As originally published in the IPC APEX EXPO Conference Proceedings.

Mobile Electronics, How to Protect Internal Circuitry from A Harsh Environment

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Abstract:
The portable electronics market has driven steep-slope growth for over a decade and continues to deliver amazing handheld electronic devices; manufacturers of these products are facing challenges they thought would be in the distant future: denser electronic substrates, more power demand and more heat to dissipate, stringent use conditions, and more importantly, demand for lower production cost.

Lowering production cost is critical to remaining competitive; hence the objectives become high “first pass quality” and low “returns for failed units.” There is high demand for manufacturing tools and processes that attain these goals.

Conformal coating is a cost effective process used to maintain the functionality of the electronic components inside a mobile device in harsh environmental conditions. This paper discusses recent developments in conformal coating that help enable the manufacturing process to meet the criteria for increased reliability at a lower cost, especially important for high production volume devices that command above average selling price.

The term mobile electronics includes cell phones, digital cameras, personal video and music players, wearable items for tracking fitness and sports training as well as health monitoring devices. They vary in size and form factor but all share one main requirement: reliability. Cell phones constitute a great example for a case study on reliability; their use model is very stringent as they must withstand moisture damage from sweat, breath, water splash or a rain shower and must endure climate environments that range from high heat and high humidity to freezing cold and snow.

Of the reported causes for cell phone failure, the two major ones are damage from moisture and damage from being dropped. This paper will focus on conformal coating protection of mobile devices against damage from moisture.

The need for better reliability derives from the evolution of the limited function phone into a “smart phone” serving the roles of digital assistant, music or video player, GPS, email, web browser, etc. People depend more on them and expect that they function properly to the end of their contract period (typically two years) or beyond. Otherwise, a disappointed and dissatisfied consumer will cost the manufacturer both in warranty claims and brand reputation.

A short review of any smart phone available for sale, gives a clearer idea of the type of capability contained in such a small package. The drive to adopt every available miniaturization technology increases the value added to the device, but also the cost of the materials that comprise it. A look inside these phones illustrates the greater challenge to selectively conformal coat these substrates for reliable moisture protection that the (conformal coating) equipment suppliers must deliver.

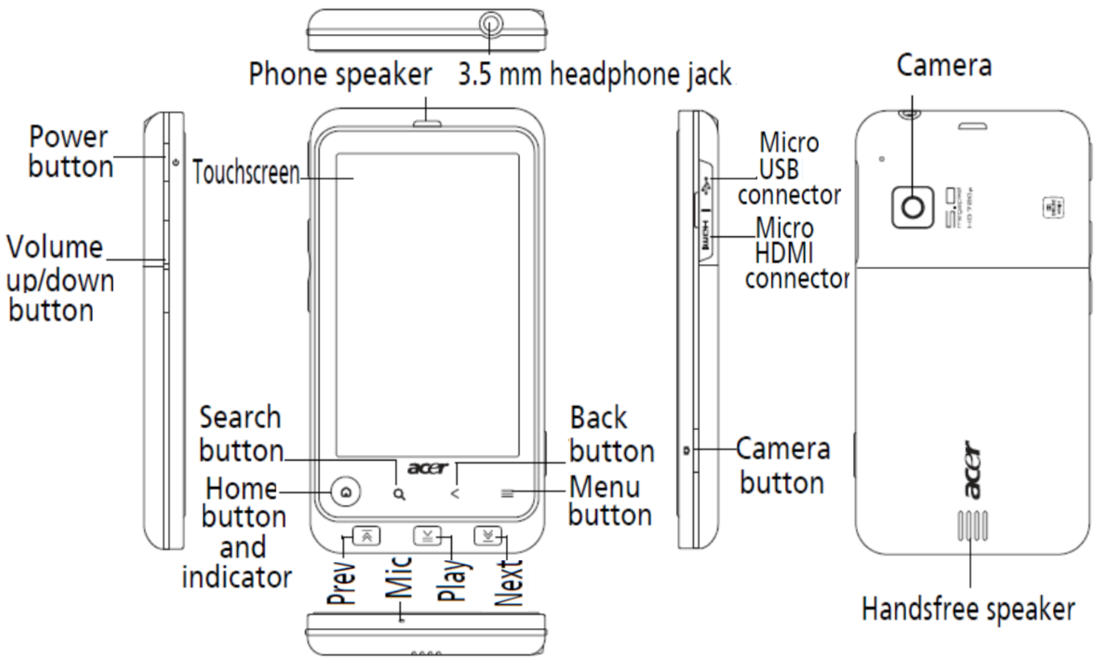


FIGURE 1 Mobile phone parts and potential water/moisture entry points

The challenge of applying conformal coating to protect an electronic assembly includes issues of applicator access to the substrate, capability of delivering a minimum coating volume, and the single-shot coating rate.

