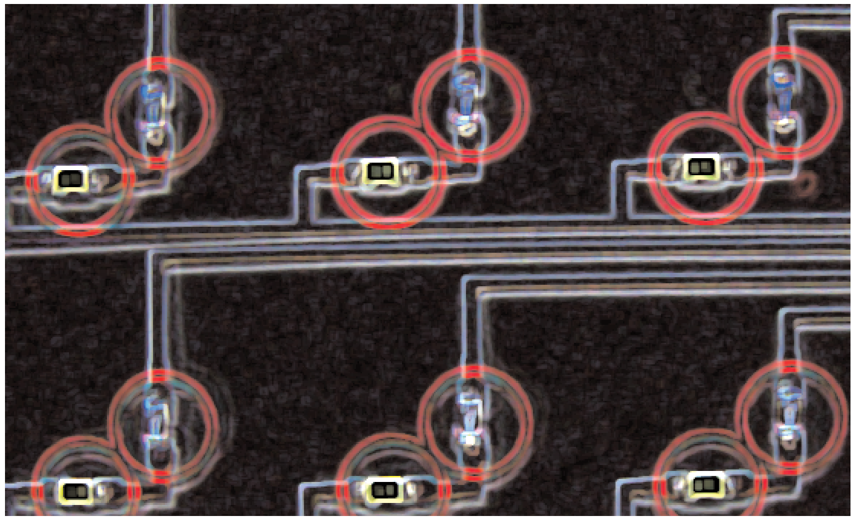
Surface Mount 101: Processing and Design Considerations for Membrane Switches



In the first article of this series, Surface Mount 101: A Primer For Applying LEDs and Other Components to Membrane Switches, (SGIA Journal, Second Quarter, 2003), we discussed material issues related to using conductive epoxy adhesives for surface mount attachment. This article deals with manufacturing and circuit design issues related to surface mounting light emitting diodes (LEDs). Special consideration is given to dot dispense processing.

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Choosing a Manufacturing Process

Surface mounting components to membrane switches involves three distinct manufacturing processes (Figure 1). The wet conductive adhesive pads are applied to the circuit, then the components are placed onto the adhesive pads and finally the circuit is heated to harden the adhesive. In some instances, it is possible to combine the first two processes at a single station. Optional fourth and fifth processes involve syringe dispensing a clear ultraviolet (UV) curable encapsulant around the component and then hardening the encapsulant by exposing the circuit to intense UV light. Some manufacturers will also place a small dot of non-conductive adhesive between the two conductive adhesive pads prior to placing the component to help anchor the component onto the circuit and prevent the conductive epoxy dots from migrating together underneath the component to create an electrical short. Others rely on the conductive epoxy as the only means to mechanically attach the component to the circuit, however, this is not recommended for flexible substrates.

Some considerations when deciding which surface mount processes to use are: budget for equipment, available floor space, number of different circuit patterns manufactured, number of components placed on each circuit and overall output required.

Printing vs. Dot Dispensing

There are two methods for applying conductive adhesive pads to circuits. The first method is stencil printing, or in rare instances, screen printing. The second method is dot dispensing.

Stencil printing involves using a thin metal sheet stretched into a frame. The metal sheet has small apertures cut into it using a laser. The side walls of the apertures are usually finished to give a smoother surface to provide cleaner pad definition and allow the adhesive to release more easily from the aperture when the stencil is lifted. The squeegee is usually thin, flexible metal.

Dot dispensing involves using a pressurized syringe with a small metal needle tip to apply dots of adhesive to the substrate.

