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Vapor Degreasing Fluids Remove Difficult Lead-Free & No-Clean Fluxes from Modern PCBs

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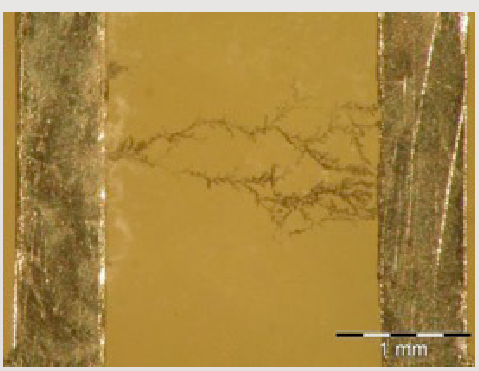

Figure 1: Dendrite growth between two leads

Advancements in the electronics industry are continuously leading to more sophisticated, more intricate and more miniaturized circuitry. In conjunction with increasing regulations on electronics manufacturing, many changes have been made to the electronics world, and thus the circuit board manufacturing process. Lead-free, no-clean and halide-free flux formulations have introduced cleaning obstacles, especially on ever-shrinking component sizes. In order to maintain high cleanliness standards for modern circuitry, more sophisticated cleaning chemistries are required.

The purpose of this paper is to present a cleaning process for difficult no-clean, lead-free and high temperature flux residues on reflowed PCBs. The proposed cleaning solvents are drop-in replacements for outdated solvent technology, or alternatives for elaborate aqueous systems. These cleaning technologies are used in traditional vapor degreaser systems, which allow for fast cleaning times and spot-free results without the need for additional rinsing or drying equipment. The improved formulas have low surface tensions (less than 20 dynes/cm), which allow access to low stand-off components and high solvency to combat the most difficult flux formulations and white residues. Visual and quantitative data are presented to assess the overall cleaning efficiency of the solvent system. Cost analysis is investigated to assess the efficacy of solvent vapor cleaning for PCB industry.

Introduction

The beginning of the circuit board manufacturing industry was, for lack of a better word, messy. Circuit boards were slathered with thick layers of fluxes, primarily foam flux agents, which would coat the entire underside of a circuit board. Aside from the inefficiency and visual untidiness, excessive flux can also lead to electro-chemical migration within the circuit and cause unintentional failures during use. Figure 1 shows an example of dendritic growth between two contacts. This migration can occur due to changes in temperature or humidity. Once the dendrite connects the two leads, the circuit can short and cause failures to the overall system. Needless to say, cleaning quickly became as important to the production process as assembly.

At the start of the electronics cleaning frenzy, solvent cleaning reigned dominant thanks to its ease-of-use, quick processing times and spot-free, dry results. One of the most common electronics cleaners of the 1980s was CFC-113 (more commonly known as FREON 113). Roughly 70% of FREON 113 use was designated to the electronics industry and in 1986 roughly 94 million pounds of FREON 113 was used in electronics manufacturing[1]. The 1980s also saw the explosion of personal electronic devices including personal computers, video game consoles, personal music players and countless other circuit board-driven products. The increase in circuit board production lead to a surge in the use of cleaning solvents, and thus solvent emissions. Before long, the connection was made between the increase in solvent emissions and our diminishing ozone layer. In 1988, the US ratification of the Montreal Protocol on Substances that Deplete the Ozone Layer forced the cleaning industry to discontinue the production of CFCs[2]. The Clean Air Act Amendment of 1990 increased the enforcement of ozone depleting substances and further restricted the cleaning industry[3]. Electronics manufacturers found themselves momentarily without cleaning options. Fortunately, the flux manufacturers were there to pick up the pieces with the development of no-clean and low-residue fluxes. Manufacturers who had previously been slathering boards with fluxes now found

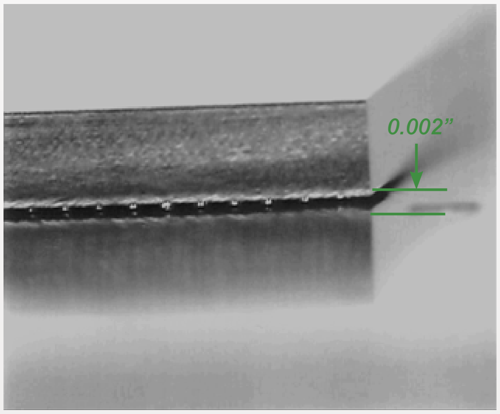

Figure 2: Integrated circuit on a substrate

themselves using more sophisticated flux application methods, such as vapor phase and reflow soldering techniques, which require less flux application and produce less residue. By 1989 electronics cleaning became a novelty for only the high-reliability circuit industry. Most manufacturers of high-throughput and short-life circuitry, such as those found in toys and inexpensive electronics, stopped cleaning all together. Those who did clean boards converted to alcohols, or soap and water systems. Despite the formulation of CFC alternatives such as n-propyl bromide and hydrofluorocarbons, the electronics industry continued to move away from solvent cleaning until recently.