Conformal coating protection for mobile electronics

Since moisture is the risk factor that needs to be addressed, a typical approach is to protect the inside electronics at the potential points of entry. High priority is given to the microphone or the speaker and the mechanical keyboard if one exists. There is also risk of humidity entering through the memory card slot, earphones connector, the battery charge connector or assembly points, like the function buttons or casing splits. Some of these zones are protected against humidity or water ingress with seals and gaskets; but since either can still permeate through to the electronic circuits, there are manufacturers who choose to add another barrier, like targeted coating of key components. The degree of protection needed depends on its lasting requirements. As stated earlier, smart phone durability is an expectation that comes with its higher price.

Coating process

Conformal coating of small PCBAs evolved from 100% coverage (with masked areas), to selective coating as PCBAs dimensions keep shrinking and coated versus not-coated areas are closer together. The protection need of mobile electronics added the high selectivity challenge to the process when the requirement of cost reduction and higher throughputs were added to the mix.

High selectivity coating is more specialized since the coating requirement is localized and the desired coating volumes are small. Jetting is the method of choice and is the newest technology available in the coating process. Jetting is ideal for coating discrete spots and precise highly selective areas on a substrate. Highly selective coatings challenges are defined as those where small coating amounts are required next to keep-out zones and minimal width buffer zones (1 mm or less with a requirement of discrete lines of ~1 mm width and 25µm to 75µm thickness). Coating thickness around the component edge/corner, a difficult parameter to measure in a non-destructive way, is scrutinized with the same care as flat surface coating thickness.

TABLE 1 THERE ARE SEVERAL COATING TECHNIQUES AVAILABLE DEPENDING ON THE APPLICATION REQUIREMENTS.

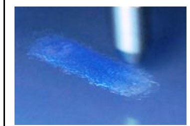
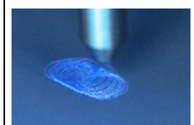
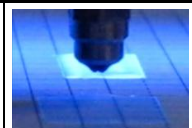
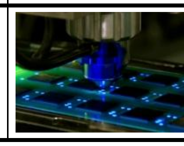
Process	Features	Downside	Parameters	Pictorial Representation
Air Spray Atomization	• Best for thin coatings • Fast speed	• Requires masking of keep out zones • Ragged edges • Prone to overspray	• Thickness: 1 - 75 µm • Pass width: 5 - 25 mm • Edge definition: ± 5 mm	
Air Assist	• More selective than air spray • Less ragged edges • Medium speed	• Thicker than air spray • Not as selective as Film coating or Jetting	• Thickness: 25 - 175 µm • Pass width: 5 - 19 mm • Dispense height: 5 - 20 mm • Edge Definition: ± 1.5 mm	
Curtain Coating Flow Coating Film Coating	• Well defined edge • Fast speed	• Viscosity range up to 100 cPs	• Thickness: 25 - 75 µm • Pass width: 5 - 20 mm • Dispense height: 5 - 20 mm • Edge definition: ± 0.75 mm	
Needle Jetting	• Precise coating • Dot dispensing • Discrete lines	• Viscosity range up to 1,000 cPs	• Dot size: 2.0 mm • Discrete line width: 2 – 3 mm • Dispense height: 0.1 - 3 mm	
Jetting	• Very precise coating • Dot dispensing • Discrete lines • Highly selective	• Slow for large areas	• Dot size: 0.6 mm • Discrete line width: 1 mm • Dispense height: 0.1 - 3 mm	