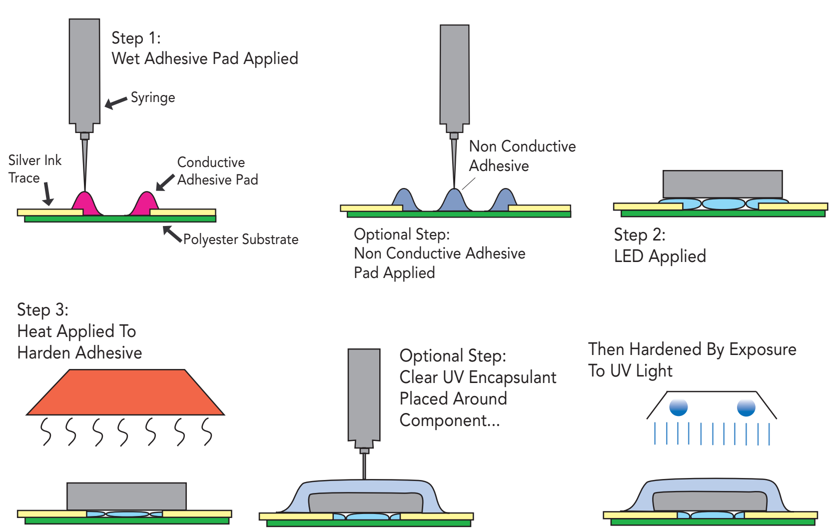
Table 1 summarizes the advantages

By **Don Banfield,** Product Manager and Co-Founder, Conductive Compounds

Stencil Printing	Dot Dispensing
Very fast throughput - one stroke covers entire print surface	Slower throughput - needle tip must travel to each point where an adhesive pad will be made
Less flexible – one stencil pattern must be maintained for each circuit layout	More flexible – pre-programmed patterns can be changed quickly at machine station
Flood of material must be maintained while printing – excess material scrap cost for fast reacting adhesives	No flood required – material is dispensed at each pad location as needed and material waste is minimal
Relatively large pads printed	Small pads possible with correct material and needle selection
Square or rectangular pads possible	Limited to round or oval shaped patterns
Pad thickness limited to .010" or less	Pad thicknesses between .003" and .020" or more are possible
No stringing of adhesive	Possible stringing with some adhesives
Fixed cost of screen for each setup, and screens must be replaced as they wear out	Uses low cost disposable syringes
Cannot laminate spacer layers prior to stenciling	Spacer layers can be laminated prior to dot dispensing
Requires other equipment for placing components onto adhesive pads	Equipment is available that will dispense adhesive, place components and place domes all at one station
Capital costs for stencil printing equipment ranges from $20,000 to $250,000, depending upon the complexity	$55,000 to $60,000 cost for a single station machine to dot dispense, place domes and LEDs at one station
Process puts tremendous shear on epoxy – reduces working time	Minimal shear on epoxy – longer working time
Limited circuit size	Can handle larger circuit formats

Table 1

Figure 1



and disadvantages of stencil printing and dot dispensing manufacturing processes.

Stencil printing is more suitable for high volume, high component density production. For small- to medium-sized membrane switch manufacturers, dot dispensing is preferred because of its flexibility, low set-up cost and low material scrap rates.

There are two notable differences between conductive adhesive pads from a dot dispense process and a stencil print process. Dot dispense generates a rounded pad with a slight peak, and stencil printing produces a square or rectangular pad with a flat top.

Pad thickness with a stencil print process is generally limited to .010" or less. At thicknesses greater than .010", there is more surface area contact between the sides of the pad and the stencil aperture relative to the surface area contact between the pad base and the circuit substrate. Irregular pad shapes will occur as the stencil lifts away from the newly formed pad and pulls adhesive away with it.

Dot dispense equipment can generate pad thicknesses of .020" or more, and the profile or thickness of the pad can be quickly and easily altered by adjusting machine program parameters.

A dot dispense process can use either one- or two-part conductive epoxy adhesive. The choice will be dictated by how much heat can be applied to the circuit to harden the epoxy. One-part adhesives generally need to reach a minimum of 125° to 135°C (257° to 275°F) to activate the chemistry. If the adhesive is not held at temperature long enough to allow it to crosslink completely, the reaction stops once the adhesive cools below the activation temperature.

When an epoxy adhesive is used in a stencil or screen printing process, the working time is reduced drastically because of the constant shearing of the adhesive by the squeegee and floodbar. This constant mixing allows the molecules of the adhesive to move freely, and introduces energy into the adhesive system that accelerates the rate of crosslinking. The amount of shear placed on an adhesive in a dot dispense process is minimal, and the working time of the adhesive will be typically much longer. For this reason, a faster reacting two-part adhesive cannot be used in a stencil printing process because the amount of material used for flooding would have to be discarded once the adhesive thickened to the point it could not be printed.

In its simplest form, dot dispensing conductive adhesives can be accomplished with a small, portable pneumatic pump. An EFD type plastic syringe containing conductive adhesive can be clipped on, and the operator can activate a foot switch to apply air pressure to the plunger to dispense dots (Figure 2). While this method is excellent for making quick prototypes or short production runs using larger components, it is not recommended as a reliable, repeatable manufacturing process in high volume production. An automated dot dispense process maintains more consistent dot profiles over the course of a long production run.

Positive Displacement vs. Pressure Pumps

Forward pressure for dispensing adhesives in a dot dispense surface mount process is generated by two different types of pumps, positive displacement and pressure pumps (Figure 3).

A positive displacement pump uses a rotating screw or auger to generate forward pressure for dispensing an exact volume of adhesive with each cycle. The adhesive is fed into the pump from a pneumatic syringe or canister at low pressure (5 to 20 psi). Because the material is fed rather than pushed it is easier to stop the flow of material after the dispenser is turned off. The speed of the auger motor determines the feed rate of the adhesive, and dispense times for a positive displacement pump are as much as 50% less than dispense time from a pressure pump. Positive displacement pumps are also less sensitive to changes in the viscosity of material than pressure pumps, as the gear motor driving the auger has high mechanical advantage. The downside to a positive displacement pump is that it is expensive, difficult to change over materials and requires extensive cleaning and purging with solvent after each use or changeover.

A pneumatic pressure pump uses a timed burst of high air pressure (25 to 80 psi) to force material out of the syringe. Higher air pressure is necessary because the adhesive contact with the surface area on the inside of the needle needs to create enough back pressure to stop the flow of material from the syringe tip when the pneumatic pressure is turned off at the end of the dispense cycle. A pressure pump process requires these two forces working against each other; high input pneumatic pressure to dispense material and high back pressure from contact between the adhesive and the inside of the needle tip to stop the material from dispensing at the end of the cycle.

Changing materials with a pressure pump requires unclipping the syringe and replacing it with a new one. A pressure pump requires essentially no cleanup or solvent purge since the adhesive is contained solely in the disposable syringe. Perhaps the biggest advantage of a pressure pump is that it requires less ongoing maintenance than a positive displacement pump, which has moving parts. Over time, the close tolerance gap between the auger and the housing that surrounds it will begin to increase due to wear from the materials being dispensed. As this gap increases the speed of the motor needs to be increased to maintain pressure. Eventually the gap between the auger and housing will become so large they must be replaced. Another consideration is if the adhesive is allowed to crosslink to the point it cannot be dispensed from a positive displacement pump, the entire pump, manifold and auger assembly will most likely have to be replaced. If the adhesive crosslinks completely in a pressure pump process, the disposable syringe is simply removed and replaced with a fresh one.

