Breadth of Dispensing Technologies Offers a Wide Variety of Conformal Coating Processing Capabilities

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Abstract

Today's conformal coating applications present a wide variety of challenges to contract manufacturers and original equipment manufacturers. Numerous types of conformal coatings are used to protect sensitive electronic circuitry from harsh environments in automotive, commercial, avionics, military and medical markets. These products come in an endless array of shapes and sizes ranging from large motherboards, and complex multi-PCB assemblies to small modules, tiny PCBs, flex circuits and individual substrates. A particularly growing trend recently has been the need to address smaller and smaller packages, which require more creative dispensing methods with increased accuracy, repeatability and selectivity. The savvy process engineer who becomes familiar with the newer technologies available today will be better able to accommodate these challenges as they arise. Subsequently, selective conformal coating equipment suppliers must continually explore and develop these new technologies and make them available to their customers.

This paper will discuss a variety of selective dispensing technologies currently available for use with conformal coatings. Applicable supportive information will also be provided. First, an overview of coating material types and a brief description of their individual properties will be presented including a comparison of solvent-based materials vs. 100% solid or "solvent-less" materials. Several applicable industry-standard performance specifications will be listed. Second, manual methods of applying coating will be explained including brushing, dipping, spraying and needle dispensing. Finally, methods of robotic or automated selective coating will be discussed. This will include range of various dispensing technologies. A sharp edge-definition, non-atomized film coating technology will be explained. A high flow-rate, tri-mode applicator technology offering a wide variety of atomized spray patterns, spot and line modes and coaxial air-assisted monofilament modes will be discussed. Newer technologies offering greater selectivity, increased accuracy and higher repeatability will be shown. Two types of high accuracy jetting technologies will be compared, including timed pulse-width modulation needle jetting and high speed, high impact "snap off" jetting. Examples such as jet-coated 0805 chip resistors will be shown.

Key Words: Film coat, tri-mode, jetting, bead, swirl, monofilament.

Introduction

Imagine for a moment that you live in the Northeast and you are embarking on a cross-country road trip. It's December and the outside temperature is below freezing. Along the way, your car is subjected to everything from the sub-zero cold in your driveway to humidity from rainstorms in the high plains to the baking dry heat of the desert, not to mention road vibrations, fumes, oil and dust. But to and from, your car never fails. How does the myriad of electronic circuitry under the hood withstand such extreme conditions? Part of the answer lies in conformal coatings.

Conformal coatings are used to protect all kinds of electronic circuitry from moisture, dust, chemicals, solvents or other types of harsh environments. Although usually only a few mils thick, they are also relied on to dampen the effects of mechanical and thermal stresses, vibrations and electrical noise. Conformal coatings have also been utilized to control dendrite growth, a potential cause of short circuits. Initially, conformal coatings were reserved primarily for expensive aerospace or military applications. Today however, they are used just about everywhere. With the explosive growth of portable electronics, increased demand for "smart" consumer appliance controls and continued growth in automotive electronics, conformal coatings are in more demand today then ever before.

There are many types of conformal coatings, each with it's own specific performance characteristics. It is important to become familiar with these characteristics so that the proper material can be selected. The correct material for the application essentially depends on what the product needs to be protected from. Is it moisture? Dust? Vibration? High temperatures? Is it going under the hood of a car or into a washing machine?

Besides performance, there are several other important factors to consider when choosing a conformal coating material such as: Will the product need to be repairable if in fact it does fail? Exactly which areas must be coated and which areas must not be coated? What are the local environmental regulations regarding chemicals, solvents and VOC (Volatile Organic Compound) emissions? What is the expected production volume?

Material Descriptions

In the broadest sense, there are two major categories of conformal coatings: solvent-based and 100% solid. Solvent-based materials have been in use for many years and in the past have been the most popular. They are relatively inexpensive and their viscosity can be easily controlled through dilution with solvents. Dilution is also used to vary the overall solids content, an effective means of controlling the final film build, or cured thickness. Although more expensive, 100% solid materials are in ever-increasing demand. Worker's health issues, increasing environmental restrictions on VOC emissions and concerns about hazardous waste disposal have helped fuel their growth. The term "100% solid" may seem like an oxymoron when describing a liquid. A more descriptive term might be "solvent-less", since these environmentally friendly materials have no added solvents and therefore are virtually VOC free. Generally, 100% solid coatings are higher in viscosity than solvent based coatings and they usually are more expensive.

