Vectored Jets to Improve Cleaning of Micro-Array IC Packages

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ABSTRACT

High volume flip chip and other micro-array packaging designs can present significant production cleaning challenges. The density of the package I/O structure leaves little space for cleaning. These factors render most cleaning systems incapable of thoroughly cleaning post soldering residues. New approaches are needed to provide a reliable high volume method of cleaning micro-array IC packages. This work benefits customers who remove flux residue to improve capillary underfill, adhesion, and reduced voiding.

Inline cleaning machines utilizing aqueous engineered cleaning fluids represent the process of choice for cleaning high I/O flip-chip assemblies. As the bump pitch becomes tighter, standard inline cleaner designs have not been able to clean adequately under array packages because of the reduced geometries. Bigger pumps and higher pressures are the obvious solution, but create their own set of problems like parts damage and material handling. The designed experiment will test the use of vectored jets to allow a higher differential pressure across the IC. The research hypothesis infers that vectored jets will improve fluid penetration resulting in higher throughput. A transparent flip chip mock-up will be utilized to provide visual understanding of cleaning differences. Standard no-clean low residue and water soluble flux joining materials will be evaluated.

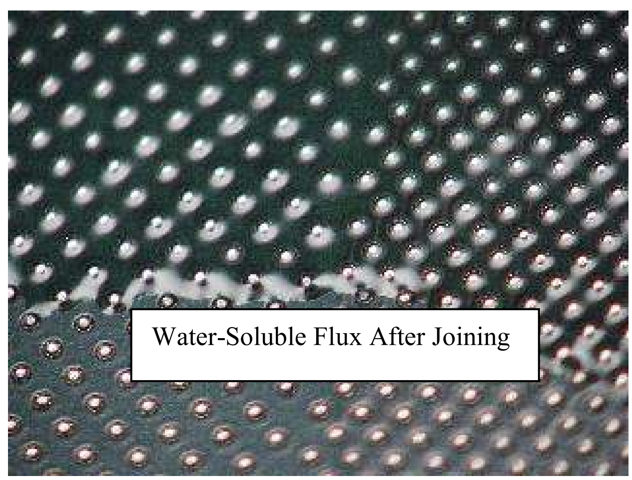
INTRODUCTION

Moore's law infers that the number of transistors that can be inexpensively placed on an integrated circuit increases exponentially[1]. Since 1965, when Gordon E. Moore co-founder of Intel made this empirical observation, the speed at which information is processed has roughly doubled every two years[1]. The result of more transistors in today's circuit designs are driven by technological complexity requiring higher I/O density, tighter pitch, and stacked die to meet performance goals.

Environmental waste electronic and electrical equipment (WEEE), reduction of hazardous substances directive (RoHS), and EU legislation to ensure all chemicals are properly tested and disclosed (REACH), demand changes in materials that are not based on performance, but based on environmental needs[2]. These environmental changes force the packaging industry to adopt alloys with higher solidus temperatures that result in residual stresses post soldering[2]. Additionally, lower-*k* dielectric materials used in high-performance die demand lower stresses be placed on the chip at the same time that the lead-free initiative implies higher stresses[2].

Higher I/O mounted die result in lower standoff heights and tighter pitch. Attaching the die with lead-free solders increases the level of tin-oxides, which necessitates higher activity flux[3]. This condition raises the stress levels surrounding the solder bumps and underfill, which may increase voiding and poor adhesion[2]. To address this deficiency, assemblers of large die join the assembly with water-soluble flux. Water soluble flux materials provide increase activity but must be cleaned post soldering. The benefits of using water soluble materials are their ease of cleaning and improved capillary underfill adhesion and flow.