It is also difficult to realign a positive displacement pump when it is removed from the machine for cleaning. Alignment after replacing a syringe in a pressure pump is simple and quick. Pressure pumps cost less than positive displacement pumps, but dispense dots more slowly.

Table 2 compares set up parameters and output between these two types of pumps.

For most membrane switch applications, the simpler and lower cost pressure pump is the preferred method for dispensing adhesive. Pressure pump dispensing technology can be easily incorporated into a single station that can also perform component placement and dome placement.

> Forward pressure for dispensing adhesives in a surface mount process is generated by two different types of pumps, positive displacement and pressure pumps

Figure 2: A pneumatic pump with EFD syringe and component placement vacuum attachment. (Photo courtesy of EFD Inc. East Providence, RI.)

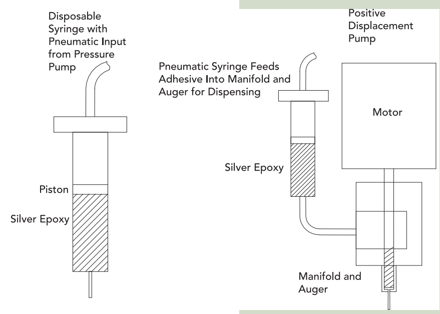


Figure 3: Pressure Pump Vs. Positive Displacement Pump.

Table 2

Method	Input Pressure To Syringe	Needle ID For Back Pressure	Dispense Time	Dots/Hour	LEDS/Hour
Pressure Pump	25-80 psi	.009" to .030"	0.5-2 secs	1,800-7,200	900-3,600
Positive Displacement	5-20 psi	.015" to .030"	0.25 to 0.5 secs	4,500-7,200	3,600-7,200

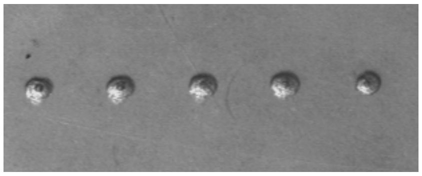


Figure 4: Typical test pattern. (Photo courtesy Assembly Automation, Toronto, Canada.)

Needle Gap and Dispense Time Duration	Side View	Top View	Description
Small Gap (Contacts Substrate) and Long Duration			• Small Indent of Needle • Thin • Un-uniform
Optimal Gap and Duration			• Consistent • Thick • Uniform
Large Gap and Short Duration			• Stringy • Conductive Falls Over & Creates Electrical Shorts

Figure 5: Affect of Needle Tip Gap and Dispense Time Duration on Dot Profile

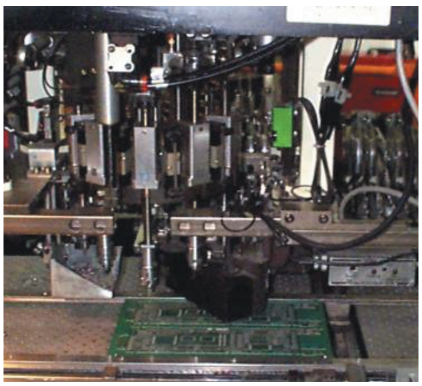


Figure 6: Chip shooter. (Photo courtesy Assembly Automation, Toronto, Canada.)

Figure 7: Gantry pick-and-place station with dome placement and dot dispense capability. (Photo courtesy Nicomatic, Warminster, PA)

Epoxy Adhesives

When using dot dispense as the means for applying conductive adhesive pads, it is important to understand the relationship between material issues and processing parameters. For example, we have already noted in the first article of this series that the viscosity of an epoxy adhesive will continue to increase as it is used in a production environment. The practical definition of working time for an epoxy adhesive is the time it takes to double the viscosity of the material. This working time, or pot life, affects the material viscosity over time, which controls the material forward pressure in the syringe, which in turn controls the dot size and consistency. When dot dispensing, the forward pressure needs to be increased gradually over the production run to accommodate the thickening adhesive.

To minimize the number of times a syringe must be replaced and to optimize dot profile consistency over the course of a production run, you should choose an epoxy that has both a low initial viscosity after mixing and a long pot life. This will also ensure only small incremental changes in pressure will have to be made over the run to maintain consistency in dispensing. Consider the two extreme examples of two-part conductive epoxy adhesives in Table 3. Epoxy A would have an apparent viscosity of 24,000 cps after 4 hours – less than half of the initial apparent viscosity of Epoxy B. One hour after mixing, Epoxy B would have an apparent viscosity of 100,000 cps and would no longer be able to be dispensed consistently – even at high pressure.

Pressure, Needle Tip Adjustments

Typically the pneumatic pressure from a pressure pump will be 25 psi at the start of a run, depending on the adhesive being used and the needle tip diameter, and will have to be increased to as much as 60 psi toward the end of the run as the adhesive thickens.

One easy method to check set-up and verify the process whenever a pressure adjustment is made over the course of a run is to have the operator run a "scrap dot" pattern on the edge of the circuit substrate. A quick visual inspection of the dot pattern under slight magnification will allow an operator to check consistency of dot size and shape. Figure 4 shows a typical test pattern on the edge of a circuit.

