Critical Cleaning Requirements to Overcome Advanced Packaging Defluxing Challenges

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***Abstract* — As technology advances, wafer-level packages have emerged in many different varieties. Computing has evolved significantly over the years. Chips integrated with additional functionalities to improve performance, processing challenges, storage and networking has become standard. The development of the packages such as SiP, fcBGA, PoP, 2.5D, etc. which utilizes multiple or larger die sizes, increased bump counts, lower standoff height and a large variety of components on the packages have reduced the effectiveness of cleaning. The common packaging interconnect is using solder and die attached to a substrate by a solder reflow process. The flux residues after soldering pose a cleaning challenge, especially underneath these extremely low-profile components. As standoff height reduces, flux residues have less area to outgas during reflow. Typically, the standoff height is <100µm and it continues to shrink further. For some components such as QFNs, LGAs, the large thermal pad at the center of the component body poses barriers to the complete removal of the flux residues. Partially removed or untouched residues can lead to reliability failures as consequences of electrochemical migration and dendrite growth as well as electrical leakage currents. Effective cleaning improves product reliability by ensuring optimal condition for subsequent processes, such as wire bonding, underfill and molding. This presentation discusses the breakthrough in cleaning challenges for advanced packaging, especially when addressing factors like high density assemblies, latest flux formulation and low standoff heights. The most common cleaning system used for cleaning advanced packaging substrate is a conveyorized spray-in-air inline cleaning system. The discussion extends to how effectively the cleaning process needs to be balanced, in terms of chemical, mechanical and thermal energies. We will also explore the key cleaning parameters that lead to successful removal of flux residues from underneath the low-profile components. For example: nozzle types, spray pressure, chemical exposure time, cleaning temperature and type of cleaning agent. We will conclude with several customer case studies to validate the above findings.**

Keywords – flux, cleaning, advanced packaging, low standoff heights, cleaning agents

I. INTRODUCTION

A. Miniaturization of Advanced Packaging

Semiconductor packaging technology has grown dramatically in the past few decades, and thousands of different semiconductor package types have been created. Back in the early 70s, the flip-chip package technology as a package solution for high pin count & high-performance package requirements was introduced. Since then, the development of the semiconductor package with flip-chip technology is ever growing and for the last decade, the trend of miniaturization has resulted in much smaller footprints, higher pin count, and higher-performance packaging to be developed.

Nowadays, chip integration with additional functions to improve performance, processing challenges, storage, and networking have become a standard. This is especially true with the growing trends of IoT, 5G technology, mobile phone, etc., which involved a significant reduction in the size of the advanced packaging while meeting the market requirement. Advanced packages such as FCBGA, FCCSP, PoP &, etc., system integration in a package (SIP) with high functioning system performance, wafer-level packaging with a high number of bump counts, and low standoff gap within the chip and substrate, may result in potential package defects caused by the presence of flux residues. Ensuring optimal surface cleanliness without residues is necessary to prevent potential defects such as leakage current, dendrite growth, and electrochemical migration, all of which can lead to failure.

II. MAIN RESEARCH

To ensure optimal package cleanliness, flux removal is one of the critical processes after the solder reflow process which entails connecting the BTC (bottom terminal connection) of a chip to a substrate using the solder and die attached method. Effective cleaning improves package reliability by ensuring optimal conditions for subsequent processes such as wire bonding, underfill, or molding. This paper will discuss the breakthrough in the cleaning challenges for advanced packaging, specifically the factors which lead to possible package failures such as high density and low standoff height within the chip and substrate, the latest flux formulation, and increases in reliability requirement.

During the soldering process, flux wet the interconnection of BTC of a chip to a substrate by reducing the surface tension, increasing heat transfer, and removing the metal oxide layer on the surface of the solder during the formation of solder joints. If left behind, the flux residues within the solder bumps under these low standoff components can cause ionic residues to migrate which may result in Electrochemical migration. The flux residues can be caused by improper flux removal during the cleaning process, thermal energy, moisture/humidity, and/or voltage. The electrochemical migration occurs by forming a conductive bridge or dendrite across the conductors which leads to the failure of the components.

For advanced packages, which utilize the flip-chip assembly process, underfill and molding processes are important to ensure product reliability. The underfill process is not only developed to prevent damage to the solder bumps from thermal excursions but also to enhance the overall reliability of the packages. This can be confirmed by performing reliability tests, such as humidity test, drop and bend test, or thermal cycling test, on the packages. A cleaning process is essential to ensure adequate wetting during the underfill process as well as determining that no flux residues or contamination underneath the flip-chip remains. It also reduces or eliminates the predominant failure in underfill or molding processes, which is delamination [1].

For the packages that require wire-bonding after the reflow soldering process, flux residues on the chip surface may cause the wire to lift off during the wire-bonding process. While the engineer can attempt to improve the adhesion of the wire by increasing the bonding time, force and energy; this may cause greater deformation, including wire breakage, heel cracks, or chip cracks. Besides, flux residues may cause the adhesion problems during the subsequent molding process, delamination may occur within the EMC layers. Due to the above mentioned scenarios, cleaning usually precedes the wire-bonding process to improve bonding quality and eliminate molding-related failures.

A. *The Cleaning Requirements And Challenges*

The latest advanced packages are trending towards a lower gap between the stacking chip and include new soldering material, either fluxes or solder pastes, to create reliable solder joints. Flux, which is part of the constituent of solder paste, is needed to remove the oxides from the interconnect surfaces so that a reliable solder joint can be formed between the two metallic surfaces. The flux residues left behind around the bumps after the soldering process, especially lead-free solder material, are difficult to remove [2]. Often time we could observe two different scenarios, either space between the bumps are filled with flux (Figure 1) or isolated flux residues surround the bumps (Figure 2). The first scenario resulted in significant cleaning challenges to completely remove the flux residues from the low standoff gap.

