Spray Fluxing—It's Not the Same Old Game

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Spray fluxing has advanced to become a versatile technique, capable of performing a variety of tasks.

Applying solder flux using spray methods has become dominant in many electronics assembly applications, from standard wave soldering of printed circuit boards (PCBs) to selective fluxing of components and assemblies. Spray fluxing began in the late 1980s, when no-clean fluxes first appeared as alternatives to the banned Freon for cleaning flux residues from PCBs. However, these new fluxes did not perform very well when applied by traditional foam or wave techniques. Spray fluxing eliminated the problems associated with foam and wave fluxing: lack of process control; solvent evaporation; non-uniform flux deposition; the constant need to titrate; and frequent dumping of the flux pot.

However, no-clean fluxes have their own process challenges. Because the percentage of active materials is generally low in comparison to traditional fluxes, process control becomes very important. Some critical process parameters in spray fluxing include: uniformity of deposition; repeatability of deposition from board to board; the amount of flux deposited per unit area; preheat temperature and temperature profile; the ability of the flux to penetrate up through-hole barrels to the topside and solder pot temperature. If any parameter is outside acceptable limits, the process is likely to produce poor results. Table 1 summarizes some of the process issues related to spray fluxing.

Other new challenges have emerged as the assembly industry seeks to move forward in terms of quality, cost of manufacturing and environmental friendliness. Some factors that have placed additional demands on wave soldering include: more demanding defect rate reduction requirements; lower cost board materials; the trend to less expensive organic solderability preservative (OSP)-coated boards; increased pallet and board widths (up to 24 in.); and increased pressure on manufacturers to switch to volatile organic compound (VOC) free fluxes. The manufacturers of fluxes, wave solder machines and spray fluxers face challenges in meeting these new requirements.

Spray fluxing equipment manufacturers must assure that their equipment operates with all types of flux, provides uniform, repeatable deposition over a wide range of flow rates, and can deliver a spray with sufficient velocity to achieve good topside fillets, a particularly difficult assignment with VOC-free fluxes on bare copper boards. In addition, the optimum spray fluxer must be reliable and easy to maintain.

Parameter		Impact
Preheat temperature	Too low	Bridges, voids, solder balls, pinholes, dewetting, cold joints, blow holes, poor solder flow
	Too high	Bridges, voids, warpage, dewetting
Solder temperature	Too low	Poor solder flow, icicles, excesive residue, cold solder joints, dull fillets, cracked fillets
	Too high	Dewetting, discolored plated-through holes, warpage
Board type (OSP or HASL)		OSP boards more difficult to solder; Repeated reflow degrades OSP coating
Flux activity		High activity produces better sodlerability and less flux usage
Deposition uniformity		Poor uniformity leads to excessive residue, skips, poor top side fillets
Deposition density µg/in²	Too low	Poor solderability
	Too high	Excessive residue
Flux type (VOC-free/alcohol)		VOC-free requires hotter pre-heats, more difficult on OSP-coated boards

TABLE 1: Spray fluxing process parameters and impacts.

The acceptable tolerance for deposition uniformity has become tighter as quality standards have been raised. In the early days of spray fluxing, 25 percent variations in uniformity were considered acceptable. Today, users expect less than 10 percent variation, which all leading spray fluxers can achieve. Repeatability, the variation in deposition from one PCB to the next, is on the order of 1 percent.

Other operating conditions are also important. To achieve good topside fillets, the spray fluxing