TABLE 2 PARAMETERS AND DIFFERENCES TYPICALLY OBSERVED IN CONFORMAL COATING APPLICATIONS

		STANDARD PCBA	MOBILE ELECTRONICS.
Coverage	• They can be discrete points or whole areas	• Differentiated areas • Better spaced	• Coating using narrow lines and discrete dots • Tight geometries
Keep out zones	• Much more critical due to closeness of components • Specially stringent on staying clear of LED lenses and flex ribbon cables	• Buffer zones • >1mm	• Buffer zones • <1 mm
Coating thickness	• Narrow window for uniformity • Minimal acceptable film thickness	• 25 – 75 µm (solv.) • 75 – 125 µm (non solv.)	• 25 µm • (including around component and lead corners)

Conformal coating materials for mobile phone protection

There is a relatively wide variety of conformal coating materials available. However, process windows are narrower in mobile electronics and the variables must be evaluated more carefully.

The common denominator in coating materials is the cure mechanism. Ultra-violet (UV) cure is preferred to obtain a rapid curing rate. Coating materials can be acrylics, urethanes or silicones with viscosities in the low (10 to 20 cPs) or high range (500 cPs to 1,000 cPs). Generally, the conformal coating material choices are specified before the equipment supplier is contacted. The challenge becomes choosing the coating applicator that will be effective within the parameter limits already established.

The conformal coating material supplier sometimes receives requests for materials with properties that are not compatible. For example viscous enough that the coating will stop flowing as soon as it is deposited, yet fluid enough that the coating self-levels to a uniform surface or thickness. These requirements are not uncommon, but it is not generally possible to accommodate them all.

High contrast of the coating material to UV light is a nice-to-have feature and some materials have it more than others. Everything else being equal, high-contrast can be the deciding factor between two coating materials. Even after a product has been shipped and is in use, a visual UV inspection that detects the presence or absence of coating helps if a warranty issue arises.

When a manufacturer or contract manufacturer is evaluating a new process, time is usually limited, and pressure is placed on the equipment supplier to provide the required coating equipment configuration and/or processed samples for evaluation. With such small margins of error for coating application compliance, several coating trials are expected before the appropriate combination of coating material, applicator, and coating parameters can be determined. These iterations are wholly justifiable given the massive production volumes required from the start.

Process Validation:

A demonstration of an application or equipment capability invariably requires running a number of customer sample parts. These completed samples are analyzed at the customer site to their specific criteria. Based on their results, customers may require additional demos, with some changes in parameters or even change of materials.

For a high selectivity conformal coating application, the typical metrics include application consistency in terms of coating volume repeatability and accurate placement of the coating on the part. The demo helps determine the process variation, which in turn reveals the certainty level within a specified parameter band.

Material characterization is the initial step in a demo and requires a series of coating samples run at different parameter settings. Sample runs can be used for calculating the process parameters and cpk for a particular set of variables, showing in a simple manner the kind of results that can be obtained or ones the customer would like to see when going through this type of evaluation.

The example below illustrates a calculation of process capability for two parameters: coating thickness and dispensed weight. Finding methods to take measurements off the demo samples can be challenging and readings must be carefully taken in order to have a representative set of data points. In the end, the statistical analysis results will be the customers' determining factor for deciding if the process is robust or whether adjusments must be made to the process before proceeding further. Demo rounds and analysis help ensure a robust production line implementation.