Depending on the design of the packages, different bumping technologies are used to develop the bumps on the chip. Printing or electroplating technology may result in higher bump height and wide bump pitch of ~200 µm

Fig. 1: Space between bumps completely filled with flux

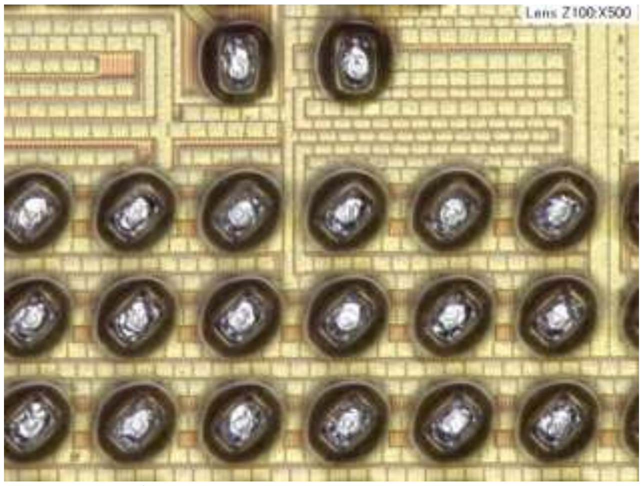

Fig. 2: Isolated flux residues around bumps

compared to Cu pillar or micro bumps technology, which could bring it down to 40µm bumps height or even lower. The key challenge for a cleaning process is to allow the cleaning agents to flow within these smaller gaps. The cleaning effectiveness is not only influenced by the standoff height, but also by the surface area of the chip. To ensure the cleaning agent can deliver within this smaller gap, effective mechanical impingement is very important to create the flow channel underneath the chip and remove the flux residues. The focus of this research is to concentrate on removing flux underneath the low standoff advanced packaging by using a spray-in-air inline cleaning process. (Figure 3)

The spray-in-air inline system typically consists of three steps: wash, rinse, and dry. Substrates travel through the system on a conveyor belt with predetermined belt speed. There are high-pressure spray bars on both the top and bottom of the belt, mainly in the wash and rinse sections. Typically, the wash section is using aqueous-based cleaning agents with a concentration range of 3 – 20% depending on the flux formulation [1], [3]. The rinse section uses deionized water while the drying section is typically heated forced air. The inline conveyorized system is ideal when cleaning advanced packaging components with densely populated bumps, low standoff heights, and a high production throughput requirement.

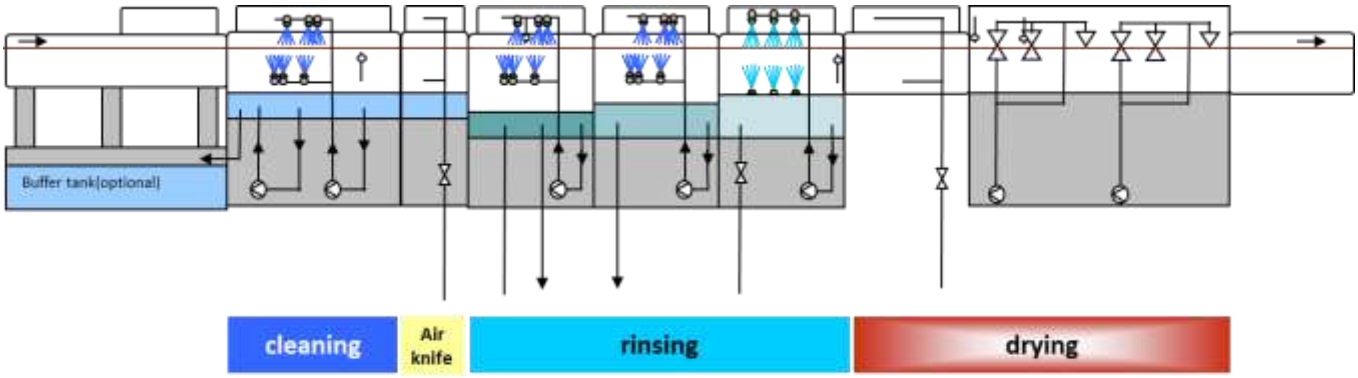

Fig. 3: Schematic of an inline cleaning system

B. Cleaning Process Parameter – Key Factors

When employing a cleaning process, four major influencing factors (Figure 4) "TECT" needs to be considered in order to have an efficient cleaning process. These are thermal energy (temperature), mechanical energy (equipment), chemical energy (cleaning agent), and exposure (wash time) to the chemistry [3] - [4].

Thermal energy or temperature affects the efficiency of the cleaning agent used. In general, you get better results cleaning at a higher temperature than at a lower temperature. The reaction of the cleaning process happens faster and easier as the temperature increases. Also, increased temperature also reduces the surface tension of the cleaning agent which enables it to flow easily under low profile components.

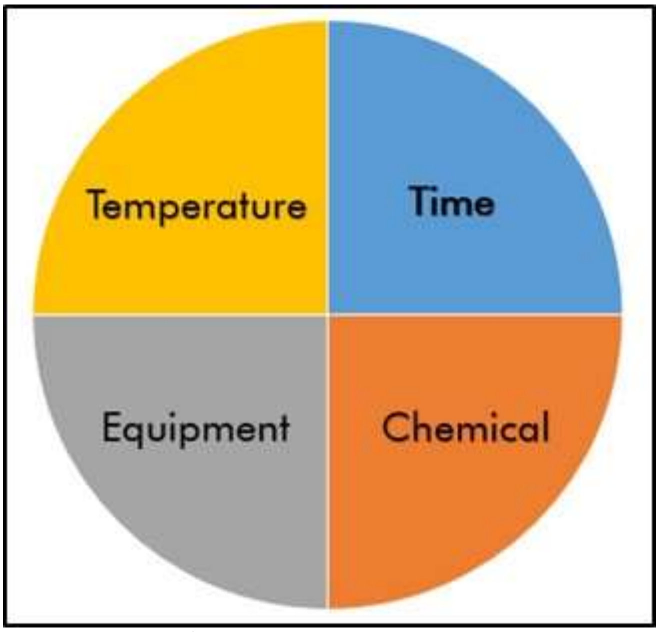

Figure 4: Four major factors

Mechanical energy is the physical attrition of removing residues or contamination from a package surface. Spray-in-air cleaning systems are typically used in the electronic industry for high-volume production lines, which combines the cleaning agent with the physical impact of the spray to effectively remove the flux residues and other contamination from the product surface and from underneath the small gaps. This technology commonly employed in semiconductor advanced packaging cleaning processes and the key parameters that's required to overcome the cleaning challenges for advanced packaging will be discussed in this paper.