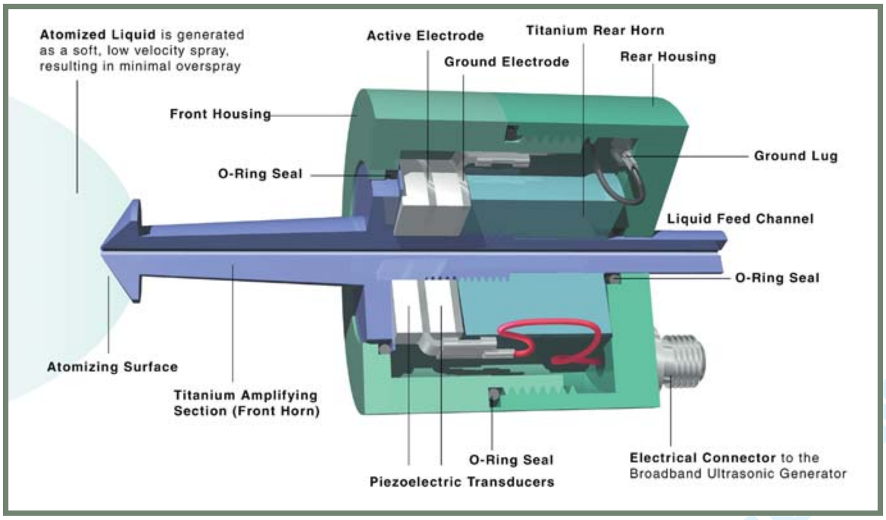

FIGURE 1: Cross section of an ultrasonic nozzle.

equipment must have high velocity spray capability, and the spray must be directed perpendicular to the board to eliminate shadowing effects. These requirements are particularly important for OSP-coated boards.

Not uncommonly, a process that generates new benefits also creates new problems. For example, one problem with OSP-coated boards is that the coating degrades when thermally cycled, such as when a board is subjected to one or more reflow cycles. Mixed-technology boards are also susceptible to the effects of thermal cycling. As the coating degrades, it oxidizes the underlying copper pads, particularly on the bottom side and in the plated-through holes, where flux is not applied until the wave-soldering process. In turn, reduced solderability results during wave soldering.

The initial thickness of the coating is reduced by as much as a factor of two on exposure to reflow temperatures. The reduced thickness serves as less of a diffusion barrier for oxidation of the underlying copper. Moreover, many OSPs are complex organometallics of copper, which are subject to oxidation upon exposure to high oxygen levels at high temperatures. Hence, the remaining layer of the coating after one reflow in air requires more flux for solder wetting to occur.

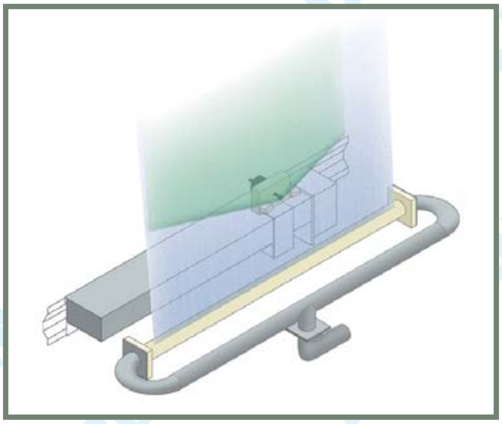

FIGURE 2: Typical ultrasonic high-velocity spray fluxer.

Spray Fluxers

Two basic types of spray fluxers have proven successful over the years: stationary types, in which the spray nozzle remains fixed relative to the substrate; and reciprocating types, in which the spray assembly traverses the width of the substrate at an angle. In some reciprocating systems, this motion is made synchronous with the movement of the conveyor.

Both types can provide acceptable results, although the reciprocating type is prone to mechanical failure because of its moving spray mechanism. In addition, the deposition uniformity of reciprocating spray fluxers is inherently flawed by the overlap in coverage required between successive passes across the assembly. Recently, some manufacturers of reciprocating spray fluxers have improved the overlap issue by spraying only in one direction: the traverse during which the arm motion has a velocity component that is in the same direction as the path of the PCB.

Although some manufacturers of reciprocating spray fluxers claim uniformity as low as 1 percent, the physics involved puts such claims in question. At present, the end user has no way to assess the claims of any spray fluxer manufacturer. Accordingly, the industry should develop standardized methods for measuring and reporting deposition uniformity.

Stationary spray fluxers are inherently reliable because they have no moving parts. All spray fluxers must consider the possibility of the nozzle clogging. Pressure operated nozzles generally have small outlet orifices so care must be taken to keep them free from blockages. The typical cleaning method of small orifices is to regularly purge them with a pure solvent such as alcohol or water.