Conformal coatings are also classified by basic resin chemistry type. The five most common types are: acrylic (AR), urethane (UR), epoxy (ER), silicone (SR) and poly-par-xylylene (XY). A few hybrids consisting of blends of more than one type are also available. Following is a short description of each of the five main types:

Acrylic resins (AR) are typically solvent-based. They are generally inexpensive, easy to apply and are considered repairable. Usually transparent, they normally dry to the touch within minutes at room temperature. They provide good protection from moisture and abrasion. Additionally, acrylics typically have very long shelf-lifes. However, they also tend to have poor solvent resistivity, poor temperature resistance and only fair mechanical strength.

Urethane resins (UR) provide excellent humidity resistance as well as improved mechanical strength over acrylics. Urethanes also have better abrasion resistance and hold up much better to solvents than acrylics. However, their durability also means they are difficult to remove, making reparability a challenge. Urethanes are available in both two component type and single component type. Many are moisture sensitive, which typically requires more frequent nozzle maintenance. Some urethanes may tend to form minute bubbles or cure with a wrinkled surface if applied too thick or if the ambient relative humidity is too high.

Epoxy resins (ER) are the least commonly used type of conformal coating. They offer excellent mechanical and abrasion resistance as well as good humidity resistance. However, epoxies generally have poor temperature resistance and poor reparability. Being very rigid once cured, they can create thermal expansion problems, particularly if allowed to flow underneath BGAs or other surface mount components. Most epoxies are the two component type – Part A must be mixed in a specific ratio with Part B. Improper mixing can lead to a coating that is either too hard, too soft, or won’t cure. Two-part epoxies also usually have a very short pot life once mixed. This can be used as an advantage in production since curing takes place quickly after dispensing. However, this quick-cure characteristic also presents a challenge for maintaining the fluid delivery system. Sometimes a disposable reservoir may be used.

Silicone resins (SR) provide excellent temperature resistance and generally have very low CTE (Coefficient of Thermal Expansion). For this reason, silicones are generally chosen for use in environments subject to extreme temperature variations such as automotive or aerospace applications. Silicone coatings offer good moisture resistance but have very poor abrasion resistance and poor mechanical strength. Silicones are available as either moisture cure (RTV), heat cure, or UV cure. UV cure types (and sometimes heat cure) types almost always have a secondary moisture cure component to allow curing of shadowed areas.

Although silicone coatings are relatively soft and easy to break through, it is virtually impossible to remove 100% of their residue. If not completely cleaned and flushed, attempting to use an organic material in a silicone fluid system can result in chronic problems such continued contamination of any new materials and de-wetting on the board. For best production practices, is it is recommended that once a fluid system is wetted up with a silicone fluid that it be dedicated for silicones only.

Poly-para-xylelene (XY) (parylene) is a specialized coating applied by vapor deposition within a vacuum chamber. It is a very thin yet strong and durable coating. The vapor deposition process ensures complete coverage. However, paralyne is very expensive, is difficult to remove and can only be applied in a batch type operation.