Chemical energy is the cleaning agent that should be considered in the cleaning process. The cleaning agent is an essential factor and should be recommended by the chemical supplier to ensure the product is effective for the specific flux residues used in the process as well as the selected cleaning system. The supplier can assist in confirming that the selected cleaning agent shall fulfil the environmental health regulations as well as compatibility with the materials used on the product or package assembly.

The results of the cleaning process depend greatly on the amount of time the parts were exposed to the cleaning agent. In manufacturing conditions, there are often limitations on the time allocated for cleaning. Reduced cleaning time means a shorter cycle time for a part to be produced, thus increasing the production throughput. For a successful desired cleaning process, (Figure 5) engineers must play around with the key parameters to ensure the flux residues were completely removed within the shortest process time.

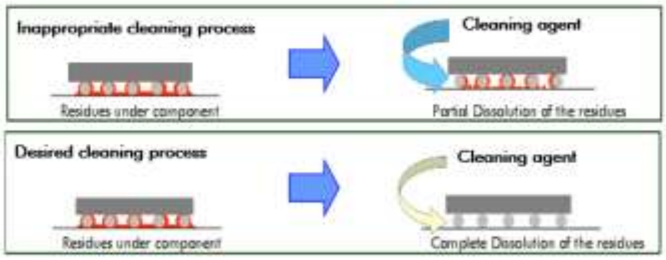

Fig. 5: Desired cleaning process

C. Cleaning Process Parameter – Optimization

Based on four major factors that influence the cleaning effectiveness, a series of designs of the experiment (DOE) is required to overcome the cleaning challenges for low standoff advanced packaging or to achieve the desired cleaning result. For inline spray-in-air cleaning process optimization, two sets of key conditions shall be considered: mechanical parameter and process parameter [1]. Mechanical parameter is the parameter that is generally involved in the cleaning equipment design or configuration, such as nozzle type, nozzle pressure, nozzle angle, and distance within nozzle and substrate.

The type of nozzle defines the cleaning agent distribution pattern during the cleaning process. The type of nozzle is differentiated by several factors such as flow volume, flow velocity, turbulent effects, density, and temperature distribution. (Figure 6)

Solid Stream Nozzle:

- Produces a coherent stream of high-pressure fluid
- Omni direction fluid movement

Delta Stream (V-Jet) Nozzle:

- Flat spray pattern that produces a uniform distribution of small to medium sized droplets
- Even coverage when multiple nozzles are used in a series

The nozzle type also determines the range of spray pressure and spray angle [5] - [6]. The difference in spray pressure will influence the volume of liquid flowing through the nozzle. The higher the flow rate, the greater the impact/momentum of the spray will be. In many cases, engineers thought that increasing the spray pressure would impact the cleaning process. However, if the nozzle is efficient at atomizing the spray (example: misting nozzle), then the increase in tension will only atomize the spray into finer droplets. This inherently will create less momentum; therefore, the increase in the flow rate will hardly affect the impact of the spray. The spray angle chosen for a particular application depends on the spray distribution coverage required [4], [6].

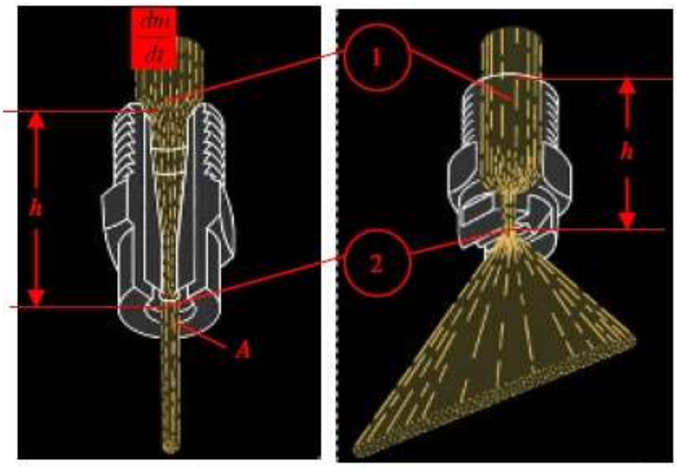

Fig. 6: Solid Stream (left), Delta Stream or V-Jet (right)

The flow of the spray motion under low standoff components in an inline spray-in-air cleaning process is highly complex. The distance of the nozzle to the substrate is vital to ensure uniform distribution, and spray impact to the substrate decreases as the distance from the nozzle increases. The machine supplier will determine the spray distance during the initial manufacturing stage based on the nozzle type and spray angle. Ultimately, you want to ensure that the spray pattern from each nozzle does not interfere with others and that the uniformity of the spray impact is maintained.

The type of cleaning application, flow rate versus pressure characteristic, how the fluid is distributed, the size of droplets that will be produced, the nozzle MOC (compatibility with the chemistry) shall be considered when it comes to the selection of the nozzle type for a particular cleaning process.

The mechanical contribution toward the overall cleaning result is an essential contributor to the distribution of the chemistry and the respective cleaning results. Cleaning under low standoff advanced packaging creates a high degree of requirements on cleaning chemistry, which can remove the contamination in the shortest time and is capable of capillary penetration. The different factors involved in the cleaning process, such as the type of cleaning agent, application concentration, chemistry exposure time, and temperature, are critical parameters that will influence the effectiveness of the cleaning. The chemistry with lower surface energy is ideal for high-speed spraying processes, which have the capability of capillary penetration [7]. Generally, the surface tension of aqueous based cleaning chemistry is <30mN/m.

The traditional surfactant-based chemistry consists of hydrophobic (non-polar / tails) and hydrophilic (polar / heads) groups, which means surfactants contain water-soluble and water-insoluble components. The insoluble hydrophobic group bonds to the contamination while the water-soluble polar group remains in the water phase; as such, it removes the contamination from the substrate surface. By improving the surfactant under dynamic conditions, a new surfactant formulation (Figure 7) with different branching in molecule structure enhances the wetting performance, leading to additional performance improvement. Other water-insoluble tails allow bonding more contamination and thus improve the cleaning performance. As a result, it cleans faster or reacts in a shorter time compared to traditional surfactants [3] - [4].