Two other key variables to consider when dot dispensing are the distance between the needle tip and substrate surface (needle gap) and the time pressure is applied for dispensing the dot (duration).

The optimal gap between the needle tip and substrate should be between .005" and .015". The duration must be long enough to allow enough material to fill the gap between the needle tip and the substrate and flow out onto the substrate to form a pad that is at least two times the inside diameter of the needle. If the gap is too small or the duration is too long the adhesive will begin to flow up onto the outside of the needle. This causes increased surface area contact between the adhesive and the needle. The adhesive pads will be inconsistent as residual material on the outside of the needle gets deposited on the next dot. This pattern alternates, with one dot getting an excess of adhesive breaking away from the outside of the needle, and the next dot not having any of this excess adhesive.

Alternately if the gap is too large or the duration too short, the adhesive material will not be able to begin to flow out onto the substrate and the needle will return to its up position before the pad can form. The result is a "spiked" dot that is tall with a small diameter. Figure 5 shows the effect of needle tip gap and dispense time duration on dot profiles.

Stringing

Some adhesives have a tendency to string. Stringing occurs when the adhesive does not break apart cleanly, and a long thin strand of adhesive connects the newly formed dot and the needle tip as the tip moves away. Eventually, the string thins to the point where it breaks, and a long line of conductive adhesive falls back onto the substrate, possibly causing an electrical short between the adhesive dot and other silver ink traces. Proper conductive epoxy formulations for surface mount are designed to break very cleanly, allowing the needle tip to move more quickly from one location to another. As two-part conductive adhesives start to increase in viscosity, the tendency toward stringing becomes more pronounced. Some pressure pump dot dispense processes have a feature referred to as suck-back, which allows a short reversal of pressure after the dot is dispensed just as the needle tip starts to lift away. This helps break the material more cleanly and quickly from the needle tip.

Table 3

	Pot Life	Starting Viscosity	Viscosity Increase Per Hour (After Mixing)
Epoxy A	4 Hours	12,000 cps	3,000 cps
Epoxy B	1 Hour	50,000 cps	50,000 cps

Dot Sizes

There are practical limitations to the size of the dot that can be dispensed from a syringe. As the diameter and height of the dot is reduced, the volume of adhesive contained in the dot decreases dramatically. Eventually a point is reached where the affinity of the adhesive for itself is greater than the affinity of the adhesive for the substrate, and most of the material is pulled away from the substrate as the needle tip moves away, without forming a dot.

Recent developments in single component adhesive technology allow for dot diameters of less than .020". They are dispensed through .009" diameter needles while maintaining consistent dot shapes and sizes.

Chip Shooters vs. Gantry Pick-and-Place

There are two options to consider when selecting equipment for applying surface mount components to the wet adhesive pads, also referred to as "pick-and-place." The two types of equipment available are chip shooters and gantry pick-and-place.

For high volume manufacturing where the number of different circuit configurations are minimal, the number of components on each circuit is large and production runs are very long, chip shooters are generally used (Figure 6). Chip shooters run at extremely fast processing rates, sometimes using more than one head to place components, but they are also expensive and require substantial floor space. The most common type of chip shooter has an x-y moving table that holds the circuit and travels below a stationary turret containing multiple nozzles. The turret simultaneously picks a component from a feeder with one nozzle while another turret at the front of the machine places a component that has already been picked from a feeder. The motion for the picking turret and the placing turret are independent from each other. Because of this dual action, a chip shooter can place as many as 12 parts per second. They are generally used in conjunction with another piece of equipment, usually a stencil printing station that applies the conductive adhesive pads prior to the circuit entering the chip shooter. While it is possible to retrofit a chip shooter to provide dot dispense capability so adhesive and components can be applied at one station, the cost for retrofitting is high. Mounting an adhesive dispenser to a chip shooter would also greatly reduce the chip shooter's most redeeming feature of high speed component placement by creating a bottleneck in the process for the much slower dot dispensing process.

Gantry pick-and-place equipment is much slower than a chip shooter, but it offers more flexibility in terms of ease of modification to accommodate dot dispensing and even dome placement at a single station (Figure 7). Gantry based systems use the same moving x-y member to first pick and then place the component on the circuit which is fixed to a stationary table. Most gantry systems have very large placement areas. A typical machine can accommodate a sheet as large as 24" by 24". Most chip shooters have a working area of less than 12" by 18", making them less desirable for the large sheet formats used by most membrane switch manufacturers.

Table 4 shows a comparison between chip shooters and gantry pick-and-place. Most North American membrane switch surface mount processes use a gantry system due to the lower cost, flexibility, ability to handle large circuit formats, smaller footprint on the production floor and the ability of the system to easily accommodate dot dispensing and automated dome placement at a single station.

One important feature for pick-and-place equipment is that it have fully programmable z-axis adjustment to optimize bond strength when the component is placed and reduce adhesive migration underneath the component, which can produce an electrical short.

Crosslinking the Adhesive

The final production step in a membrane switch surface mount process is crosslinking the adhesive by applying heat. For small production runs, it is possible to use an offline walk-in oven to batch cure the circuits. For higher volume applications, an in-line conveyor oven just after the pick-and-place station is used.