Performance Specifications

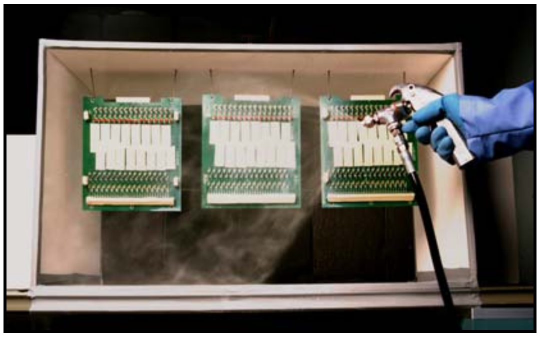
Certain qualification and performance standards have been established relating to conformal coatings. These specifications can be used to aid process engineers in selecting the appropriate material for their particular applications. The most commonly referred to standards are: IPC-CC-830, Qualifications and Performance of Electrical Insulating Compounds for Printed Board Assemblies (Commercial); MIL-I-46058C Insulating Compound, Electrical (U.S. DOD); MIL-P-28809 Printed Wiring Assemblies Inspection Criteria, (U.S. DOD); and UL746E Polymeric Materials – Use in Electrical Equipment Evaluations (UL Recognition). Note that IPC-CC-830 is currently being used to supercede MIL-46058C, now generally considered obsolete. Most material suppliers will readily list which particular specifications their materials have been qualified for.

Manual Dispensing Methods

There are many ways to apply conformal coatings. The most common are brushing, dipping, air spraying or needle dispensing. Brushing requires the least amount of investment. It is essentially a manual process and as such is most suitable for low volume production, prototypes or repair work. A brush is simply dipped into a pot of material and it is applied where needed. Brush coating is generally the least repeatable, since it is entirely operator dependant. Care must be taken not to apply too much or too little. Too many brush strokes can result in bubbles, inconsistent coverage or brush fibers being left in the coating.

Dipping is a process that uses a tank of material in which the assembly is immersed and then retracted, usually at a specific rate. This can be a manual process, but more often than not it is automated to some degree. The rate at which the assembly is immersed and retracted, as well as its orientation must be controlled. Even though the dipping process can be automated, any areas on the assembly that are not to be coated must be properly masked off prior to dipping. Masking itself can be a very time-consuming and labor-intensive manual process. In using an open tank, solvents will eventually evaporate such that the viscosity of the material changes. Therefore, viscosity must constantly be monitored as well. Solvent can be added as needed.

Manual air spraying is the most widely known method of coating circuit boards. This method uses a spray gun that mixes a high flow of air with the material, creating a wide spray or mist. The spray is directed at the PCB and the gun can be moved back and forth to ensure even coverage. This process is inherently wasteful since it generates a great deal of over-spray. Also, masking prior to spraying is required to protect those areas that are not to be coated. Here again, masking can be very labor intensive and time consuming. Sometimes a spray booth may be used to contain excess over-spray or any harmful vapors.



Spray Booth

With needle dispensing, material flow through a needle is controlled by turning a valve on and off. Any number of valving technologies can be used, including spool valves, diaphragm valves, pinch tubes or simply by switching air pressure into a syringe off and on. Needle dispensing produces a bead of material. Many types and gages of dispensing needles are commonly available to produce the right size bead. The beads are placed as needed throughout the board and material is allowed to flow outward. Needle dispensing can be performed manually or by a robot. With a properly trained operator, manual needle dispensing can produce excellent results with very little investment. However, manual dispensing is only practical for low volume situations. For higher volume production and greater repeatability, automated robotic dispensing is most practical.

Automated (Selective) Dispensing

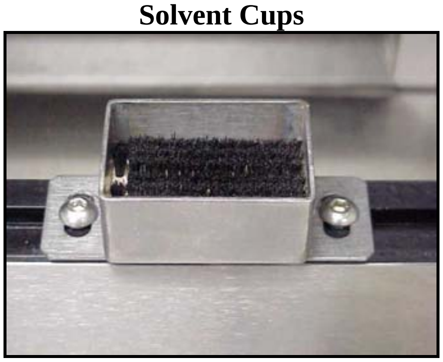
Automated or selective coating is well suited for high volume applications where repeatability, speed and efficiency are essential for success. Selective coating uses a programmable robotic X-Y-Z positioning system to accurately manipulate the applicator in and around the product being coated. By using an automated system, repeatability is introduced and speed is greatly enhanced. With proper programming, material waste can be greatly reduced and in many cases masking can be completely eliminated.