Fig. 7: Traditional Surfactant and dynamic surfactant

Another cleaning media, based on two-phase emulsification technology or micro phase cleaning (Figure 8), is generated through temperature or solution agitation, and is responsible for removing the non-polar and organics (solvent-like) components of the contamination, and the ionic contaminants are removed by the aqueous phase [1]. Since the ability to keep the organic contaminants in the micro phase is limited by the loading level, the emulsifying substances are released into the aqueous phase. Due to their non-polar organic nature, they precipitate out of the fluid and can be removed by a simple filtration method.

Due to the described cleaning principle, extremely long bath lifetimes can be guaranteed with excellent cleaning results. The microphase cleaning media are tailor-made for different cleaning equipment such as high and low pressure spray systems, spray under immersion, and ultrasonic applications.

The variations in concentration and alkalinity of the cleaning chemistry play an essential role in achieving good cleaning results. The compatibility of cleaning chemistry with the material of the product to be cleaned and equipment parts shall be checked and confirmed before the testing.

Another two factors are wash solution temperature and exposure time. Temperature affects the properties of flux. As temperature increases, the flux becomes softened, thus allowing it to be penetrated by the cleaning agent and easily removed from the product surface by mechanical energy, which means that cleaning time can be shorter if the temperatures are raised. On the other hand, the temperature increase can be harmful to the part surface. Higher temperatures may lead to an increase in aggressiveness of the chemical which results in corrosion or etching taking place faster. Additionally, higher temperature increases the volatility of the cleaning agent, leading to higher evaporative losses, equipment operating, and maintenance costs. It is important to formulate a well-balanced aqueous cleaning agent for this reason.

The longer the part is exposed to the cleaning chemistry, the more contamination will be removed. In the ideal condition, cleaning would take as long as necessary to ensure the part is clean - however, time spent in production translate directly to the cost. Thus, there will always be pressure to minimize the cleaning process cycle time. It requires a good combination of mechanics and chemical energy to achieve the penetration under low standoff height of the advanced packaging components in short periods and a dynamic cleaning process.

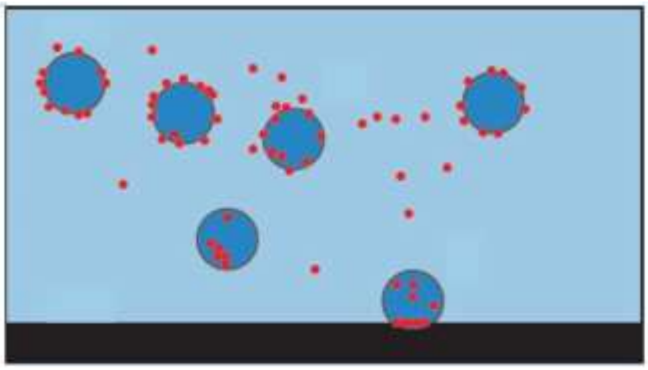

Fig. 8: Microphase cleaning media

III. CASE STUDIES

In addition to the research on significant factors and optimizing parameters of cleaning process, the authors collaborated with an OEM and an EMS provider to examine cleanliness improvement by altering the cleaning process parameter.

A. CASE STUDY A

Customer is a mid-size full-service EMS provider serving customers within the communications and automotive industries. With the new packages with three different types of low standoff components on their substrate, they faced a challenge in underfill process to avoid solder extrusion. Experiments were designed to explore the right chemistry for an inline spray-in-air cleaning system and remove the flux residues trapped within the bumps. Additionally, the cleaning agent must be compatible with the OSP finishing substrate and avoid oxidation on the copper surface after cleaning.

- Substrate Type: FR4 substrate with FCBGA & Cu-OSP finishing
- Die Size: 23 X 23mm, 13.8 X 13.8mm, & 14.5 X 10mm
- Solder Bumps size: 200 µm (max)
- Pitch: 650 µm – 800 µm
- No. of Solder bumps: 900 bumps (max)
- Flux: Rosin based lead-free solder paste

In phase I, the customer provided six substrates of Cu-OSP finishing substrate with FCBGA to be cleaned at the ZESTRON technical center utilizing a spray-in-air inline cleaning system to establish the type of cleaning agent and its parameter. Cleanliness assessment was performed on all substrates at ZESTRON technical center via visual inspection, wherein all FCBGA were removed from the substrate to enable surface inspection underneath them. Based on initial test results, all flux residues were completely removed underneath the low standoff components, and compatible with the OSP finishing surface; a dynamic surfactant-based cleaning agent with inhibitors was chosen at a concentration of 20% and wash temperature of 65ºC.

Based on the phase I results (table 1, 2), customer selected a spray-in-air inline cleaning system using a dynamic surfactant-based cleaning agent. In phase II testing, the customer requested ZESTRON support to optimize the Inline spray-in-air cleaning system at the customer facility considering the mass volume production, type of inline spray-in-air system and process control limits.

Summary of case study A:

- The substrate was completely cleaned on the surface and underneath the FCBGA. A cleanliness assessment was conducted by detaching the component and enabling surface inspection underneath the FCBGA to confirm that no flux residues were left after cleaning. (Figure 9 & 10)
- No deterioration of OSP finishing and no copper oxidation. (Figure 11)
- Pass the underfill process without solder extrusion and delamination.

To ensure the consistency of cleaning results and maintain the production throughput, customer decided to utilize the cleaning parameter 4, using a dynamic surfactant based cleaning agent at 18% concentration, with a belt speed of 40cm/min and 65ºC wash temperature. The cleaning process has been run in customer A production for more than five years.

TABLE 1. CLEANING TRIALS WERE CONDUCTED USING DYNAMIC SURFACTANT-BASED CLEANING AGENT.

