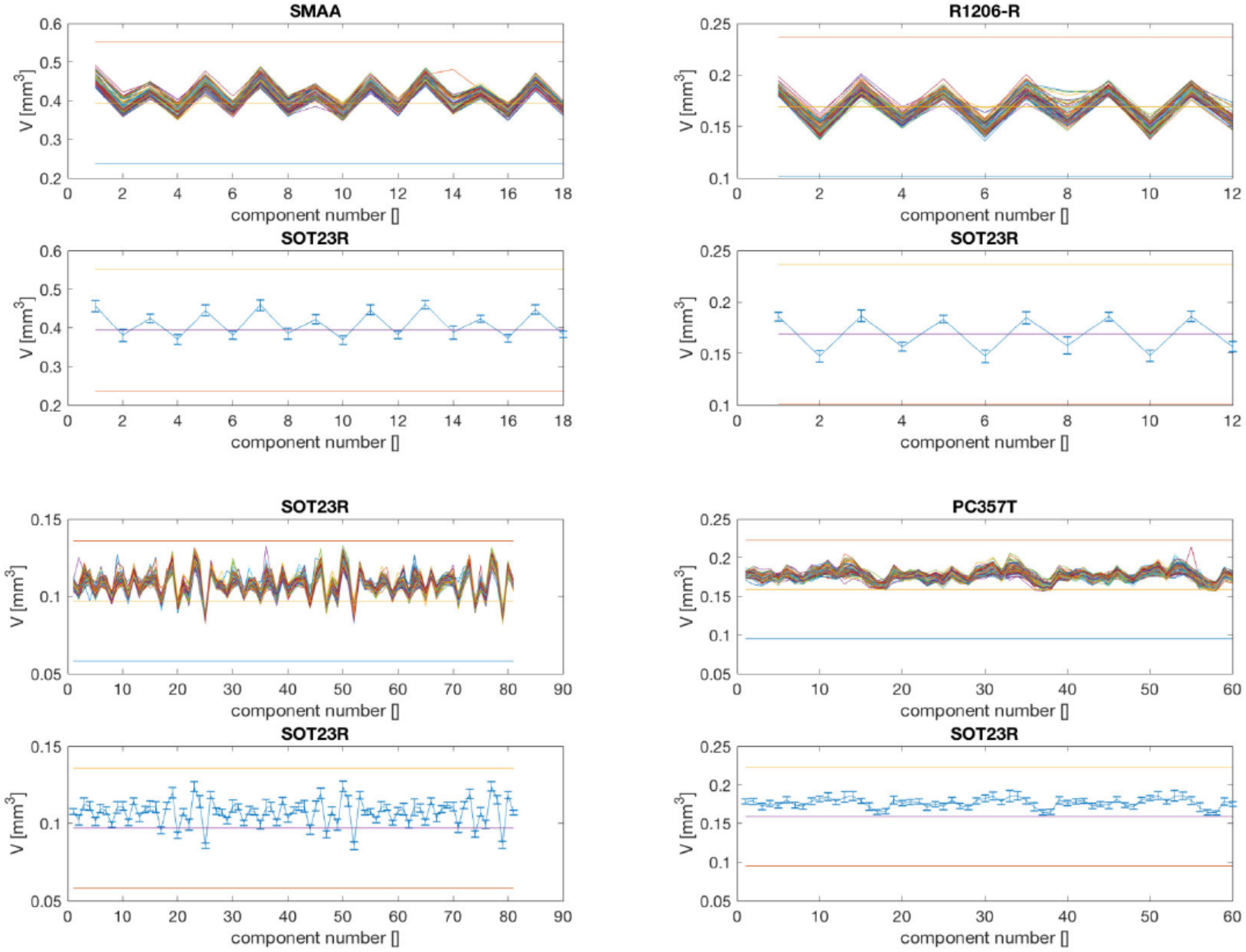
Distributions

Jetting of Layout D follows the distributions of jetting frequency and deposit diameter





SPI results


SMAA
R1206-R
SOT23R
SOT23R
SOT23R
PC357T
SOT23R
SOT23R
V [mm³]
component number []

Summary

- Volume repeatability is excellent at the component level ($\sigma_V < 5\%$)
- Volume average (and to some degree repeatability) for jetting depends on the jetting job planning
- Work is continuing on path optimisation to ensure even higher repeatability