There are two general types of ovens available for heating – forced hot air and infrared. Forced hot air (convection) involves heating air, usually by a gas-fired burner, and blowing it into the oven chamber. An infrared (radiant) oven uses a lamp or ceramic element that generates radiation in the IR spectrum. The primary difference between a gas-fired and an IR oven is that IR heats objects instead of the air around the objects. When IR radiation contacts a surface, it causes the molecules to vibrate rapidly, producing heat. Some IR ovens also use blowers for circulating air within the oven chamber to more evenly distribute heat from radiant sources within the oven that have been heated by the IR energy.

The type of carrier or pallet a membrane switch is put on to carry it through an IR oven determines how quickly the adhesive will heat up. A black pallet will heat up more quickly than a light colored one, and pallets made from polymeric materials will heat up much more quickly than a metal pallet when exposed to IR energy.

Heating an epoxy adhesive to crosslink it is much different than heating a solvent or water based ink to dry it. Crosslinking depends on heating the actual glue line to a specific temperature and holding it there. When drying ink, air flow patterns and dryness of the air are factors to consider when trying to optimize how quickly the solvent or water is evaporated from the ink. With crosslinking, the only factor is getting the glue line quickly up to temperature and holding it there. One of the most common mistakes is assuming the adhesive is reaching a temperature because the oven controls are dialed to that setting.

It is essential to perform a profile on the ovens used in surface mount production. The best way to perform a profile of an oven is to attach a small thermocouple to the surface of a membrane switch substrate. The thermocouple should be attached to a long length of appropriate wire, and plugged into a suitable temperature readout. As the pallet moves through the oven,

Table 4

	Processing Rates	Types of Application			Equipment Cost ($thousands)		
		LEDS	Domes	Adhesive	New	Refurbished	Retrofit
Chip Shooter	10-50,000/hour	YES	*	*	300-2,000	100-300	50-100
Gantry	1-9,000/hour	YES	YES	*	120-300	20-120	15-30

* Possible depending on the make and model and the control system. The retrofit cost would apply.

the thermocouple temperature should be noted at regular time intervals. The time intervals can be converted to feet by multiplying the belt speed by the time. A plot of distance into the oven versus temperature will give you an indication of temperature cycling within the oven chamber. Running this profile with a thermocouple on the left, middle and right side of a switch substrate will give an indication of any inconsistencies in temperature across the width of the oven chamber.

Some newer ovens have built-in software and thermocouple hardware for generating oven profiles directly from the control station. Figure 8 shows a typical profile for a 16-foot long, two zone IR and forced hot air oven set up to run on a membrane switch surface mount process.

Once a benchmark oven profile is performed, it is possible to change the belt speed and oven zone temperature settings to develop an optimal profile. This optimal profile will heat the adhesive quickly to the highest temperature possible without distorting the circuit substrate or damaging any other components, and hold the adhesive at this temperature through the entire length of the oven chamber.

Even off-line walk-in ovens need to be profiled by placing thermocouples at different locations within the oven chamber and recording the temperature. We have found these ovens have distinct hot and cold spots within the oven chamber. When circuits are placed on large racks and wheeled in, the racks and circuits act as baffles to the air flow and can cause even greater temperature gradients within the oven chamber.

The importance of understanding the time and temperature profile of the oven used in a surface mount process cannot be overemphasized.

If encapsulant is used after component placement, the encapsulant performs two functions – anchoring the component securely to the substrate and providing mechanical stress relief to the conductive epoxy joints if the circuit is flexed or heated and cooled rapidly. The hardness and flexibility of the clear encapsulant selected are crucial to maintaining electrical and mechanical joint integrity.

A hard, inflexible encapsulant will securely lock the component in place, but it will tend to pop free of the substrate if the circuit is flexed. Even slight flexing will cause a rigid encapsulant to easily fracture the conductive silver ink trace at the line where the encapsulant ends on the silver ink trace.

An encapsulant that is too soft and flexible will not separate from the substrate or fracture a silver ink trace as easily when the circuit is flexed. However, the too-soft encapsulant will allow the component to move against the conductive adhesive joint, which may cause fractures in the joint leading to latent electrical opens that sometimes show up after a switch is tested and sent to a customer.

After extensive evaluation of different encapsulant formulations and chemistry, we have established a simple, though not too scientific means for determining appropriate flexibility and hardness for an encapsulant used on membrane switch surface mount components. If you press your thumbnail firmly into a dot of encapsulant that has been dispensed, crosslinked and allowed to cool to room temperature, you should just be able to see a mark on the surface where an indentation is starting.

Even with an optimized encapsulant, if a surface mount joint fails, the most likely failure will be the silver ink trace breaking and separating from the substrate right at the line where the encapsulant dot ends on the ink trace, as opposed to the encapsulant separating from the substrate.

Another thing to be aware of with encapsulant is that unlike flat layers of screen printed UV dielectric, the encapsulant on the sides of the surface mount component are not getting a direct hit of energy from the UV lamp, because the sides of the component are at a 90° angle relative to the circuit surface and the lamp. Care must be taken to assure the encapsulant is crosslinked completely.

If a center dot of non-conductive adhesive is not used to mount the device, sometimes a small amount of encapsulant gets underneath the component and does not harden. This is referred to as the "shadow effect" since the material is blocked from the UV energy by the component, and the crosslinking chemistry cannot be activated. This small amount of uncured encapsulant will not adversely affect joint integrity or the adhesives, conductive inks or dielectrics used in membrane switch manufacturing provided the encapsulant does not contain solvents or other materials that may act as solvents on other polymers.