Automated Coating Platform

Virtually any type of coating applicator can be mounted onto a robot. Of course, electrical and/or pneumatic control signals must also be interfaced. The applicator is then sequentially triggered at the appropriate positions, speeds and pressures through a programmable controller. However, because of the potential complexity in "teaching" the controller the specifics of the board, the applicator and the material, as well as the intricacies involved in the programming of individual line parameters, a user-friendly software package specifically designed for conformal coating will provide tremendous benefits in programming efficiency. Additionally, a well-designed software package will also provide enhanced process feature options such as flow monitoring of material, bar code matching of a specific product to a specific program, closed-loop fan width control and graphics import for board identification. The software must also be able to readily accommodate a wide range of applicators.

Material build-up on the nozzle is very common with conformal coatings. Therefore, scrubbing or wiping is sometimes necessary in order to maintain a consistent pattern. Accordingly, the well-designed automated coating platform will have useful features such as a solvent soak-cup for parking the nozzle tip during idle times, a brush-box for nozzle scrubbing and a purge cup. With an automated dispenser, maintenance sub-routines can be programmed to automatically clean the nozzle at specified intervals. This is just one of the many levels of process control that an automated system can take off the shoulders of the operator.

Solvent Cups



Brush Box

System Safety

Operator safety is of utmost importance with any automated dispenser. Coating platforms specifically must have a properly engineered and integral ventilation system to remove any potentially dangerous vapors. The ventilation system should ensure complete evacuation of any enclosed areas prior to powering up and it should continually monitor for adequate ventilation during use. Other important safety features include door interlocks, a fluid reservoir de-pressurization mechanism and a spill containment system.

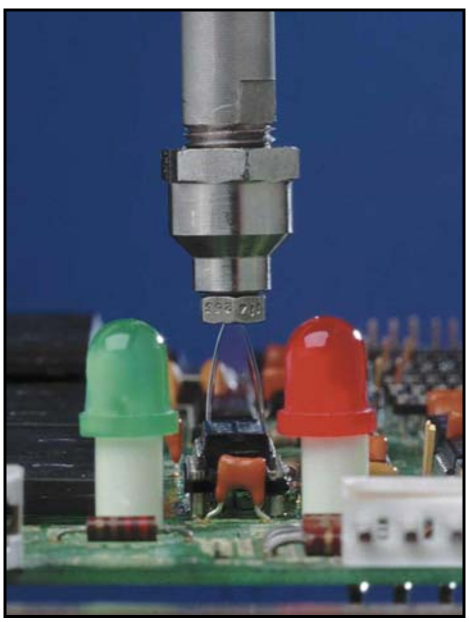
Automated coating systems can be either conveyorized for in-line processing or non-conveyorized for batch type processing.

Selective Needle Dispensing

Needle dispensing, as described earlier, can be automated to make it more repeatable. However, even with automation it still has some inherent drawbacks. Since the material shutoff point is typically some distance from the actual needle tip, drips are a common issue. Additionally, material may tend to cling to and climb up the side of he needle, resulting in blobs or uneven lines. Small gage needles are delicate and can be easily bent out of position. Also, the bead produced may result in too high of a film build or it may be too small of a bead to make large area coverage practical. Nonetheless, with proper programming and procedures, selective needle dispensing can be an effective means of applying conformal coating, particularly in difficult to reach areas.

Selective Film Coating

Film coating solves many of the problems associated with needle dispensing. A film coating applicator uses a specialized crosscut nozzle, which is much more robust than a needle. The special geometry of a crosscut nozzle produces a fan-shaped, non-atomized curtain of coating. This applicator is a time/pressure type, incorporating needle and seat valving technology. A spring forces a needle into a seat, shutting off fluid flow. When a trigger signal is received, air pressure through a solenoid overcomes the spring force, lifting the needle and opening the seat. Fluid pressure forces the material out through the nozzle. Unlike needle dispensing however, the crosscut nozzle can withstand the rigors of brushing or wiping during maintenance routines.