During the past decade the growing demand for smaller and smaller electronics has forced circuit board manufacturers to miniaturize circuits, and pack more components into tighter spaces. This miniaturization causes a greater likelihood for even minor electro-migration to bridge components and result in failures. Figure 2 depicts an example of a low standoff integrated circuit component on a substrate. As you can see, the distance between the component and the substrate is only 0.002 inches, and several solder balls hold the component in place. A very low surface tension liquid would be required to remove any debris, flux, or residues from the component underside. It is also understandable how even slight dendritic growth or debris could impact such an intricate circuit.

Though no-clean flux formulations are intended to remain on the board and leave minimal residues, these residues are still capable of attracting moisture, inhibiting conformal coating uniformity, or simply leaving aesthetically unacceptable visual results.

Further regulation restrictions have also forced electronics manufacturers to reduce or remove leaded ingredients from solder; this has forced solder and flux manufacturers to reformulate to accommodate higher melting-point metals. These high temperature soldering jobs often leave burned flux residues, which are more difficult to clean. Although the aqueous cleaning industry has been the superior cleaning guru for the past 10 years, these new soldering hurdles have shed light on the many limitations of water. The surfactant formulations are continuously advanced to assist in removing these difficult residues, however, the high surface tension of water still poses a problem when it comes to rinsing under intricate components. If the surface tension of the mixture manages to allow for cleaning under the low standoff circuitry, it is unlikely that the deionized water will penetrate the same areas to remove the residing surfactants. Other factors to improve cleaning include operating temperature, chemistry concentrations, rinse cycles, water purity and spray/wash mechanisms. With all of these different elements, it is easy to be overwhelmed with numerous options that provide less than ideal cleaning.

Electronics manufacturers who have considered solvent cleaners have also been met with shortcomings; ionic removal is a difficult task for many hydrofluorocarbon based solvents due to the lack of polarity. However, recent solvent and co-solvent formulations coming to the market have proven capabilities at removing ionic contamination and cutting through burned-on residues. Most importantly, these advanced solvent formulations offer new benefits to solvent-cleaning without the need for new equipment. These solvent formulations, whether co-solvents or mono-solvents, operate the same way as hydrofluorocarbon solvents in current two-sump vapor degreasers. Manufacturers who are currently using a vapor degreasing

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process but looking for new solvents to improve cleaning will be able to do so without additional capital investment in equipment.

Vapor Degreasing

The original concept of vapor degreasing revolved around vapor-only cleaning. Vapor degreasing equipment was manufactured with one primary tank, where the solvent could be heated to form a vapor layer of solvent. Room temperature parts placed into this vapor layer would cause the solvent vapors to condense on the part's surface, and cause the oils and debris to be solubilized and rinsed off as the solvent dripped off the part. One of the primary benefits of this type of cleaning system is that cleaned parts are only ever in contact with pure, clean solvent in the vapor zone. Additionally, as the cleaned parts heat to the temperature of the vaporized solvent, the liquid will stop condensing and the part can be slowly removed from the vapor blanket to allow all remaining solvent to vaporize and leave the part dry and spot-free.

Modern vapor degreasers have been modified to allow for liquid immersion in addition to vapor cleaning. This has further improved the ability for solvent to penetrate intricate geometries and solubilize difficult soils. Many modern machines are equipped with two immersion tanks for cleaning: the “boil sump”, which contains the heating elements to produce the vapor zone, and the “rinse sump”, which collects the clean distillate. These machines function, essentially, as industrial stills; the liquid is boiled in the boil sump, condensed in the vapor zone, and then collected in the rinse sump as pure solvent. This means that even as contamination is introduced into the machine during the cleaning process, clean solvent is continuously distilled into the rinse sump, allowing for the contamination to stay trapped in the boil sump. Modern equipment also benefits from improved cold traps, which restrict solvent emissions and improve the distillation process. Figure 3 illustrates the design of a modern two-sump vapor degreaser with two sets of cooling coils. The freeboard chiller coils help reduce humidity from the environment, which can otherwise cause diffusional losses of solvent. The primary condensing cooling coils act as the boundary for the solvent vapors. Once the hot vapors reach the first set of cooling coils, they condense and drip into the water separator and the rinse sump. Moving parts into and out of the machine may cause disruptions in this vapor blanket; the freeboard chiller coils also prevent loses from occurring due to vapor disturbances.