Figure 1: High I/O Die Joined with Water Soluble Flux



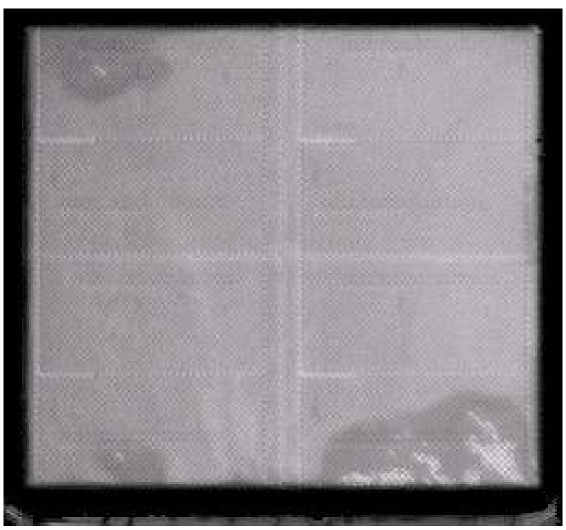
ARTICLE SUMMARY

The Research in Brief – the core research: High performance flip chip packages leverage the experience curve gained from accumulated industry experience. The experience curve is the general principle that makes sense of such familiar ideas as Moore's Law. The experience curve allows manufactures to push down costs and raise levels of performance over time.

High I/O flip-chip die create a problem with the residues under the die. Residues must not impede capillary underfill flow in packages with 75 µm and less gap height and bump pitch less than 150 µm[2]. To address this problem, designers find improve performance from removing the flux residues post soldering. Joining the die with water soluble flux pastes and removing the residues using spray-in-air continuous inline cleaning machines, supplemented with engineered cleaning fluids, provides a solution.

Engineered cleaning fluids reduce water's surface tension; rapidly solvate burnt flux residues at the corners and center of the die, and reduce foam from the mechanical stress employed by high pressure spray jets. Assemblers report that DI-water only is insufficient at removing oxidized residues that result from heat gradients at different points under the die, at the corners of the die, and edges of the die (Figure 2). Aqueous designed cleaning materials solvate burnt on residues and work at low concentration in the range of 2-10% as a means of solving this problem.

Figure 2: Voiding From Low Levels of Residue under Die



Over the past five years, cleaning material and cleaning equipment companies have jointly researched spray impingement designs for improving cleaning efficiency under low standoff components. Research findings indicate that fan sprays lose energy needed to remove all residues under large die. To correct this deficiency, higher pressure angled spray V-jets improved cleaning performance.

Coherent jets shorten the spray angle and hold pressure longer. This research studied progressive energy impingement designs for removing low-residue and water-soluble residue under the die. Two spray configurations were studied. The research provides process engineers with insight into the value of using vectored spray nozzles. The vector nozzles deliver a flat thin fan-shaped spray with sharp definition on the edges. This spray delivers very high impact over the area covered. The pre-engineered angled nozzles deflect away from the centerline of the spray nozzle to improve cleaning performance.

The Research in Practice – applying the data findings: Higher I/O dies with reduced pitch and standoff increase cleaning difficulty. To address this problem, cleaning machine companies increase wash section length and pump size. This research presents an optimal nozzle design that improves penetration under the die using a combination of directional, fluid flow, and pressure forces to remove flux residues.

Optimal spray delivery opens the process cleaning window. High I/O die are cleaned using shorter wash sections, smaller pump size, and lower wash temperatures. The research studied progressive energy dynamics using coherent and vectored nozzle designs (Figure 3). The research findings conclusively report the beneficial properties of vectored nozzles.

Figure 3: Progressive Energy Dynamics

The research reports the soil effect differences. Low I/O flip chip die were commonly joined with low residue no-clean flux pastes. Designers who find benefits in removing flux residues post underfilling found cleaning problems with cleaning low residue materials under the die. This research compares cleaning findings using both low residues no-clean with water soluble flux pastes. The data conclusively indicates that water-soluble residues are easier to clean (Figure 4).

Figure 4: Flux Removal Comparison

Low Residue After Cleaning	Water Soluble After Cleaning
	

PROCESS CLEANING RATE

The inferences from the cleaning rate theory[4] predict two parts to the total cleaning rate; one component is the static rate, the other is the dynamic rate. The static rate plus the dynamic rate equals the process cleaning rate. This relationship is expressed in Equation 1.

Equation 1: Process cleaning rate equation: $R_p = R_s + R_d$
Where;
Process cleaning rate = R_p
Static cleaning rate = R_s
Dynamic cleaning rate = R_d

The static cleaning rate is the rate at which the cleaning material dissolves flux residues in the absence of impingement energy. The static rate is determined by placing the flip-chip assemblies in an uncirculated dip tank and calculating the time required to dissolve surface flux residues. The static rate depends upon the residue and the cleaning agent being used. It is influenced by temperature and, in aqueous solutions, the engineered cleaning fluid composition and in-use concentration.