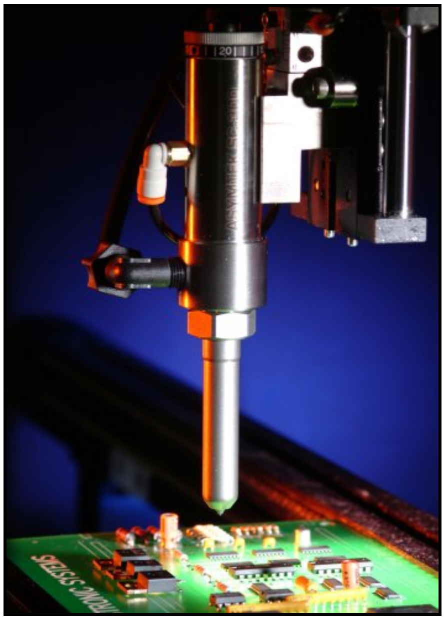
Film Coat Fan Pattern

Fan widths with a crosscut nozzle typically range from 6-19mm. By orienting the fan perpendicular to the length of the programmed line, a wide coating stripe is achieved. Running the fan parallel to the line results in a "knife-edge" pattern for narrow areas or for spots. For maximum flexibility, a rotate mechanism on the applicator allows automatic switching to either orientation for any given programmed line. This allows full coverage in both the X and Y axes. Each stripe can be programmed at a specific orientation, direction, speed and dispense height in order to achieve the desired results.

Film coating is usually the dispensing method of choice when the material viscosity is less than about 100 centipoise. Since film coating is entirely non-atomized, the resulting pattern has a very distinct edge. This can be crucial to many applications where overspray from an atomizing spray valve may not be tolerated. Typical film builds with a film coater are usually between .02-.20mm with line speeds of up to 510mm/sec and edge tolerances as good as +-0.762mm. Film builds can be easily controlled by adjusting the percentage of solvents and/or the robot's speed.

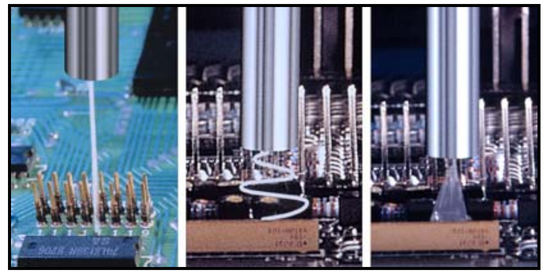
Selective Tri-mode

For many applications, more than one dispensing method may be needed for effective coverage. Tri-mode dispensing technology combines the wide area benefits of an atomized spray with the selective benefits of a non-atomized bead, all within a single applicator. This single applicator can produce three distinctly different patterns: non-atomized bead, non-atomized monofilament and atomized swirl, or spray. By combining three patterns into one cost-effective applicator, flexibility of the dispensing system is maximized, allowing for accommodation of a much broader range of applications. Additionally, the three modes are accomplished without sacrificing dispense area. Typically, tacking on two or three separate applicators to a robot’s head can drastically reduce the system’s overall effective dispense area.



Tri-mode Applicator

The tri-mode applicator has a unique co-axial air assist feature. It is the precise control of this coaxial air assist along with control of fluid that allows three patterns to be produced from one applicator. By adjusting the direction, angle and flow of the coaxial air assist, a wide range of swirl and monofilament patterns is possible. A relatively low fluid flow rate with a relatively high air assist flow rate produces a finely atomized conical spray pattern. A relatively high fluid flow rate with a relatively low air assist flow rate produces a non-atomized monofilament pattern. By turning on the fluid without any air assist, a solid stream of material is dispensed to create non-atomized lines or small spots.



Bead, Monofilament, Spray Patterns

The width of the swirl and monofilament patterns is controlled by adjustment of the angle and the flow of the air assist air. By combining adjustments of both the angle and the flow, a broad range pattern widths is possible from very narrow for tight access areas to very wide for large area coverage. Pattern widths with a tri-mode applicator can range from 2.5mm in bead mode up to 19mm in monofilament mode with line speeds of up to 510mm/sec. Typical edge tolerances can be +-0.635mm in bead and monofilament modes and +-1.5mm in swirl mode.