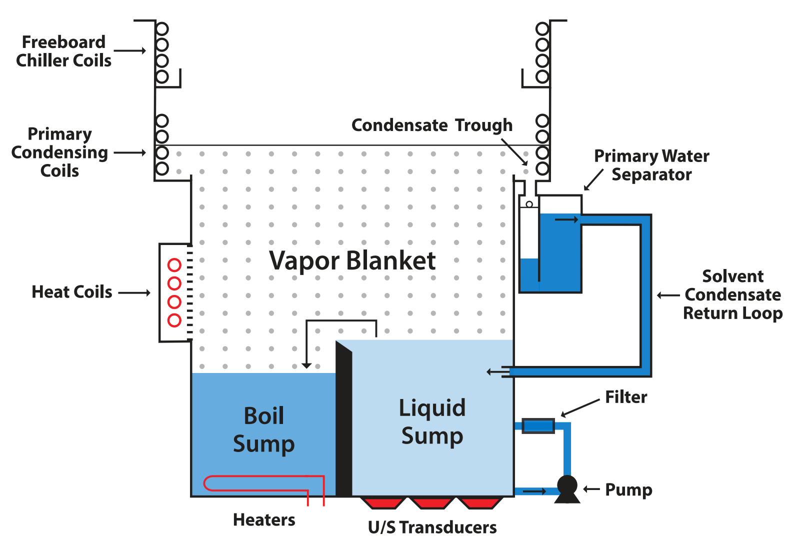

Figure 3: Modern two-sump vapor degreaser.

The cleaning process in a vapor degreaser typically requires only minutes to complete. Although cycle times vary based on part geometry and soil difficulty, most cleaning cycles require less than 15 minutes to completely clean and dry a rack of parts. Cleaning a circuit board can take place in either one or multiple immersion sumps, depending on the difficulty of the flux residue. For RMA and rosin-based fluxes, cleaning can typically occur in the vapor zone and rinse sump only. Difficult no-clean and high-melt-point fluxes may require immersion in both the boil sump and the rinse sump. The boil sump is very important to the cleaning process, as the hot solvent can provide better solubilizing properties. Additionally, as flux residues begin to accumulate in the boil sump, the dissolved residues actually help the solubility; in the cleaning industry, it is well known that "like dissolves like". Some electronics manufacturers express concerns about immersing circuitry into the "dirty" boil sump due to recontamination or damage from solid particulate, such as solder balls. However, recontamination is avoided by following the boil sump immersion with a rinse in the rinse sump, and solder balls can be contained by using an auxiliary still or filtering the boil sump fluid, which is common in most vapor degreasing equipment. Once the boards have been cleaned in the boil sump and rinsed in the rinse sump, the vapor zone will remove any remaining particulate or residue with clean distillate and allow for instant drying as the boards are removed from the equipment.

Cost of Ownership

Although cleaning is crucial to many electronics industries, it is still only one aspect of the total manufacturing process, and so the cost of cleaning needs to remain reasonable to the overall manufacturing cost. Fortunately, the cost-per-cleaning for the vapor degreasing process is considerably low and can be comparable or less than that of aqueous cleaning. When comparing solvent vapor degreasing to aqueous cleaning systems, there are many factors to consider including capital investment, equipment footprint, power supply, cleaning time, detergent/solvent supply, and waste disposal. In other words, a vapor degreaser and an aqueous machine capable of cleaning the same number of parts-per cycle will have different overall costs, thus different costs-per-part cleaned. Aqueous systems typically have larger working footprints, power requirements, and longer cleaning cycles; these are due to the need for several washing and rinsing stations, high temperature inputs, and reliance on mechanical spraying and washing mechanisms. Although vapor degreasers require less time and overall maintenance, the cleaning solvents are typically more expensive than aqueous detergents; however, properly maintained equipment should retain solvent, and the distillation process keeps solvent pure for continuous use.