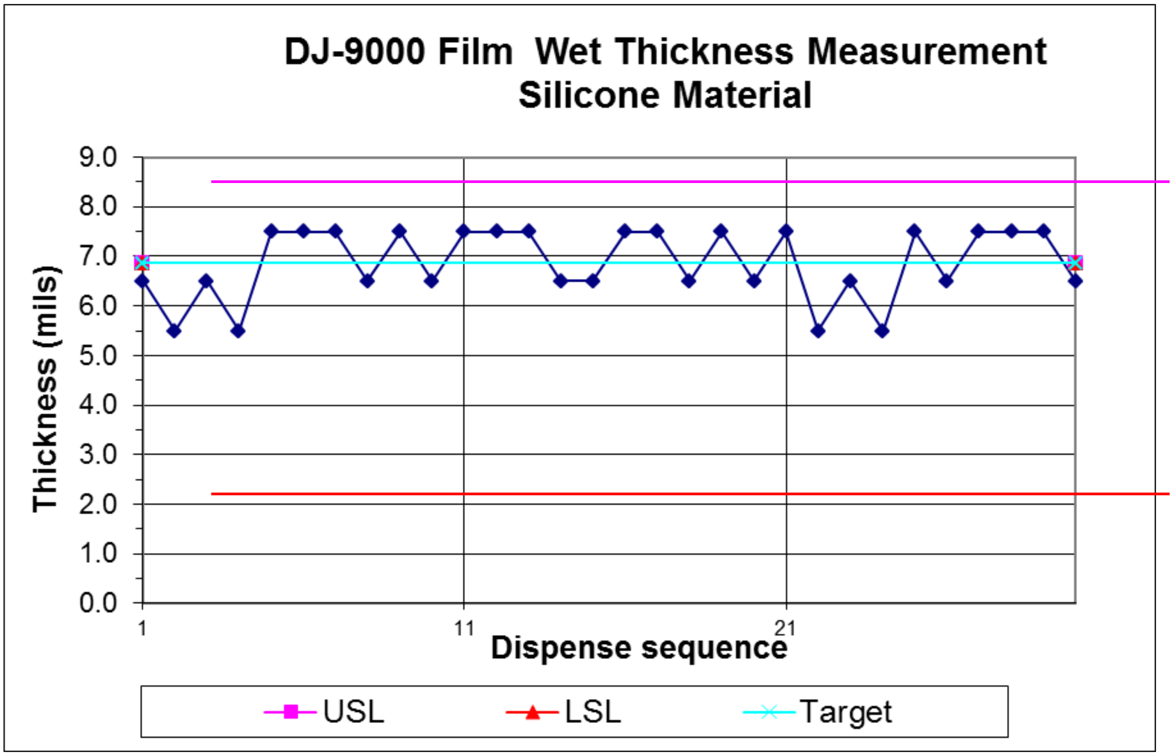


CHART 1 FILM THICKNESS MEASUREMENT FOR JETTING APPLICATION

NOTES to Film thickness measurement data:

- Thickness measurement has a variation of up to 0.002 inches (2 mils)
- IPC thickness standards establish a value of:
- 0.001 to 0.003 inch film thickness dry for solvent based materials
- 0.003 to 0.008 inch for 100% solids
- Thickness target is between 0.005 and 0.008 inch for silicone material

Table 3
Wet Film Thickness Measurement Readings

Sequence	Part #	Location	Thickness (mils)
1	1	South	6.5
2	1	East	5.5
3	1	North	6.5
4	1	West	5.5
5	2	South	7.5
6	2	East	7.5
7	2	North	7.5
8	2	West	6.5
9	3	South	7.5
10	3	East	6.5
11	3	North	7.5
12	3	West	7.5
13	4	South	7.5
14	4	East	6.5
15	4	North	6.5
16	4	West	7.5
17	5	South	7.5
18	5	East	6.5
19	5	North	7.5
20	5	West	6.5
21	6	South	7.5
22	6	East	5.5
23	6	North	6.5
24	6	West	5.5
25	7	South	7.5
26	7	East	6.5
27	7	North	7.5
28	7	West	7.5
29	8	South	7.5
30	8	East	6.5
31	8	North	6.5
32	8	West	5.5
33	9	South	7.5
34	9	East	7.5
35	9	North	7.5
36	9	West	6.5
37	10	South	6.5
38	10	East	6.5
39	10	North	7.5
40	10	West	6.5

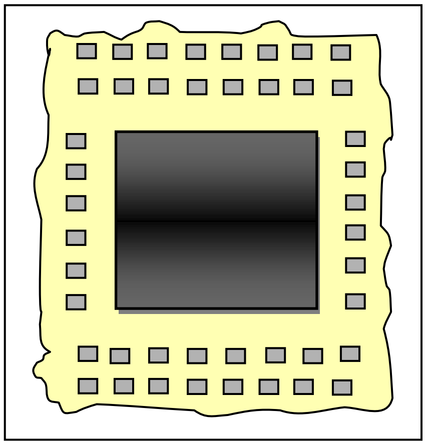


FIGURE 2
JETTING APPLICATIONS TEST VEHICLE.
- YELLOW COLOR REPRESENTS COATED AREAS.
- GRAY SQUARES REPRESENT COATED COMPONENTS.