Overall fluid flow rate on the tri mode applicator is controlled by a combination of nozzle size, a valve opening control and fluid pressure. Balancing the valve opening control with fluid pressure allows equivalent fluid flow rates to be achieved for various selections of nozzle sizes.

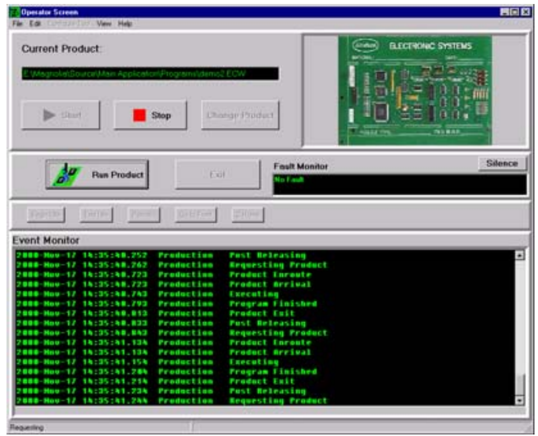
Fluid flow rate	Air flow rate	Resulting pattern
Low	High	Atomized spray
High	Low	Monofilament
High	Off	Bead

Table 1. Effects of fluid flow rate vs. air flow rate using tri-mode applicator.

With many valves, such as needle dispensers, the fluid shutoff point is some distance from the actual needle tip. This creates a cavity between the tip and the shutoff point. Through capillary action, a certain amount of material stays inside this cavity after shutoff. With many quick cure materials, particularly moisture cure silicones, that material eventually begins to cure, leading to pattern variations and/or clogs. Eventually, the needle must be removed for cleaning.

Although the new generation tri-mode applicator is still a time/pressure valve incorporating needle and seat valving technology, it is designed with a solution to this problem. It is a zero-cavity design, meaning the very tip of the nozzle is the fluid shutoff point. There literally is no place for material to collect. Any minute amount of material that may cling to the outside of the nozzle can be easily removed with a brush box and scrub routine.

With such a wide range of coating materials on the market, each with it's own unique fluid property characteristics, it is crucial that the timing of both fluid and air be synchronized with the robot's travel speed and dispense height. This process can be intensive, time consuming and frustrating, particularly when considering the starts and stops of each line. Uniformity of the pattern from beginning to end is essential for process repeatability. Fortunately for the process engineer, a well-designed software package capable of handling teaching of the fluid characteristics to the system makes the process very simple. A self-guided process walks the user through from start to finish. Once taught, the software remembers the fluid's characteristics and how it reacts to the robot's settings to ensure overall uniform coverage.



Integrated Software Screen

Tilt Capability

Some boards are very complex, multi-dimensional assemblies. Many have large, tall components or overhanging obstructions that may interfere with a vertically dispensed pattern. Sometimes a piggyback board is mounted at a ninety-degree angle to the main board. For these applications, a tilting applicator can be a handy tool. This option provides more flexibility with angled dispensing from all four sides, as well as vertically.

Tilt Function

Jetting

As with many manufacturing processes, the continued drive to shrink board size and increase component density poses new challenges for coating as well. A growing number of tiny circuit boards, flex circuits and high-density packages have requirements that exceed the placement and volumetric accuracy limitations of traditional selective coating platforms. As a result, many of these smaller applications such as hearing aids, multi-chip modules, pagers and a multitude of medical devices are being coated very tediously by hand under a microscope. Fortunately a technology exists today that offers new potential solutions – jetting.

Having already proven itself in SMA, no-flow underfill and flux applications, jetting is also a viable alternative for many coating applications that require highly accurate and repeatable placement of very small amounts of material. Jetting is also inherently a high volume technology where speeds of up to 200 dots per second are possible.