Wash Stage	
Equipment	Spray-in-air inline cleaner
Cleaning Agent	Dynamic surfactant-based
Concentration	18%
Conveyor Belt Speed	30, 40, 50, 60 & 70 cm/min (Refer to Table 2)
Pre-wash Spray configuration (Top/Bottom)	2-spray bars / 1-spray bar
Pre-wash Pressure (Top/Bottom)	65 PSI / 45 PSI
Wash Spray Configuration (Top/Bottom)	10-spray bars / 8-spray bars
Wash Pressure (Top/Bottom)	65 PSI / 45 PSI
Pre-wash and wash Temperature	65°C
Rinsing Stage	
Rinsing Agent	DI-water
Pre-rinse Spray Nozzle Configuration (Top/Bottom)	1-spray bar / 1-spray bar
Pre-rinse Pressure (Top/Bottom)	60 PSI / 30 PSI
Pre-rinse Temperature	60°C
Rinse Spray Configuration (Top/Bottom)	7-spray bars / 6-spray bars
Rinse Pressure (Top/Bottom)	60 PSI / 30 PSI
Rinse Temperature	60°C
Final Rinse Spray Configuration	1-spray bars / 1-spray bars
Final Rinse Pressure (Top/Bottom)	30 PSI / 20 PSI
Final Rinse Temperature	Room Temperature
Drying Stage	
Drying Method	Hot Circulated Air
Drying Temperature	80°C

TABLE 2. CLEANING PARAMETER AND RESULTS

Trial #	Belt Speed	Wash Temperature	Test Result
1	70 cm/min	65ºC	Minor residues observed underneath the low standoff gap
2	60 cm/min	65ºC	Minor residues observed underneath the low standoff gap
3	50 cm/min	65ºC	No residues observed underneath the low standoff gap
4	40 cm/min	65ºC	No residues observed underneath the low standoff gap
5	30 cm/min	65ºC	No residues observed underneath the low standoff gap

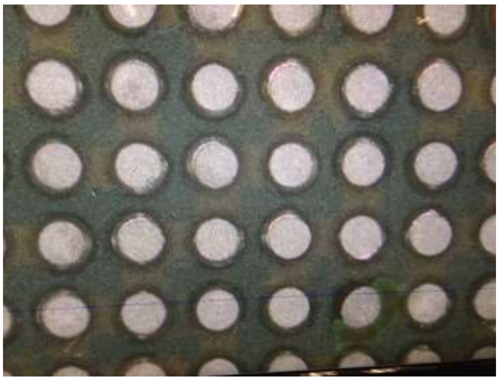

Fig. 9: Fully clean - substrate surface after FCBGA detached

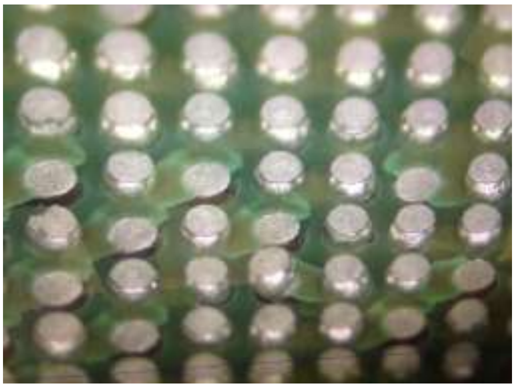

Fig. 10: Fully clean - underneath FCBGA component after detached

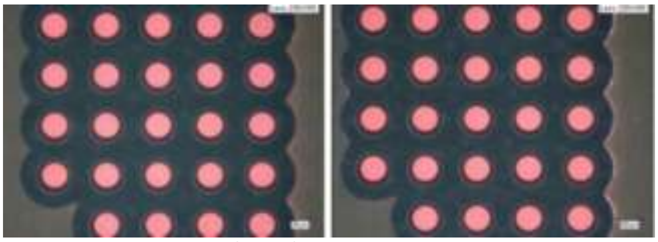

Fig. 11: No deterioration of OSP finishing and no copper oxidation (Left: Before cleaning, Right: After cleaning)

B. CASE STUDY B

Customer is a world-leading OEM producing signal processing packaging supporting its products serving the automotive, communications, and consumer industries. They used no-clean lead-free solder paste for soldering the QFN and DFN components with multiple passive components on their SIP packages and dynamic surfactant-based chemistry using an inline spray-in-air cleaning process. With QFN & DFN having a large ground pad under the components and standoff height between 25 - 50 µm (Figure 12), the cleaning agent faces difficulty in creating flow channels that could effectively remove all residues trapped under the component. (Figure 13)

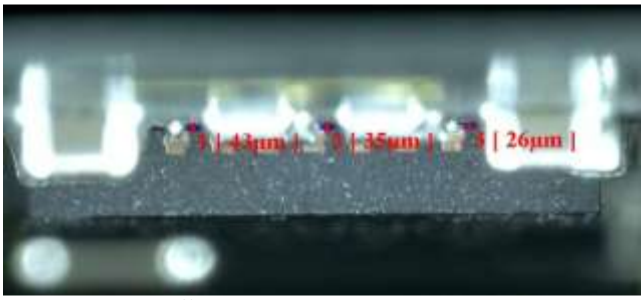

Fig. 12: QFN standoff height

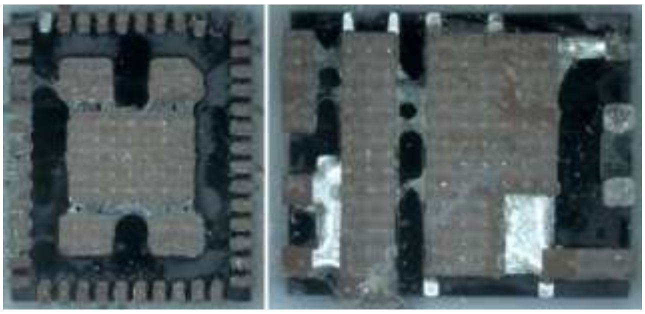

Fig. 13: Flux residues under the QFN & DFN

- Substrate Type: System in Package substrate
- Low standoff components: 3 units of QFN & DFN on each package
- Flux: No-clean lead-free solder paste
- Standoff height: 25 - 50 µm

The existing cleaning process requires two wash passes in a spray-in-air inline cleaner to completely remove the flux residues. The first pass at 0.1m/min belt speed and the second pass at 0.5m/min, the spray pressure for the current process parameter is 100 psi and 90° spray angle V-jet nozzle type with 1.53L/min on each nozzle. The QFN and DFN components were detached after cleaning to visually inspect flux residues underneath them. Minor flux residues were observed underneath the QFN & DFN components after the first cleaning pass, and the flux was completely removed after the second cleaning pass. A set of experiments involving the cleaning agent concentration, wash temperature, and exposure time had been conducted without good results using the existing cleaning system and other cleaning agents. As a result, Customer B is looking for different mechanical configurations and nozzle types.