It is possible to use "dual cure" chemistry for an encapsulant, where a side chemical reaction occurs to crosslink the material that is shaded by the component after the UV curing is complete. The biggest disadvantage to a dual cure product is they have reduced shelf lives, and the cost for

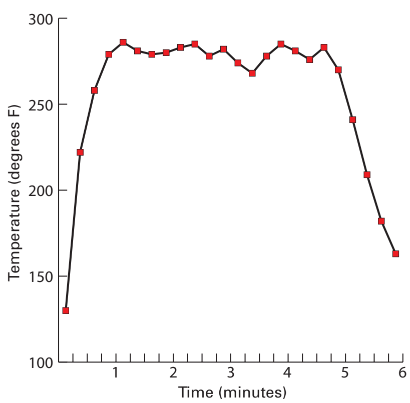


Figure 8: Oven Profile For Typical Surface Mount Oven Used to cure Adhesive.
16 Foot Long Two Zone IR Oven with Forced Hot Air, Belt Speed 2.5 Feet/Minute. Profile Shows Actual Temperature at Surface of Polyester Substrate As Circuit Travels through Oven Chamber

storage and shipping can be greater than for a UV curable encapsulant.

Circuit Design Issues

Before adopting surface mount processing, it is essential to understand some design considerations for placing components onto membrane switches.

Surface mount materials perform two functions – mechanically attaching the components to the circuit and providing an electrical path from the screened ink traces to the component anode and cathode.

Determining Pad Size, Placement

The size of the surface mount component determines the possible adhesive pad size and placing, which in turn affects four factors: migration area, conductive area, bond strength and sensitivity to variation. Migration area is the distance the adhesive can travel underneath the component before creating an electrical short by touching either the edge of the other adhesive pad, or the edge of another silver ink trace. Conductive area is the amount of surface area contact between the component anode or cathode and the conductive adhesive and between the adhesive and the silver ink trace. Bond strength is determined by the total contact area between the component and adhesive, and between the adhesive and silver ink trace or circuit substrate. Sensitivity to variation is the affect of ink and component placement registration variance on the above three factors.

The crucial performance tradeoff to consider when designing for component placement is how to maximize migration area, conductive area and bond strength while minimizing sensitivity to registration variation. The larger the component size, the greater the migration area, the greater the conductive area and resulting bond strength, and the less sensitive the component is to variance in registration.

Consider the difference in surface area for three common LED component sizes shown in Table 5. Figure 9 shows these three components surface mounted using .060” wide conductive adhesive dots and appropriate spacing between the dots.

The 1206 component has optimal conductive area and bond strength by maximizing contact between the component anode and cathode areas and the conductive adhesive dots. The migration area is also maximized by leaving .060" spacing between the edges of the adhesive dots before placing the component.

With the shorter 0805 component, the adhesive dots must be moved closer together to maintain the conductive area and bond strength. Even with this closer dot spacing, the amount of contact between the component and the adhesive dot is still much less than it is with the 1206 component. More importantly, the migration area is reduced from .060" to .040" to maintain the conductive area and bond strength.

Finally, the 0603 component shows minimal conductive area and bond strength. The migration area is maintained at .040” to prevent migration and shorting, which means the overall contact between the component and the adhesive will be reduced.

Figure 10 illustrates how the adhesive pads migrate toward each other as a component is placed onto the pads. The 1206 LED is placed onto .060" diameter adhesive dots with a height of .015", spaced .060" apart before placement. The component is placed to within .010" of the substrate surface. As the component is placed, it begins pushing the adhesive pads inward toward

The size of the surface mount component determines the possible adhesive pad size and placing.

Table 5

Component Type	Length (Inches)	Width (Inches)	Surface Area (In^2)	Surface Area Reduction
1206	0.120	0.060	0.0072	——
0805	0.080	0.050	0.0040	44.4%
0603	0.060	0.030	0.0018	75.0%

Table 4: Bond Strength, Conductive Area & Migration Area for Three Common LED Types.

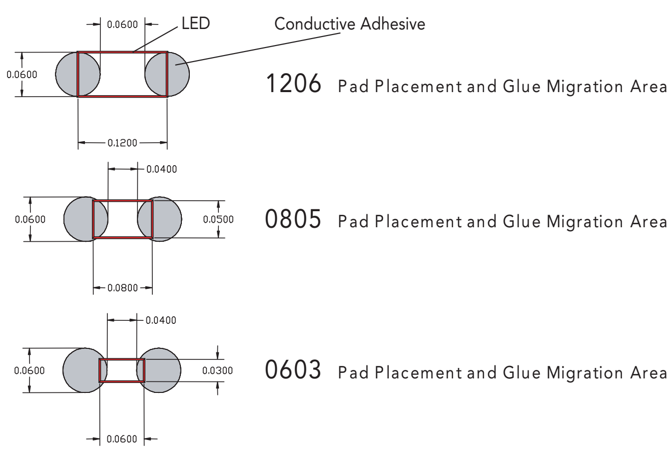


Figure 9: Bond Strength, Conductive Area & Migration Area for Three Common LED Types.