In contrast, ultrasonic spray nozzles are impervious to clogging. A typical ultrasonic nozzle is shown in Figure 1, and the spray assembly in which it is installed is shown in Figure 2. The spray from the nozzle is entrained in an air stream to produce uniform spray patterns, which can be varied up to 24 in. in width by adjusting the airflow. The orifices associated with ultrasonic nozzles used in whole board PCB assembly are nearly 0.1 in. in diameter, so blockages are virtually impossible. Spray fluxing equipment using stationary ultrasonic nozzles has proven to be very reliable.

Selective Fluxing

Spray fluxing has advanced well beyond its original intent of spraying entire PCBs. Selective fluxing is now used for applying flux to precise areas on through-hole PCBs, spraying component leads to be tinned, and various other restricted area fluxing applications.

In all cases, the requirements for selective fluxing equipment are similar. The objective is to apply flux as precisely and uniformly as possible, in carefully controlled amounts, without any flux being deposited outside the targeted area. In addition, the equipment should handle any type of flux, from low-solids alcohol or water-based, no-clean fluxes to high-viscosity tack fluxes.

Selective fluxing can be further classified according to whether flux is applied to the top or bottom of the substrate. In through-hole applications, where portions of PCBs or individual components are coated, flux is applied to the bottom of the substrate. In applications involving surface-mount assemblies or for semiconductor devices such as ball grid arrays (BGAs) and flip chips, the flux is applied to the top. In other operations such as tinning, flux may be simultaneously applied to the top and bottom.

Several techniques used to address the range of selective soldering applications include:

- selective wave soldering machines with a small solder fountain used for soldering over small areas of PCBs such as individual through-hole components
- conventional wave soldering equipment where flux is applied over broader areas of a PCB; a computer controlled reciprocating spray fluxer is often used because it can be turned on and off at selected locations as it traverses
- top-down fluxing of small geometry features such as surface-mount devices, BGAs and flip chips that are subsequently reflowed.

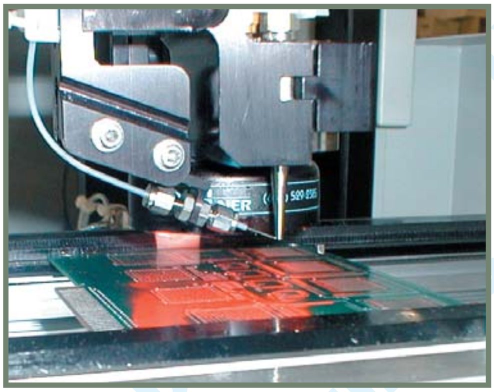

FIGURE 3: Ultrasonic spray nozzle used for topside fluxing.

Selective Wave Solder Machines

Selective wave solder machines are designed for applying solder to small areas of PCBs. The assembly to be soldered is placed on an x-y-z robotic table where flux is applied to the selected areas. The entire mechanism, including the board to be soldered, then moves to the wave solder area. Depending on the process, a preheat stage may be used after fluxing to activate the flux, or the PCB itself may be preheated before flux is deposited.

The substrate moves over the solder fountain, which can vary in diameter from 3 mm to several inches. Through the motion of the table, the solder fountain contacts the board only at the sites where flux has been applied.

The choices of flux application methods are limited. Small foam fluxers are not particularly practical because they have little or no control of the amount of flux deposited or cannot adequately confine the area to which flux is applied. Pressure spray nozzles are also unacceptable because their spray patterns almost always exceed the size of the desired deposition area, and the amount of flux deposited is excessive.

The two techniques that are practical and give good results are ultrasonic spray nozzles and ink jet devices. Ink jet systems can provide very small dots or extremely thin lines of flux, less than 1 mm. They are also less expensive than ultrasonic systems.

The minimum dot or line size from an ultrasonic spray nozzle in this application is about 1.8 mm. This difference in minimum size does not affect the soldering process because the minimum effective solder fountain diameter in state-of-art equipment is about 2 mm. Therefore, any flux within a 2-mm dot will either be used in creating the solder bond, or it will be burned off if it is outside the bond area but within the minimum fountain diameter.