Cleaning trials were conducted using different types of inline spray-in-air cleaning systems at the ZESTRON Application Technology Center. The study plan looked at different types of spray nozzles and compared them to the existing equipment configuration, cleaning agent concentration, and wash temperature at the customer facility. (Table 3, 4)

New configuration and variable parameter:

- Nozzle type: V-jet with 65° spray angle
- Flow rate: 3.6 L/min
- Spray pressure: 60 Psi
- Wash temperature: 60 – 80°C
- Concentration: 10 – 20%

The first optimization was focused on the nozzle type; the cleanliness was improved by using the low angle high flow nozzle and following the existing cleaning parameters. Minor flux residues were still observed, and further optimization with the wash temperature and cleaning agent concentration was conducted to improve cleanliness. Given the increased cleaning agent consumption at higher wash temperatures, multiple conditions were tested to define the optimum parameters for consistent cleanliness and reasonable chemical consumption.

The best results were achieved with parameters 4 & 5. Considering that the high evaporation rate with the higher wash temperatures at 78°C may result in increased chemistry consumption, final testing was completed using 70°C wash temperature. An additional ten strips of SIP substrates were conducted, showing complete removal of flux residues underneath the QFN & DFN components. (Figure 14 & 15)

Final parameter:

- Dynamic surfactant: 20%
- Belt speed: 0.1m/min
- Wash Temperature: 70°C
- Nozzle type and flow rate: 65° spray angle with 3.6L/min flow rate
- Spray pressure: 60 Psi (4.2kg/cm^2)

TABLE 3. CLEANING TRIALS WERE CONDUCTED USING DYNAMIC SURFACTANT-BASED

Wash Stage	
Equipment	Spray-in-air inline cleaner
Cleaning Agent	Dynamic surfactant-based
Concentration	10, 13, 15 & 20% (Refer to Table 4)
Conveyor Belt Speed	0.1 m/min
Pre-wash Spray configuration (Top/Bottom)	2-spray bars / 2-spray bars
Pre-wash Pressure (Top/Bottom)	60 PSI / 30 PSI
Wash Spray Configuration (Top/Bottom)	6-spray bars / 6-spray bars
Wash Pressure (Top/Bottom)	60 PSI / 30 Psi
Pre-wash and wash Temperature	65°C, 68°C, 70°C, 75°C & 78°C (Refer to Below Table 4)
Rinsing Stage	
Rinsing Agent	DI-water
Pre-rinse Spray Nozzle Configuration (Top/Bottom)	1-spray bar / 1-spray bar
Pre-rinse Pressure (Top/Bottom)	60 PSI / 30 PSI
Pre-rinse Temperature	55°C
Rinse Spray Configuration (Top/Bottom)	6-spray bars / 6-spray bars
Rinse Pressure (Top/Bottom)	60 PSI / 30 PSI
Rinse Temperature	55°C
Final Rinse Spray Configuration	2-spray bars / 2-spray bars
Final Rinse Pressure (Top/Bottom)	30 PSI / 20 PSI
Final Rinse Temperature	Room Temperature
Drying Stage	
Drying Method	Hot Circulated Air
Drying Temperature	100°C

TABLE 4. CLEANING PARAMETER AND RESULTS

Trial #	Wash parameter		Result[a]		Number of Strip tested
	Wash Temperature	Concentration	Chip	Substrate	
1	75ºC	10%	7/15	7/15	1 strip
2	78ºC	10%	1/15	1/15	1 strip
3	78ºC	13%	1/15	1/15	1 strip
4	78ºC	15%	0/15	0/15	3 strips[b]
5	70ºC	20%	0/15	0/15	2 strips[b]
6	68ºC	20%	1/15	0/15	1 strip
7	65ºC	20%	1/15	1/15	1 strip

[a] Result showing residues left versus the number of QFN components inspected.
[b] The best results with complete removal of flux residues underneath the QFN & DFN components

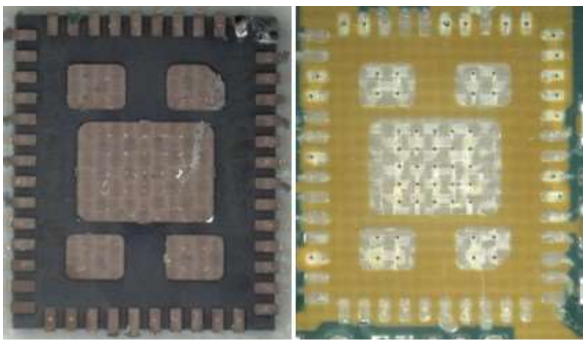

Fig. 14: QFN – Fully Clean.

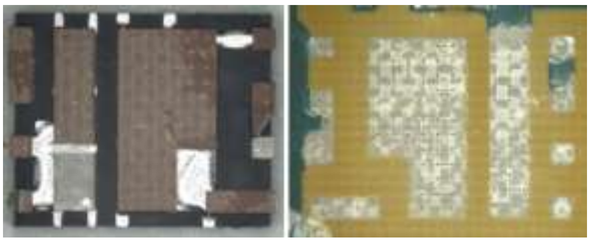

Fig. 15: DFN – Fully Clean.

Summary of case study B:

- The goal of one-pass cleaning was achieved by optimizing the equipment and critical parameters of the chemical.
    - It was found that lower spray angle nozzles, medium spray pressure with higher flow rate had improved the cleaning performance, but minor flux residues remain trapped underneath the QFN & DFN.
    - Further optimizing the wash temperature and cleaning agent concentration led to flux residues underneath the QFN & DFN components being completely removed.
- A good combination of four significant factors was observed in this case that is mechanical energy (spray pressure and flow rate), chemistry energy (concentration), thermal energy (temperature), and chemistry exposure time.