The cleaning fluid design influences the static cleaning rate. Aqueous engineered cleaning materials are formulated with solvating materials, builders that soften or react with the flux residue, wetting agents that drop surface tension, and minor ingredients to control foam and protect metal alloys. Cleaning material design influences the dissolution rate, saponification, foam propagation, material compatibility, bath life, and metal inhibition. Best in class cleaning materials dissolve all types of flux residues including polymerized and charred residues; penetrate and wet under low standoffs; offer a wide compatibility window on materials of construction; break surface foam at rates greater than foam build; low in toxicity and odor; and protect metal alloys during the cleaning process.

The dynamic rate is the energy forces applied from the machine and its fluid delivery system. The dynamic cleaning component is directly related to fluid flow, fluid pressure at the board surface, and directional forces delivered to the surfaces and gaps to be cleaned.

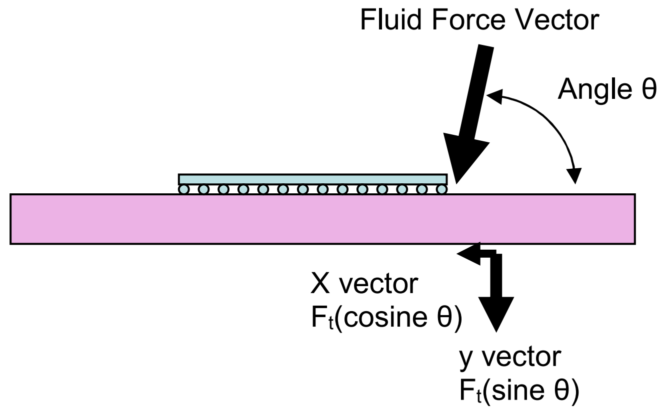
Spray-in-air inline cleaning equipment provides a platform for delivering spray impingement perpendicular or angled to the flip-chip being cleaned. The dynamic cleaning rate decreases the process cleaning rate. In a typical spray-in-air cleaning machine, the time needed to clean all residues under flip chip high I/O die is commonly less than 10 minutes of direct spray impingement. In the absence of fluid force, fluid pressure, and directional forces consistently applied to the flip chip assembly, residue removal is inconsistent at best. Additionally, water-soluble flux residues trapped under low flip-chip die create a flux dam and requires energy consistently applied to develop a wide process window.

NOZZEL IMPROVEMENTS

A vectored jet is defined to be a jet set at an angle of attack greater or less than 90º. A vectored jet delivers more fluid force laterally. Previous research has shown, the higher the lateral force, the stronger the flow under closely spaced components. In analyzing vector forces, it is recognized that a vector force can be viewed as having an x and y component. A perpendicular cleaning jet at a 90º angle to the substrate surface can be viewed as 100% "y" component and 0% "x" component. As the angle decreases the "y" vector increases and the "x" vector decreases.

Calculating the amount of the force in the x and y direction is a function of the sine and cosine of the angle of the jet with respect to the surface of the substrate. This is shown in Figure 5.

Figure 5: Vector Components



The force of the fluid vector can be thought of mathematically as having and x and y component. The relationship of the x and y forces with regard to the force of the fluid jet and be expressed in equation 1

Equation 1

Force Vector $= F_t$
$= F_y + F_x$
$= F_t = (\cos\theta \times F_t) + (\sin\theta \times F_t)$

Changing the angle of the fluid jet improves the forces needed in "x" to create higher flow under the device being cleaned. An angle of 30 degrees would direct 50% of the fluid force to the "x" vector.

The magnitude to the total fluid force vector is determined by the velocity and mass of the fluid jet at the point of impact with the assembly. Several variables influence this. The mass delivered per unit area is determined by the manifold pressure, the orifice size, the nozzle type and the fluid jet interaction with the air.

The interaction with the air turns out to be a major consideration. How the fluid stream interacts depends on the type of stream generated by the nozzle. A fan nozzle spreads the fluid stream and creates more interaction, slowing the velocity significantly in relatively short distance of just a couple of inches. A solid stream "coherent jet" holds together longer and interacts less with the atmosphere.