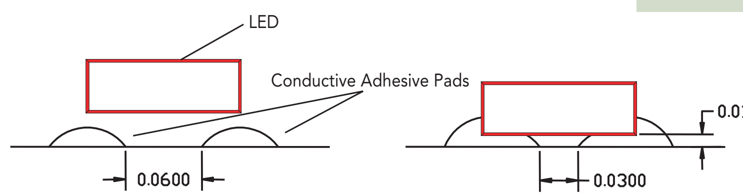


Figure 10: 1206 Component Placement Causing Conductive Adhesive Migration

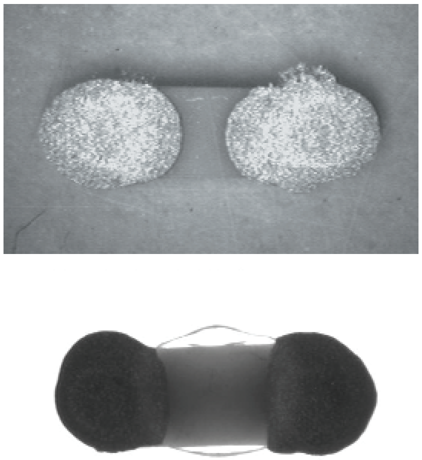


Figure 11: Oblong distortion of two migrating conductive epoxy adhesive pads underneath a properly placed LED (above) and reduced migration of the conductive adhesive using a center dot of non conductive adhesive before component placement (below). (Photo courtesy Nicomatic, Warminster, PA)

The single largest cause of component failure on membrane switches is electrical shorting induced by registration variance.

each other and outward, creating a higher profile of adhesive around the edges of the component. Ultimately, the original spacing of .060" between the adhesive dots is now reduced to .030" migration area after the component is seated .010" above the surface of the substrate. The closer the component is pushed to the surface of the substrate, the more the adhesive is displaced and the greater the chance of shorting. This is why it is essential to have programmable z-axis control regardless of the type of pick-and-place process selected. Figure 11 shows the oblong distortion of two migrating conductive epoxy adhesive pads underneath a properly placed LED, and the same component mounted using a center dot of non conductive adhesive to minimize migration.

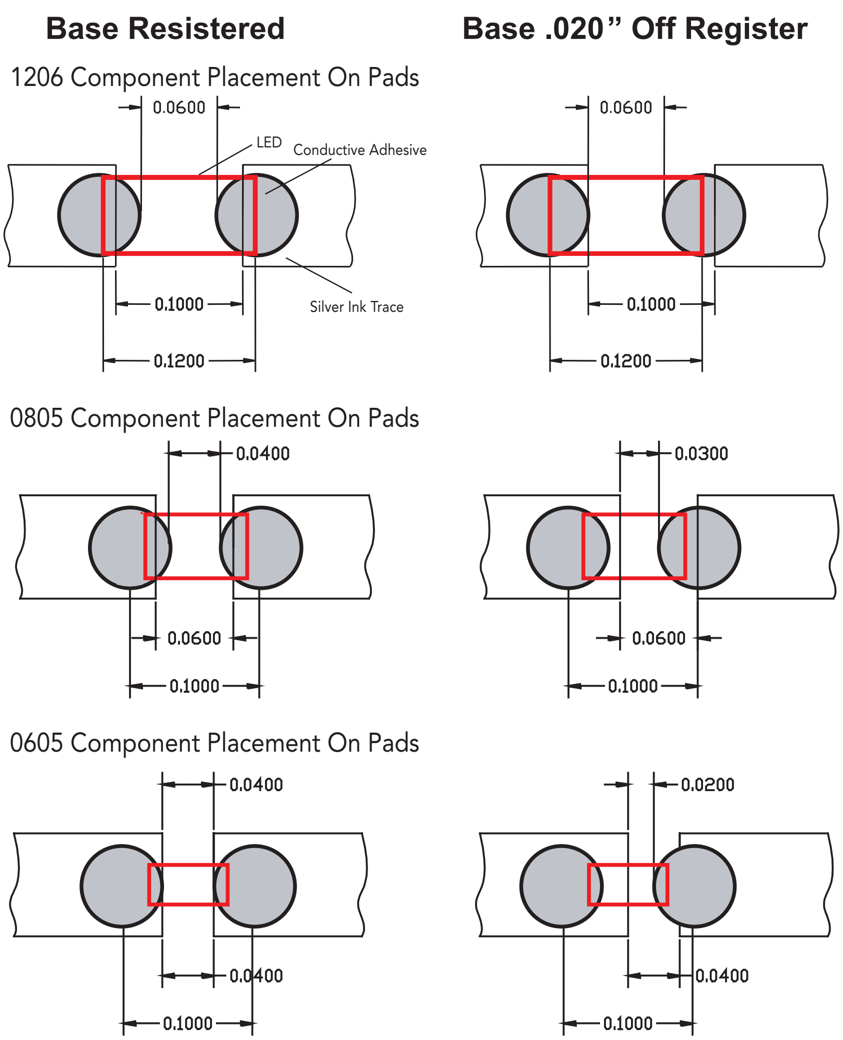


Figure 12

Wicking

Once the component is placed, adhesive migration is further aggravated by a phenomenon called wicking. When the circuits are heated to crosslink the epoxy adhesive, the wet adhesive will migrate underneath the component by capillary action and the edges of the adhesive pads will move closer toward each other. This is the same principle plumbers use when soldering copper pipe sections together. The outer sleeve of the junction is heated, and the solid metal solder is placed on the edges of the joint. The heat pulls the molten solder into the small joint by this same capillary action. For this reason, it is essential to maintain sufficient migration area underneath the component, even if it means a reduction in conductive area and bond strength.