Customer B had employed a new cleaning system based on the configuration tested, and the yield and process cycle time have been improved since then.

C. CASE STUDY C

Customer is a leader in making secure mission-critical technologies specifically for the aerospace and defense industries. They used no clean lead-based tacky flux on their packages and were looking into a cleaning process to effectively remove post-solder flux residues from flip chip assemblies. (Figure 16 & 17) Below are details on the flip chip assembly provided for conducting the study.

- Die Size: 50mm X 32mm
- Solder Bumps: 175 µm tall x 200 µm wide
- Pitch: 300 µm (staggered)
- No. of Solder bumps: 16,540
- Flux: No clean lead-based tacky flux

Phase I study involved cleaning trials at ZESTRON's Application Technology Center to define the best settings to successfully remove the flux residues. Once the process parameters were established, a Phase II study would be conducted at the customer site wherein the chemical would be implemented in their inline cleaner used on the production floor. (Table 5, 6)

Summary of case study C:

- Promising results were achieved during the cleaning trials conducted on flip chip assemblies. The flux residues were successfully removed from the flip chip assemblies in inline cleaner.
    - As part of the Phase I study, visual inspection was conducted to verify the cleanliness level on the flip chip assemblies. Very minor amounts of residues were visible underneath the die
    - It was found that a better fluid delivery system (optimized spray & nozzle configuration and distance of spray nozzles from the packages) would be required to achieve 100% cleanliness under the dies.
- It was also found that the wash spray configuration #4, which is 16 spray bars enhanced intermix, gave the best results when it came to successfully removing the lead-based no-clean tacky flux residues from underneath these flip chip assemblies. (Figure 18)

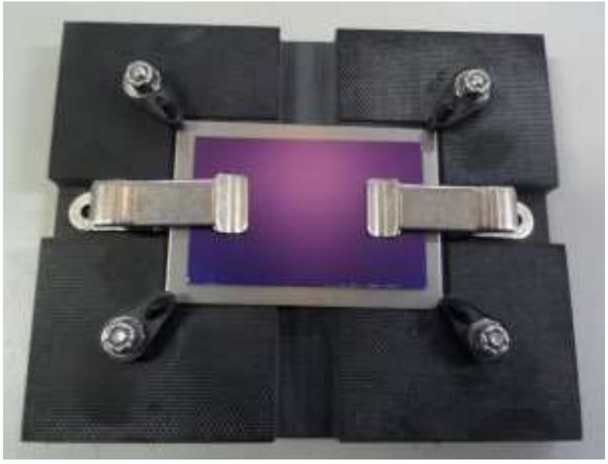

Fig. 16: Flip chip assembly along with carrier used for handling the assembly during the wash process

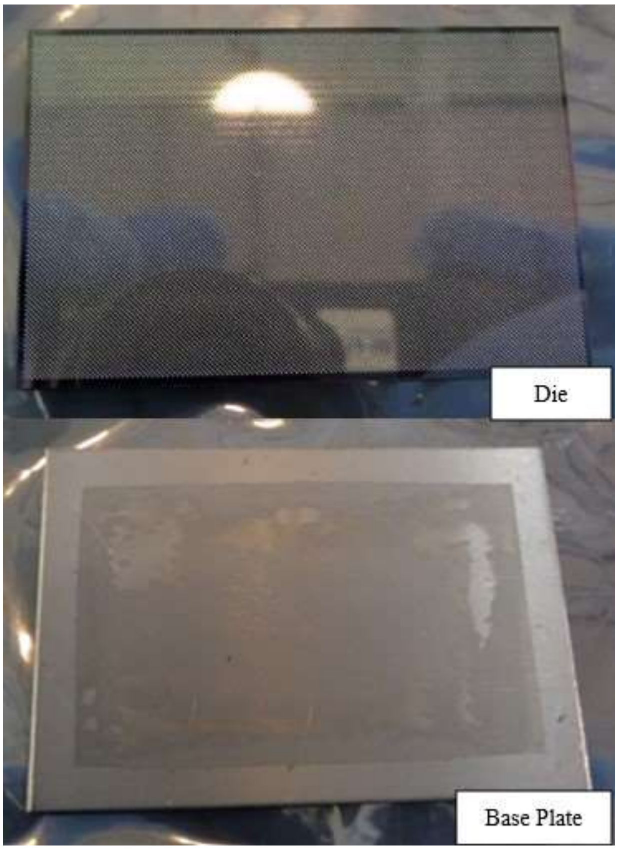

Fig. 17: Die and Base plate after detached from flip chip assembly

TABLE 5. CLEANING TRIALS WERE CONDUCTED USING MICROPHASE CLEANING MEDIA

Wash Stage	
Equipment	Spray-in-air inline cleaner
Cleaning Agent (Concentration)	Microphase cleaning media (15%)
Conveyor Belt Speed	1 ft/min
Wash Spray Configuration	Refer to table 6
Pre-wash Pressure (Top/Bottom)	
Wash Pressure (Top / Bottom)	
Chemical Isolation Pressure (Top/Bottom)	25 PSI / 20 PSI
Pre-wash and wash Temperature	76°C (170°F)
Rinsing Stage	
Rinsing Agent	DI-water
Rinse Spray Configuration	8-spray bar standard intermix
Rinse Pressure (Top/Bottom)	80 PSI / 60 PSI
Rinse Hurricane Pressure (Top/Bottom)	40 PSI / 30 PSI
Rinse Temperature	60°C (140°F)
Final Rinse Pressure (Top/Bottom)	35 PSI / 30 PSI
Final Rinse Temperature	Room Temperature
Drying Stage	
Drying Method	Hot Circulated Air
Drying Temperature (D1)	82°C (180°F)
Drying Temperature (D2)	104°C (220°F)
Drying Temperature (D3)	104°C (220°F)