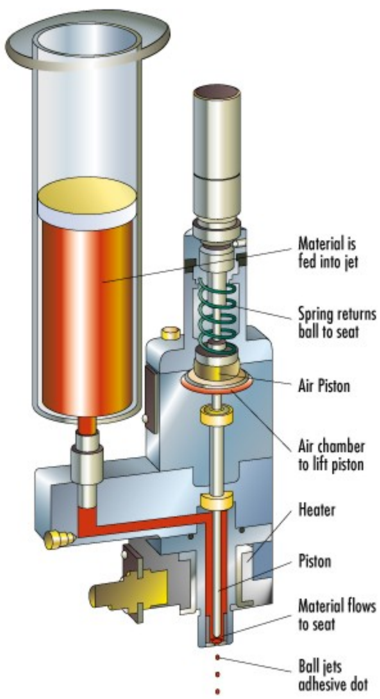
When spraying large circuit boards, a drop or two of material clinging to the nozzle usually does not present much of an issue. However, when the objective is to dispense only a single dot, it's a whole different story. By virtue of their very design, conformal coatings tend to cling to whatever surfaces they come in contact with, including the dispensing needle or nozzle itself. They can be difficult to separate from the tip, particularly when trying to dispense small dots. Frequently when dispensing small dots through a needle, the material just builds up until a blob forms on the tip, eventually falling off due to it's sheer weight. Jetting technology alleviates that issue.

1120 Dot Grid Jetted with 100% Solid Silicone. 4mm Dot Diameter.

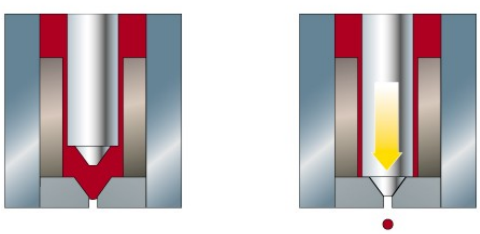
Jetting Demystified.

So just what is jetting and how can it be applied to conformal coating? A jet applicator is essentially a needle and seat device. The big difference of course, is how the material comes about leaving the nozzle. With traditional needle and seat technology, a fluid is fed into a chamber under constant pressure. At the bottom of the chamber is a seat, or outlet port of the chamber. Inside the chamber is a needle. The bottom of the needle is positioned such that it protrudes into the seat and is held there via a compressed spring, sealing off the fluid chamber. The top of the needle is sealed off from the fluid by seals and is inside an air chamber. When this air chamber is pressurized with enough pressure to overcome the compressed spring pressure, the needle's piston lifts the needle tip off the seat, allowing fluid to flow out of the chamber. When the air pressure is released, the spring returns the needle's tip, sealing off the seat and shutting off fluid flow.

With a jet applicator, the geometric relationship of the size and shape of the needle to the size and shape of the seat is very specific. The two are designed such that when the needle returns to the seat, a short pressure spike is created in the chamber, accelerating the fluid rapidly and ejecting it out of the nozzle in the form of a droplet. It is this impact of energy that allows a clean snap-off material from the nozzle tip, an action simply not possible with a needle dispenser.

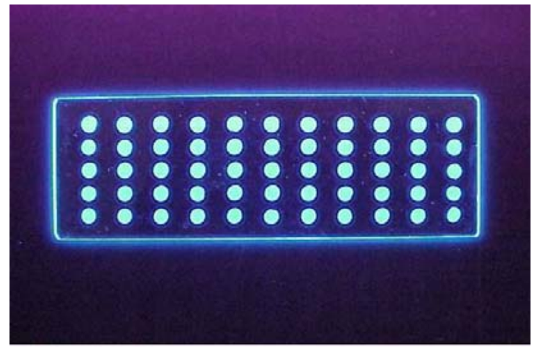


Jet Applicator Cutaway View



Needle Impacting Seat Ejects Droplet

Dot size through the jet applicator can be controlled by variation of nozzle size, micro-adjust, pre-load spring pressure and valve on time. While with jetting the amount of material dispensed with each dot is relatively small; effective dot size can easily be increased by repeatedly dispensing multiple dots in the same location. Additionally, by spacing adjacent dots appropriately then stepping and repeating, larger areas are covered.