Electrical Shorting

According to Dave Fisher of Nicomatic North America, the single largest cause of component failure on membrane switches is electrical shorting from conductive adhesive migration which can be aggravated by registration variance between the silver ink printing and the surface mount processes. To reduce this variance, it is essential to minimize factors that affect registration variance such as substrate shrinkage during ink drying, and to select surface mount equipment that can be quickly and easily aligned with reference points (fiducials) on the circuit surface. One of the advantages of a single station dot dispense and pick-and-place station is that it is relatively easy to optically register adhesive dispensing and component placement using fiducials printed during the same pass as the silver ink traces on the circuit.

As component sizes get smaller, the impact of registration variance on component failure becomes more pronounced. The effect of component size and conductive adhesive dot spacing on sensitivity to registration variation is illustrated in Figure 12.

Optimal base registration for the three LED types is shown first, with .060" diameter adhesive dots and appropriate spacing between the conductive ink trace pads and the two adhesive dots before component placement. This ideal base registration is then compared to the surface mount process being .020" off registration with the conductive ink traces.

The 1206 component has a migration area of .060" at base registration before component placement, as measured between the two edges of the adhesive dots. If registration is off by .020", notice the migration area is still .060", as measured from the edge of one adhesive dot to the edge of the other adhesive dot and ink trace.

The 0805 component has a migration area of .040" at base registration, as measured between the two edges of the adhesive dots. Notice the silver ink traces are also spaced closer together than the longer 1206 component. If registration is off by .020", the migration area is now reduced to .030" as measured from the edge of the adhesive dot to the edge of the opposite silver ink trace. The component is now more prone to shorting out if the conductive adhesive wicks underneath.

The 0603 component has a migration area of .040" at base registration, as measured between the two edges of the adhesive dots. The silver ink traces are spaced even closer than the longer components. If registration is off by .020", the migration area reduces to .020" as measured from the edge of one adhesive dot to the edge of the opposite silver ink trace. This virtually guarantees an electrical short from conductive adhesive migration and wicking underneath the component.

Another observation about off registration of the LEDs is that in all three instances, bond strength is reduced in the dot on the left side of the off-registered LED. This is because the adhesive dot rests entirely on the conductive ink trace. The conductive area is reduced in the dot on the right hand side because of the reduced contact between the adhesive dot and the silver ink trace. Remember, ultimate adhesive strength is stronger between the conductive epoxy and the bare polyester substrate than it is when the adhesive is on the silver ink trace. The silver ink trace does not adhere as well as the conductive epoxy to the polyester substrate. Even with a reduction in bond strength and conductive area from off registration, an LED will still be fully functional provided the adhesive does not wick together to produce a short and both conductive adhesive pads contact the silver ink trace.

Variation in bond strength and ease of electrical shorting from off registration are the primary reasons why clear UV curable encapsulants or nonconductive adhesive dots between the conductive adhesive pads are used to anchor smaller components more securely onto substrates. Fisher claims most manufacturers use the non-conductive center dot mainly as a barrier to prevent conductive adhesive migration and shorting, and the clear encapsulant anchors the component much more securely than the non-conductive center dot of adhesive. About half of Nicomatic's customers use both the center dot and encapsulant for component placement.

We have also found some customers will use only a single center dot of nonconductive adhesive to stake the component, then put the conductive adhesive on the outside edges of the component anode and cathode after placement. There are also instances where a device is placed onto the wet conductive adhesive pads, and the clear encapsulant is immediately applied and hardened using UV light. The conductive epoxy is then allowed to crosslink at room temperature. While these two techniques may offer reduced shorting from migration and wicking and possibly faster throughput in production, overall joint integrity is compromised. The potential for latent failures caused by hairline fractures in the conductive adhesive showing up after circuit testing is greatly increased.

Historically, the membrane switch industry has been forced to use LEDs designed for PCB surface mount applications. As smaller PCBs continue to emerge, the components they use must become smaller in length, width and height as board space is at a premium. Most membrane switches do not have this surface area constraint – the primary limiting factor is the height of the component due to spacer layer thickness. To minimize component height, switch designers are forced to use the 0603 packages with reduced surface area. Nicomatic recently commercialized a 1206 package size LED with a height of only 0.5mm, designed specifically for the membrane switch industry (Figure 13). This component allows a switch designer to virtually eliminate shorting from adhesive migration and wicking while maximizing conductive area and bond strength and reducing component height.

Conclusion

Surface mounting components onto membrane switches uses technology and processes that have been used in traditional circuit manufacturing for decades. While surface mount production methods are quite different than the typical screening, die cutting and assembly operations used by membrane switch manufacturers, there are resources available to assist with implementing a turnkey surface mount production line into any size membrane switch company. Since automated dome placement can be easily incorporated into the surface mount process, the financial payback analysis for equipment investment becomes more favorable.

As pricing becomes more competitive within the industry, surface mounting provides a way to offer value added products while maintaining profit margins.

The author would like to thank Mike Streun from Assembly Automation for providing technical information and data.

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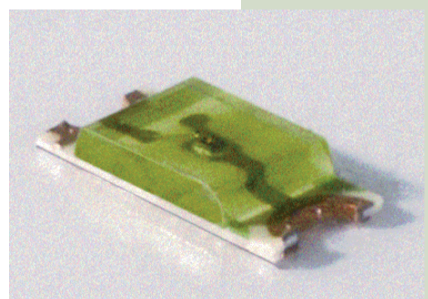

Figure 13: Nicomatic 0.5 mm high 1206 LED designed for the membrane switch industry.