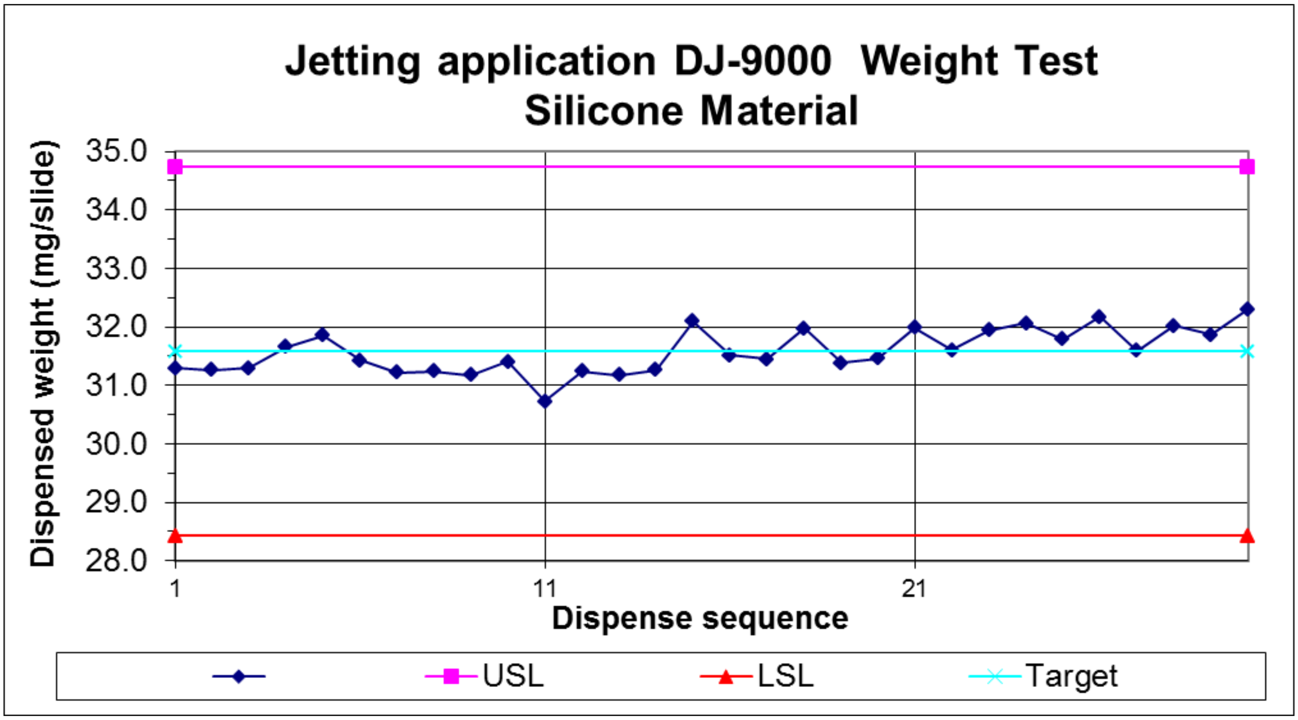


CHART 2 JETTING APPLICATION, PRECISION COATING WEIGHT MEASUREMENT

Data readings are taken on each side of the test vehicle (bottom -south, right- east, top-north and left-west)
Measurements were taken in inches (0.001 inch = 1 mil =25.4 µm)

Table 4
Jetting application, weight measurement readings

Dispense #	Net (mg)
1	31.30
2	31.26
3	31.29
4	31.66
5	31.85
6	31.43
7	31.22
8	31.24
9	31.18
10	31.41
11	30.73
12	31.24
13	31.18
14	31.26
15	32.09
16	31.51
17	31.45
18	31.97
19	31.38
20	31.46
21	31.98
22	31.60
23	31.94
24	32.06
25	31.79
26	32.17
27	31.59
28	32.02
29	31.87
30	32.30

Table 5 Jetting application, weight measurement statistical calculations for chart plotting

TABLE 5 JETTING APPLICATION, WEIGHT MEASUREMENT STATISTICAL CALCULATIONS FOR CHART PLOTTING

Target =	31.58	±	10	%

USL	LSL	UCL	LCL	#of excp.	#of samples
34.74	28.42	32.71	30.45	0.00	30

Avg. Wt.	% diff.	Cp	Cpk
31.58	0.00%	2.800	2.800

□	3 □	3 □□%	Min	Max
0.376	1.128	3.57%	30.73	32.30

(Data for plotting USL, LSL, and Target)

	USL	LSL	Target
1	34.74	28.42	31.581
30	34.74	28.42	31.581

Weight measurement is the method of choice for process control in jetting applications.