Equally important is the jet to jet interaction. Opposing vectors can diminish the lateral forces needed to create high flow by canceling each other. Vectored jets with unidirectional lateral force can have and additive affect. The spacing jet to jet is critical as well as the spacing of the manifolds.

The vectored jets used in these test were designed with a high attack angle and were additive. The spacing of the manifolds was sufficient to prevent directional canceling. The coherent nozzle diameters in the vectored manifolds were similar to the standard PED manifolds.

RESEARCH HYPOTHESIS

H$_1$: Vectored jets will improve flip-chip fluid penetration resulting in higher throughput cleaning efficacy.

METHODOLOGY

Progressive energy dynamics using coherent and vector nozzles were studied. Glass die were bumped with anisotropic adhesive bumps. The bumps were milled down to 2 mil standoff height. Glass die were placed over the bumps. Two flux pastes - no-clean flip chip polymer flux, and water-soluble flip chip flux were dispensed and reflowed. The concentration of the engineered cleaning fluid for each flux was defined from static cleaning studies. The conveyor speeds studied for the no-clean polymer flux were 0.3 feet-per-minute (FPM), 0.5 FPM, and 0.75 FPM. The conveyor speeds studied for water-soluble flux were 0.5 FPM, 1.0 FPM, and 1.5 FPM.

Removal of no-clean polymer flip chip flux requires longer wash times and increased cleaning material concentration. The static cleaning rate for removing the polymer flux residue required more than 4-hours to dissolve all residues under the die. The static cleaning rate for the water-soluble flux was approximately one hour. These tests were conducted in a non-agitated beaker of the engineered cleaning material using lower engineered cleaning fluid concentration. The wash temperature was set at 150°F.

The factorial experiment evaluated the variables of flux type, nozzle selection, wash time, wash temperature, and engineered fluid concentration (Tables 1). Wash concentration and wash time were increased for the no-clean polymer flux and reduced for the water-soluble flux pastes studied.

Table 1: Experimental Factors

Nozzle Type	Flux	Wash Time	Wash Temp.	Wash Conc.
Coherent	No-clean polymer	4 min.	150°F	18%
Coherent	No-clean polymer	6 min.	150°F	18%
Coherent	No-clean polymer	10 min.	150°F	18%
Vectored	No-clean polymer	4 min.	150°F	18%
Vectored	No-clean polymer	6 min.	150°F	18%
Vectored	No-clean polymer	10 min.	150°F	18%
Coherent	Water-soluble	4 min.	150°F	6%
Coherent	Water-soluble	6 min.	150°F	6%
Coherent	Water-soluble	10 min.	150°F	6%
Vectored	Water-soluble	4 min.	150°F	6%
Vectored	Water-soluble	6 min.	150°F	6%
Vectored	Water-soluble	10 min.	150°F	6%

DATA FINDINGS

The substrates evaluated were 1,600 I/O glass dies with a 2-inch by 2' inch die. The bumps were milled down to a standoff height of 2 mils. After cleaning, digital images of the glass die visually show the cleaning result under the die. The data findings will show the cleaning differences for the no-clean polymer flux as compared to the water-soluble flux and the coherent as compared to the vectored nozzles.

The first set of test comparisons evaluated cleaning removal of a no-clean polymer flux. No-clean fluxes are not designed to be cleaned. Engineered cleaning materials will remove these materials but process conditions of time, temperature, and wash concentration will need to be increased. Due to the difficulty of removing all residues under flip chip die, assemblers who clean prefer water soluble flux pastes. Figure 6 illustrates the data findings of coherent versus vector jets using the following process parameters:

- Flux ~ No-clean polymer
- Wash Time ~ 4 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 18%

There was flux remaining under the die with both nozzle types. The level using the vector nozzle was less.

Figure 6: Coherent versus Vector Nozzles

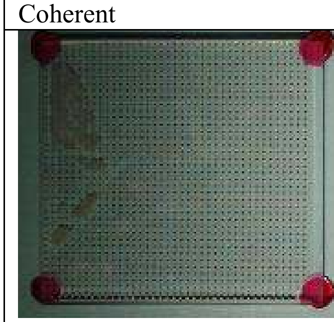
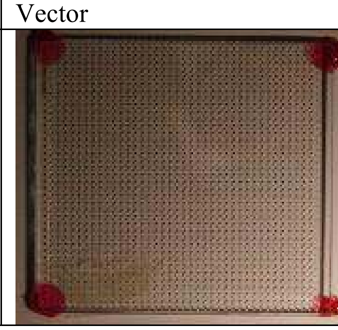
Coherent	Vector
	

Figure 7 illustrates the data findings of coherent versus vector jets using a longer wash time of six minutes using the following process parameters:

- Flux ~ No-clean polymer
- Wash Time ~ 6 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 18%

There was flux remaining under the die with both nozzle types. The level using of residue was similar for both nozzle types.