Table 1 compares cost and maintenance differences of an aqueous system and a vapor degreasing system using the same sized basket and cleaning the same number of parts. As expected, many of the maintenance and operation requirements of the aqueous system are greater than those of the vapor degreasing system. However, the cost of the solvent is three times greater than that of the aqueous detergent. There are certainly other cleaning processes outside of vapor degreasing and aqueous cleaning that are less costly, such as manual cleaning with water or solvents, though these processes tend to compromise the effectiveness of cleaning. The most important factor to keep in mind when comparing cleaning processes is the outcome; it does not matter how much cheaper a processes is if it does not work. In most industries, the cost of cleaning is less than the price of product failure.

Table 1: Operation of Aqueous vs. Vapor Degreasing

Comparing an aqueous in-line system and an open-top vapor degreaser both using a 1600in^3 basket.

	Aqueous	Vapor Degreasing
Capital Investment	>$100,000	<$100,000
Power	~20kW/hr	~7kW/hr
Footprint	~40sqft	~20sqft
Cleaning Cycle	20-25 minute	10-15 minute
DI Water	30-40 gallons/hr	None
Waste Treatment	100,000 gallon/yr	10 gallons/yr
Detergent/Solvent	$50/gallon	$160/gallon

Current Study

The MicroCare Critical Cleaning Lab conducted cleaning trials in order to evaluate the cleaning capability of new vapor degreasing chemistries on difficult flux and solder paste formulations. The study evaluated three flux formulations and seven solder pastes containing leaded or unleaded ingredients. The pastes and fluxes were chosen based on customer recommendations and market trends. The flux pastes evaluated were AIM 217, AIM No-Clean Paste Flux and AIM Flux Pen. The solder pastes that were evaluated were AIM M8, AIM RMA258-15R, Loctite GC3W, Alpha OM350, Indium 8.9HF1, Loctite GC10 and Indium SMQ92-J. The Loctite GC3W, Alpha OM350, Indium 8.9HF1 and Loctite GC10 are all lead-free, no-clean formulations. The AIM M8, AIM RMA258-15R and Indium SMQ92-J are leaded pastes. The Loctite GC3W was the only water-soluble paste chosen for this study.

Evaluated Fluxes & Solder Pastes

Paste/Flux	Type	No-clean	Lead-Free
AIM 217	Flux	✓	NA
AIM NC Paste Flux	Flux	✓	NA
AIM Flux Pen	Flux	✓	NA
AIM M8	Solder Paste	✓	✓
AIM RMA258-15R	Rosin-Based Solder Paste	✗	✗
Loctite GC3W	Water-Soluble Solder Paste	✓	✓
Alpha OM350	Solder Paste	✓	✗
Indium 8.9HF1	Solder Paste	✓	✗
Loctite GC10	Solder Paste	✓	✗
Indium SMQ92-J	Solder Paste	✓	✗

Two specially formulated solvents were selected for the cleaning trial and were compared to a more common, hydrofluorocarbon solvent. The specialty vapor degreasing solvents will be referred to as Solvent A and Solvent B. Solvent A is composed of a blend of trans-dichloroethylene, alcohol and hydrofluorocarbons with a proprietary additive to improve flux removal. Solvent B is a non-chlorinated blend of hydrofluorocarbons, alcohol and proprietary nonvolatile ingredients. Both chemistries can be used in modern two-sump vapor degreasers without modification, so long as the equipment has adequate cooling. These solvent compositions were compared to a common SNAP-approved flux-cleaning solvent with a composition of hydrofluorocarbons, trans-dichloroethylene and an alcohol; this solvent will be referred to as "Classic Solvent".

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Table 2: Evaluated Cleaners

Cleaner Designation	Cleaner Formulation
Solvent A	Hydrofluorocarbons, alcohol, transdichloroethylene, proprietary additive
Solvent B	Hydrofluorocarbons, alcohol, proprietary, non-volatiles
Classic Solvent	Hydrofluorocarbons, transdichloroethylene, alcohol

Surface Insulation Resistance (SIR) testing was performed in order to evaluate the boards for failure due to dendritic growth. SIR testing is common in electronics manufacturing in order to verify that changes in temperature and humidity will not cause unexpected failures in the field. Many no-clean fluxes and pastes have been formulated to pass SIR evaluations, though not all. In our study, we found that most of the no-clean pastes were capable of passing SIR evaluation without cleaning; however, three of the no-clean pastes did suffer failures during the evaluations when they were not cleaned.