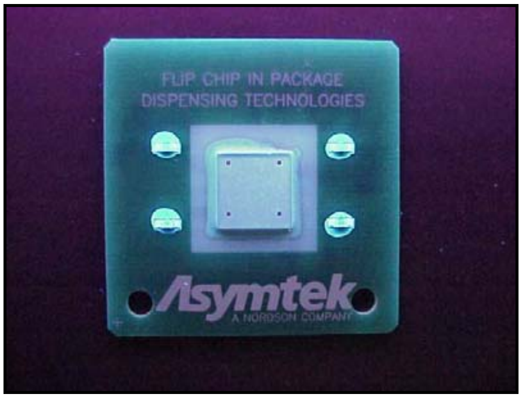


2.5mm Acrylic Dots Jetted on Glass Slide

170mm x 40mm Area Jetted

Another important feature of a jetting applicator is a built-in closed-loop heater control. The viscosity of most coating materials will fluctuate depending on temperature. Some are much more sensitive than others. By taking control of the temperate of material within the jet itself, the effects of ambient temperature fluctuations are eliminated. The coating material viscosity is maintained, allowing even further process optimization.

Most standard automated coating platforms simply rely on mechanical stops or clamps to position the board when loaded. However, when dispensing small dots on small parts, a camera-assisted vision system may also be required. Consequently, a vision system with pattern recognition is commonly used with jetting. Once fiducials are taught, the camera automatically locates each part each time, ensuring a much higher degree of accuracy and repeatability.



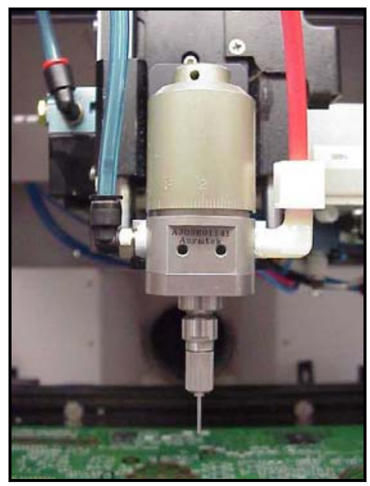
Jet Coated 0805 Peripheral Resistors

Jetting is not without it's limitations. In jetting SMA on unpopulated circuit boards, dispense heights of < 1mm are not uncommon. This is simply not feasible in most coating applications where dispense heights of 10-20mm are more typical. However, many flex circuits, substrates and tiny PCBs have very low profiles without major height restrictions. Nonetheless, sometimes a specialized extended jet nozzle may be required to allow closer positioning.

Special Jet Nozzle with Extension

Semi-jetting

Some materials, particularly those with very low viscosity, simply will not jet well. Or the application's tight access limitations may rule out even the extended jet nozzle mentioned above. A hybrid applicator is available that combines the benefits of jetting technology with needle dispensing. This applicator uses a standard dispensing needle at its very tip along with the impact effect of a jet to eject small amounts of material. It can be used as a jet applicator for small dots or as a needle applicator for lines or larger areas or any combination of both.



Hybrid Needle-Jet Applicator

Much like the jet, this hybrid applicator allows adjustments of the energy imparted to the fluid by the needle as it impacts the seat. It also controls the valve on and off times through pulse-width modulation of its solenoid signal. By using this method, the overall flow rate of material is precisely regulated, allowing very fine control of dispensed lines.

Conclusion

The demand for conformal coating continues to grow and become more diverse every day. Coated products come in an endless array of shapes and sizes ranging from large motherboards and complex panels to small modules, tiny PCBs, flex circuits and individual substrates. Markets served include automotive, commercial, avionics, military, consumer and medical. Add to this a multitude of coating materials to choose from, each with it's own specific properties. Soon it becomes obvious that no one system or process can accommodate everything. A particularly growing trend recently has been the need to address smaller and smaller packages, which requires even more creative dispensing methods with increased accuracy, selectivity and repeatability. The savvy process engineer who becomes familiar with the latest technologies of today will be better able to accommodate new challenges as they arise. Subsequently, selective conformal coating equipment suppliers must continually be innovative and explore these new technologies, refine them and make them available to their customers.

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