Figure 7: Coherent versus Vector Nozzles

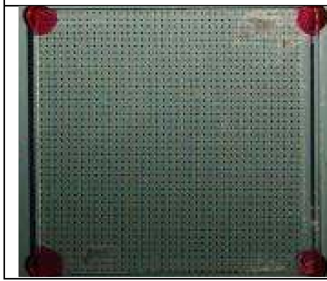
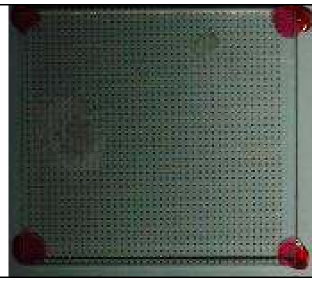
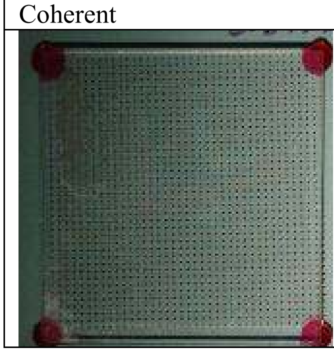
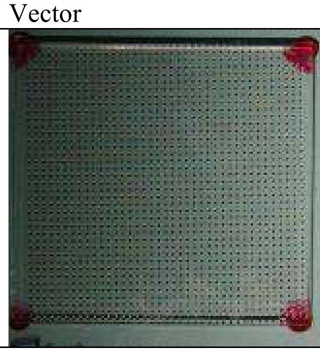
Coherent	Vector
	

Figure 8 illustrates the data findings of coherent versus vector jets using a longer wash time of 10 minutes using the following process parameters:

- Flux ~ No-clean polymer
- Wash Time ~ 10 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 18%

There was flux remaining under the die using the coherent nozzles and minor flux using the vector nozzles. Even with cleaning improving from longer wash times, the consistency of improvement appears to vary. The difficulty of cleaning a no-clean polymer flux under flip chip die is indicated by this experiment.

Figure 8: Coherent versus Vector Nozzles

Coherent	Vector
	

The second set of test comparisons evaluated cleaning removal of a water-soluble paste flux. Water-soluble flux lead-free pastes provide increased activation and thermal stability. Water soluble flux residues from soft residues and are more easily cleaned than the no-clean polymer flux pastes. Engineered cleaning materials at low concentration improve the removal of water soluble flux residues, especially burnt on residues at the edge and corners of the die. Process conditions of time, temperature, and wash concentration are also important variables. The wash concentration needed to improve cleaning efficacy is less for water soluble residues due to the improved static cleaning rate. Figure 9 illustrates the data findings of coherent versus vector jets using the following process parameters:

- Flux ~ Water Soluble Flux Paste
- Wash Time ~ 2 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 6%

The data findings illustrate improve cleaning using the vector nozzles. Note that the wash time was likewise shortened when testing water soluble paste fluxes. At two minutes residence time, a low level of flux remained under the die cleaned with vector nozzles while a significant level of residue remained from the coherent nozzle design.

Figure 9: Coherent versus Vector Nozzles

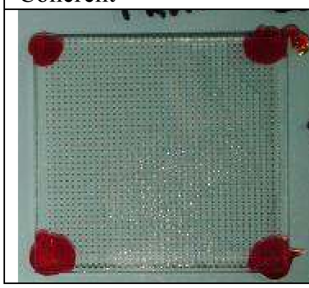
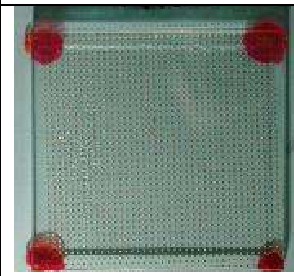
Coherent	Vector
	

Figure 10 illustrates improved cleaning data findings of coherent versus vector jets using a longer wash time of four minutes. The following parameters were tested:

- Flux ~ Water Soluble Flux Paste
- Wash Time ~ 4 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 6%

The data findings show a much higher level of flux remaining under the die cleaned with coherent nozzles as compared to the die cleaned with the vector nozzles. The die cleaned with vector nozzles was free of all flux residue using these process conditions.