PROCEDURE

Visual Evaluation

A visual analysis was preformed to compare the cleaning efficiency of Solvent A, Solvent B and the Classic Solvent. B-36 coupons were reflowed with three different no-clean solder pastes: Indium NC-SMQ 92 SAC305, Indium 8.9HF1 and Alpha OM-350 96.5sn/3.0Ag/0.5C. The boards were prepared and reflowed by Altek Electronics in Torrington, CT. Ten boards were prepared with each paste. An additional set of ten B-36 boards was prepared with AIM NC217 flux at the MicroCare Critical Cleaning Lab according to the product's technical specifications. Boards were visually examined at 15x and 40x magnification before cleaning. One set of traces was photographed for each paste type before cleaning as a reference.

The boards were separated by flux type and labeled to represent the flux/paste and the cleaner to be used. Three boards of each paste were cleaned in each of the solvents: Solvent A, Solvent B and Classic Solvent. The remaining boards were retained for future cleaning. Cleaning was conducted at the MicroCare laboratory in a Branson B452R two-sump vapor degreaser, and an Ultronix BBMLR120 with retrofitted Zero-0-Coils and an automatic hoist. No ultrasonic agitation was used during cleaning. Each vapor degreaser was fitted with a basket of approximately 500in^3 in size. The three boards of the same paste were cleaned simultaneously. The three boards were stacked vertically in the baskets with wire boundaries on each side to keep the boards from touching. The cleaning cycle remained consistent for each set: 30 seconds in the vapor zone, 5 minute immersion in the boiling liquid, 5 minutes in the rinse liquid and 30 seconds in the vapor zone. The timing was controlled and monitored by an operator or by a timed automatic hoist when available. After the final 30-second vapor rinse, the boards were held in the cooled freeboard area for approximately 30 seconds to allow for any excess solvent to drip off. After cleaning, the boards were immediately inspected at 15x and 40x magnification and evaluated for cleanliness. One representative set of traces was photographed for each paste and each cleaner.

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SIR Evaluation

The two advanced solvent formulations, Solvent A and Solvent B, were selected for cleaning evaluation with visual inspection and SIR analysis. The Classic Solvent was omitted from the second round of visual analysis and the SIR testing due to the poor cleaning results of the first visual evaluation. A selection of three fluxes and seven solder pastes were evaluated. A total of 98 B-24 boards were prepared for the SIR testing: 6 boards were supplied without flux- 3 were cleaned in Solvent A and 3 were cleaned in Solvent B; 60 boards were reflowed with flux/paste- 30 were cleaned in Solvent A and 30 were cleaned in Solvent B; 3 boards of each flux/paste were reflowed and left un-cleaned as controls; 2 boards were supplied with no flux/paste and were un-cleaned as blanks. Each of the boards contains four pads of traces. No components were attached to the pads. All of the B-24 boards were prepared and reflowed by the AIM Solder lab in Montreal, Canada, per IPC-J-STD-004A controls. Cleaning was again conducted at the MicroCare Critical Cleaning Lab in a Branson B452R two-sump vapor degreaser, and an Ultronix BBMLR120 with retrofitted Zero-0-Coils and an automatic hoist. No ultrasonic agitation was used. All boards were visually inspected before any cleaning was preformed. The boards were visually examined at 15x and 40x magnification and one of the four pads was photographed for each representative paste/flux.

The boards were separated by flux type and labeled to represent the flux/paste and the cleaner to be used. Three boards of the same flux type were cleaned simultaneously in one of the solvents. The cleaning process used for all solvents was the same as the visual evaluation cleaning: 30 seconds in the vapor zone, 5 minute immersion in the boiling liquid, 5 minutes in the rinse liquid and 30 seconds in the vapor zone. The timing was controlled and monitored by an operator or by a timed automatic hoist when available. After the final 30-second vapor rinse, the boards were held in the cooled freeboard area for approximately 30 seconds to allow for any excess solvent to drip off. The boards were immediately inspected again at 40x magnification, photographed, packaged in ESD anti-static bags and labeled. Visual evidence was recorded with photographs and an overall assessment of the cleanliness was determined. The packaged boards were boxed and shipped out to the National Technical Systems laboratory in Baltimore for SIR evaluation. The SIR method followed IPC-TM-650 Method 2.6.3.3, requirements per IPC J-STD-004A, paragraph 3.2.4.5. After testing, all boards were sent back to the MicroCare Critical Cleaning Lab for disposal.

Results

Visual analysis of the boards prior to and after cleaning showed positive effectiveness of the cleaners. Visual analysis was conducted on each pad of traces on each board at 15x and 40x magnification. The visual results were approximately quantified using a percentage system: if all three boards of the same paste set had no visible residue after cleaning they were designated 100%; if one-three visible contaminated traces were found on the three boards of a paste set they were designated 90%; if more than a total of three contaminated traces were found on the three boards of a paste set they were designated 50%; if boards contained mostly contaminated traces with softened or dried residues they were designated 10%. Contamination is defined as any solid or liquid substance found on or around a trace where there was once flux. The full set of results is summarized in Table 3.