Both techniques can deliver flux over a wide throughput range, from a few microliters for small dots to significantly more for larger target areas. The delivery rate is also variable and can be changed on-the-fly. Typically, a pressurized reservoir liquid delivery system is used, although in ultrasonic nozzle systems positive displacement gear pumps can also be used.

Although both types of spray fluxing systems have been used successfully, ultrasonic nozzle systems have certain advantages over ink jet devices. Ultrasonic nozzles are inherently reliable, do not clog and are fabricated from corrosion-resistant titanium, making them ideal for use with all fluxes. They generally are not prone to failure, can operate continuously in hostile environments for many years and require little maintenance.

In contrast, ink jet devices are not nearly as robust and, because of their very small internal orifices, have a tendency to clog. Cleaning ink jet devices is an important aspect of the overall process. If an ink jet system is left idle for more than about 30 minutes without purging the device, clogging may occur.

Topside Fluxing

Topside fluxing is gaining importance in applications dealing with the packaging of semiconductor devices such as BGAs, flip chips and other advanced components. The application of flux in these cases is demanding. It must be precise in terms of exactly where flux is applied and how much is put down, and no flux can be deposited beyond the intended target area.

Tack fluxes are often used in these applications. Besides performing their normal functions, they keep the device that is positioned over the fluxed area in place during subsequent processing.

Currently, two strategies have proven to be suitable for topside fluxing. Both replace the high-maintenance dipping operation, which does not offer the control, repeatability or speed required in modern manufacturing processes. Both also use a high-speed x-y platform, on which is mounted a moving dispense head to apply the flux.

One technique uses a generator that creates patterns by rapidly dispensing individual flux dots over an area, along a line or in a circle that can be as small as an individual dot. This technique relies on the individual dots coalescing to create a continuous coating over an area or along a line. Dot generator equipment has been available for several years and will provide complete coverage with consistent film thickness and no flux deposition outside the target areas. Its repeatability is 0.025 mm and resolution is 0.025 mm. Flux is delivered to the dispense head by either a pressurized reservoir system or a syringe pump.

The other strategy is spray nozzles with ultrasonic atomization. This method produces precise patterns because the ultrasonic spray nozzles can generate pattern widths as small as 0.25 mm and apply less than 5 microliters per square inch of flux after solvent evaporation.

The finest patterns are produced by feeding the flux externally to the nozzle's atomizing surface through a capillary tube, while low-pressure air is sent through the central bore of the nozzle (Figure 3). The small diameter air stream entrains the flux spray and precisely directs it to the substrate with no overspray.

Depending on the specific requirements, this method is flexible in that much wider spray patterns and heavier deposition densities can be achieved. Liquid delivery is precisely controlled through a syringe pump, which regulates flow rates on-the-fly.

One principal requirement for a topside fluxing system is that it must not create a bottleneck in the overall process stream. Accordingly, the system must deposit patterns at a relatively high rate. Several factors affect the system's ability to achieve high throughput: the speed at which the platform moves; the width of the pattern being deposited; the number of sites to be coated; process parameters and site density. Dot generator equipment can move considerably faster than ultrasonic systems and, in many applications, can achieve higher throughput.

Recent tests conducted at a semiconductor manufacturing facility indicate that the ultrasonic method produced satisfactory soldering results on a chip-scale package (CSP) with a flux film as low as 3 mg/in.^{2}. This result contrasts with the 12 mg/in.^{2} delivered by the dot dispensing technique. The dot generator's principle of operation precludes deposition densities much below this value.

Both techniques have their advantages and disadvantages. The choice of which one to select depends on the nature of the application.

Summary

Spray fluxing has advanced in little more than a decade. Challenges such as OSP-coated boards, VOC-free fluxes, selective fluxing and more stringent production standards in terms of reduced defect rates and tighter process standards have transformed the nature of spray fluxing.

Previously, spray fluxers were viewed as a necessary evil to apply no-clean fluxes, being used only because traditional ozone-depleting CFC cleaning compounds had been banned. Today, spray fluxing can perform a variety of tasks in applying flux to PCBs, semiconductor packages and for tinning. New challenges will emerge as the industry moves away from lead-based solders. New fluxes will emerge and, with them, a new set of process parameters relating to flux application. ■

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