Figure 10: Coherent versus Vector Nozzles

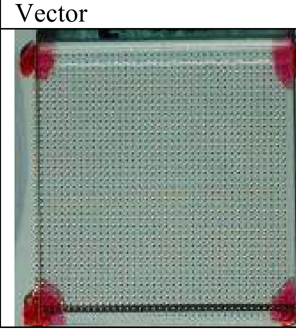
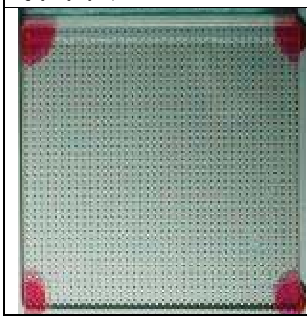
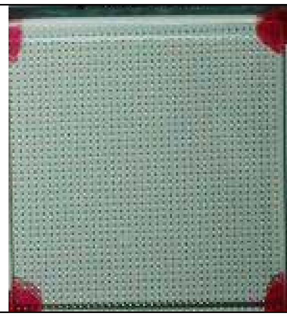
Coherent	Vector
	

Figure 11 illustrates the data findings of coherent versus vector jets using a longer wash time 6 minutes. The process parameters used for this test are as follows:

- Flux ~ Water Soluble Flux Paste
- Wash Time ~ 6 minutes
- Wash Temperature ~ 150°F
- Wash concentration ~ 6%

The data findings show minimal flux remaining under the die cleaned with coherent nozzles and no flux remaining under the die cleaned with vector nozzles. The data indicates improved cleaning and a wider processing window when increasing the wash time. Additionally, the vector nozzles provide improve cleaning and process consistency.

Figure 11: Coherent versus Vector Nozzles

Coherent	Vector
	

INFERENCES FROM THE DATA

The data findings show visual evidence that vector jets improve flip-chip fluid penetration that results in higher throughput cleaning efficacy. This finding supports the research hypothesis. Additionally, the research findings infer strong evidence of the soil effect. Soft residues increase the static cleaning rate, which improves the process cleaning rate.

The vector nozzles use coherent sprays while improving cleaning at the angle of attack. With the spray hitting the edge of the die laterally, more fluid is pushed under the die creating a strong flow. Conversely, the coherent sprays impacted the die perpendicular to the plane. When sprays hit the die perpendicular to the plane, a good bit of the spray bounces back and does not penetrate under the die.

The data findings indicate two important process variables when cleaning under micro-array IC packages. First, the selection of the flux paste influences the cleaning rate. Water soluble soft residue fluxes dissolve in hot water at a fast rate. Low levels of engineered cleaning fluids increase the static cleaning rate. Dissolving the soil at a faster rate is an important parameter when cleaning under low standoff components that are shielded with thousands of small solder bumps. The visual data shows erratic cleaning, even at longer wash times, when removing the no-clean polymer flux. The visual data conclusively shows improved cleaning when using water soluble flux pastes to join the die to the substrate.

The second finding shows visual evidence of improved cleaning when selecting nozzles that improve spray pressure, penetration, and directional forces under the die. The vector nozzles provide a high attack angle and continuously moves wash fluid under the die. When cleaning water soluble flux pastes, the process cleaning window was well defined for achieving a repeatable cleaning process.

CONCLUSIONS

High I/O micro-array IC packages result in lower standoff heights and tighter pitch. Attaching the die with lead-free solders increases the level of tin-oxides, which necessitates higher activity flux. Flux residues have been shown to cause failures due to poor adhesion, voiding, and electrochemical migration. Removing the flux residues prior to underfilling improves reliability when all flux residues are removed.

The research data reports improved cleaning rates when removing water-soluble flux residues as compared to no-clean polymer flux residues. The research conclusively shows visual evidence of cleaning improvement from the selection of mechanical delivery of the wash cleaning fluid.

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