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Table 3: Flux Cleaning Results

Flux	SIR Results	Visual Results Classic Solvent	Visual Results Solvent A	Visual Results Solvent B
AIM 217	A: Pass B: Pass	100%	100%	100%
AIM NC Paste Flux	A: Pass B: Pass	NA	100%	100%
AIM Flux Pen	A: Pass B: Pass	NA	100%	100%
AIM M8	A: Pass B: Pass	NA	100%	100%
AIM RMA258-15R	A: Pass B: Pass	NA	100%	90%
Loctite GC3W	A: Pass B: Pass	NA	100%	100%
Alpha OM350	A: Pass B: Pass	10%	50%	100%

The rosin-based and RMA fluxes were fully cleaned (100%) in both classic vapor degreasing solvents and in the advanced solvent formulas. No-clean fluxes cleaned in classic vapor degreasing solvents resulted in only 10% cleaning and formed white ionic residues. Solvents A and B fared better on the no-clean formulations; most of the solder pastes could be entirely removed by at least one of the formulations. A visual cleaning comparison of the Classic Solvent and Solvents A and B can be seen in Table 4. The Indium 8.9HF1 and Indium SMQ92-J were the most difficult for both of the solvent formulations to remove. Visual comparisons of Indium SMQ92-J can be seen in Table 5.

Table 4: Visual Cleaning Comparison 1

Cleaner	Indium 8.9HF1
Reflowed Paste	
Classic Solvent	

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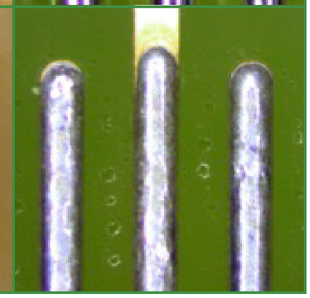
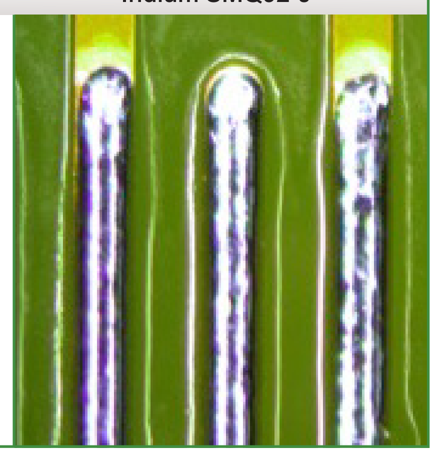
Solvent A		
Solvent B		

Solvent A was able to clean 7 out of 10 fluxes to 100% flux removal and Solvent B was able to clean 6 out of 10 fluxes to 100% flux removal. The lead-free, no-clean formulations were the most difficult to clean, though all formulations had at least 50% of the flux removed during the cleaning cycle.

The SIR testing showed favor to the advanced solvent formulations; all of the boards that were cleaned in Solvents A and B passed SIR testing, while some of the un-cleaned fluxes suffered failures. This verifies that even though cleaning was not 100% successful on some of the boards, the residues were not altered in a way that caused electrochemical migration when exposed to heat and humidity.

Table 5: Visual Cleaning Comparison 2

Cleaner	Indium SMQ92-J
Reflowed Paste	

Conclusion

Flux and solder formulations with better safety profiles and processing efficiency hold an importance in modern electronics assembly; however, these benefits come with hurdles of their own, including potentially detrimental residues. Processes that require high-reliability electronics require high-reliability cleaning. Modern vapor degreasing techniques and solvent formulations are environmentally conscientious, time efficient, safe and effective on some of today's most difficult soils. Although ionic residues may be an issue for current vapor degreasing solvents, there are new technologies available to combat even the toughest flux residues. Solvents A and B showed major visual improvements over the Classic Solvent when cleaning no-clean and lead-free flux residues. The advanced solvents were able to remove at least 50% of the flux residue from all of the different flux formulations during the cleaning cycle. Increasing cleaning cycle times or utilizing ultrasonic agitation may be able to further improve the visual results. The SIR evaluation confirmed that the cleaning formulations did not impact the circuit operation and that any remaining residue was not detrimental to the circuit performance.

Acknowledgements
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