Cpk target is 1.3 or better

10% variation range is a standard requirement for jetting applications.

Financial Justification for a Coating process in mobile electronics

In a competitive market segment like smart phones, manufacturers are constantly aware of the need to provide a quality product that will work flawlessly through its warranty period and beyond. Users can punish a brand that is perceived as less than excellent, especially if the device commands premium price.At the same time, network providers demand minimal repairs and replacement phones at minimal additional cost.

Examining the total cost of ownership (TCO) is crucial to ensure profit margins are maintained; manufacturers must weigh the benefit of each step in the manufacturing process. Conformal coating reduces field failures and reduces hardware replacement cost, which offsets the cost of a conformal coating process and can increase product life expectations

Total cost of ownership (TCO) consists of many calculation factors, and it's a complicated exercise for factories that run different production lines with numerous pieces of equipment and overlapping processes.

An accurate analysis for a mobile phone production line requires an understanding of cost and benefits beyond the scope of this paper. However, a simplified model can be used to quickly determine whether an investment in a coating process would provide tangible benefit from the "cost of failure" standpoint.

TABLE 6 SIMPLIFIED MODEL FOR TCO CALCULATION

TABLE 6 MAIN COMPONENTS OF A SYSTEM TCO

Description	Itemized quantity	1 Year rate	Calculations / Comments
Equipment investment	$200,000.00	$ 200,000.00	Coating unit ,conveyors, cure equipment, etc.
Operation cost /yr (15%)	$ 30,000.00	$ 30,000.00	Estimate... varies by application
Material Cost	$ 100.00/kg	$ 6,250.00	62.5 Kg/yr x $100.00 /Kg $6, 250.00/yr
TOTAL CAPITAL INVESTMENT		$ 236,250.00	
COST/ UNIT		$ 0.23625/ unit	$ 236,250.00 / 1,000,000 units = $0.24 / unit
Cycle rate 24/7 operation 95% up time	30 seconds / unit	1,000,000 units	1 day = 86,400 sec 365 day x 86,400 sec = 31,536,000 sec /30 sec/unit 31,536,000 sec/yr / 30 sec/ unit = 1 051 000 unit/yr 1,051,000 unit/yr x 0.95 = 998,640 unit/yr ~ 1,000,000 unit/yr (1 million)
Conformal coating application 80% efficiency	50 mg /unit	62.5 Kg/yr	0.050 gr/unit /0.8 = 0.0625 gr/unit 1 Kg = 1,000 gr 1,000 gr / 0.0625 gr/unit = 16,000 unit/kg 1,000,000 unit/yr / 16000 unit /Kg 62.5 Kg/yr
High end phone hardware assembly cost	$200/unit	$ 200,000,000.00	$200 / unit x 1,000,000 units = $ 200,000,000.00 (Two hundred million)
Cost of 1% failure in the field (per 1 million units)	10,000 units	$ 2,000,000.00	1,000,000 units x 0.01 = 10,000 units $200 /unit x 10,000 units = $2'000,000.00

For a 1% reduction in failures, there could be $2 million savings per every million phones sold at a cost of 24 cents per phone. Therefore, there should be a great incentive to minimize field failures

In closing, mobile electronics may have unique needs for applying coating protection, and when conventional technologies do not appropriately meet the parameter requirements; there are coating advances that will fill that special requirement.

The challenge for equipment manufacturers is to stay abreast of the needs in order, to always have an alternative to offer when the occasion arrives.

There is also the need to maintain a cost justifiable alternative, otherwise it might be difficult to adopt. It must be remembered that mobile electronics technology is always reducing it's cost with each new advancement step.

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