TABLE 6. SPRAY BAR CONFIGURATION

#	Wash Spray Configuration	Pre-Wash Pressure (Top/Bottom)	Wash Pressure (Top/Bottom)	Wash Hurricane Pressure (Top/Bottom)
1	8-spray bar enhanced intermix (J x V J x V x x H x x V x J V x J)	50 PSI / 30 PSI	60 PSI / 50 PSI	40 PSI / 30 PSI
2	8-spray bar enhanced intermix + 4 Deflector (x D V J V J D x H x D V J V J D x)	50 PSI / 20 PSI	65 PSI / 0 PSI	30 PSI / 15 PSI
3	8-spray bar enhanced intermix (x x V J V J x x H x x V J V J x x)	50 PSI / 30 PSI	60 PSI / 50 PSI	40 PSI / 30 PSI
4	16-spray bar enhanced intermix (V J V J V J V J H V J V J V J V J)	50 PSI / 0 PSI	60 PSI / 0 PSI	20 PSI / 0 PSI
5	12 V-jet spray bars + 4 Deflector (V V D x x D V V H V V D x x D V V)	50 PSI / 0 PSI	75 PSI / 0 PSI	20 PSI / 0 PSI
6	16 V-jet spray bars (V V V V V V V V H V V V V V V V V)	50 PSI / 0 PSI	65 PSI / 0 PSI	20 PSI / 0 PSI

IV. Conclusion:

The standoff height of the component is inconsistent across the underneath of the components, the variation depending on the soldering process, chip, and substrate material. This is causing a cleaning challenge underneath the advanced packaging, which has a high density of solder bumps.

Mechanical energy, chemistry energy, thermal energy, and chemical exposure time are the four significant factors in achieving a good cleaning process. Short of either one factor, the cleaning effectiveness will be significantly impacted.

Based on the customer case studies, selecting the right cleaning agent is essential to ensure good cleaning performance under low standoff advanced packaging and provide good material compatibility and be environmentally friendly.

The spray nozzle configuration significantly improves the cleaning process regardless of chemistry energy, spray pressure, and chemistry flow leading to the breakthrough for removing the trapped flux residues underneath the advanced packaging. The aggressiveness of the cleaning agent is greatly influenced by wash temperature and the wash exposure time. Both factors influence each other and influence overall process cost based on chemical consumption and cleaning process cycle time, which lead to the overall product throughput.

Material compatibility, such as the sensitive surface, must be considered before selecting the cleaning agent. Further process parameter optimization shall be conducted in the actual production site to ensure the stability of the cleaning process.

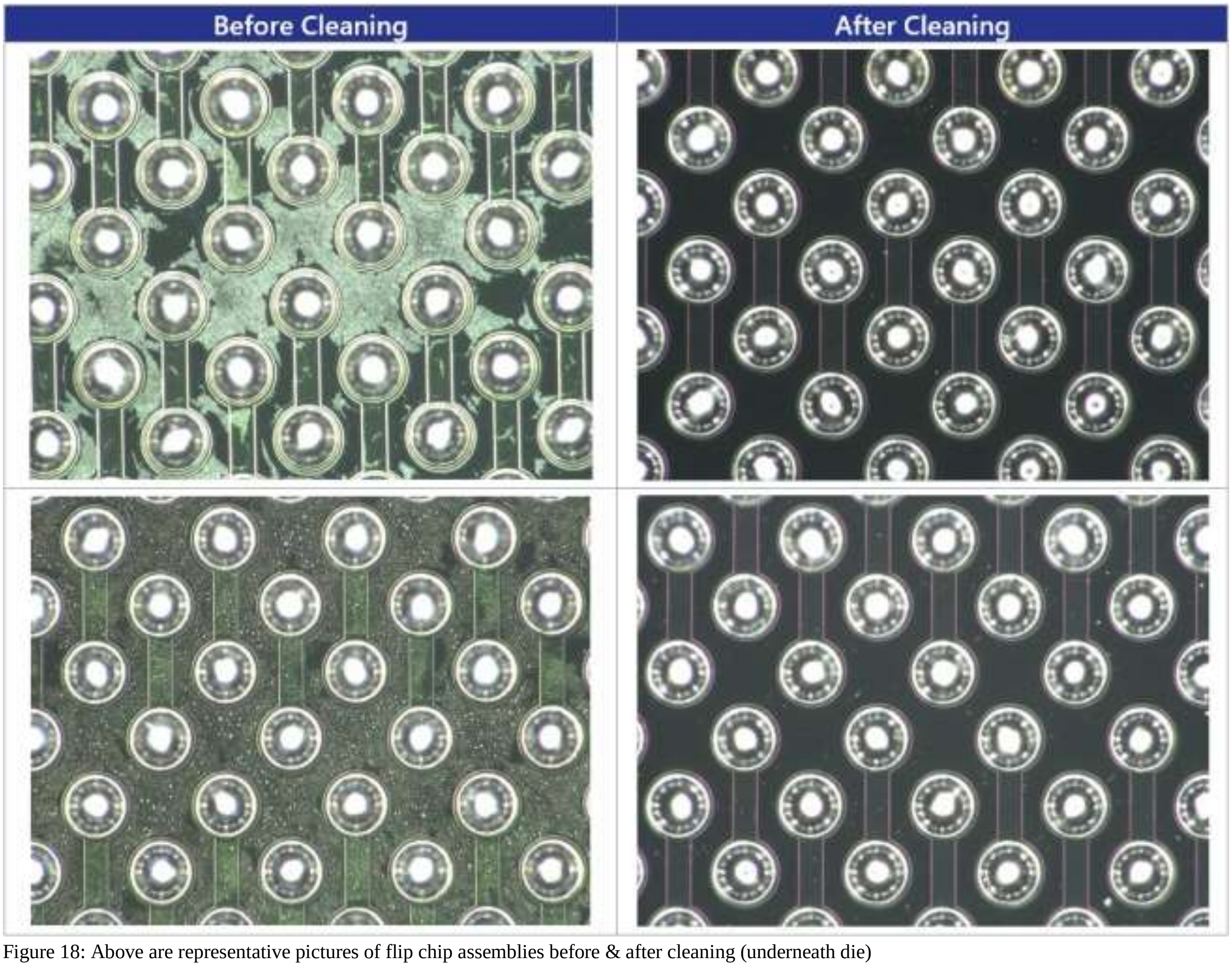

Figure 18: Above are representative pictures of flip chip assemblies before & after cleaning (underneath die)

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