Conformal Coatings: Challenging Environments Lead to Growth

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Advances in technology have resulted in the need for electronic devices to continue functioning even when placed in harsh environments. Widespread use of cell phones, laptop computers, and other personal electronic devices, the increased number of electronic controls in home appliances, and the ever more extensive utilization of digital technology in the automotive industry have led to a growing demand for printed circuit boards (PCBs) that can perform under difficult conditions. Conformal coatings provide a protective barrier that enables the PCBs to function in these demanding environments. This growth in demand comes despite the cost and numerous difficulties associated with the application of these coatings. Many conformal coatings manufacturers are investing in the development of new technologies that minimize these difficulties. Others are involved in developing disruptive technologies that will serve as alternatives to traditional conformal coatings processes.

The main function of conformal coatings is to protect PCBs from humidity, corrosive gases and solvents, dust, fungi, and other contaminants. They also provide stress relief and protection for the insulation resistance of the circuit board, minimize dendritic growth and the electromigration of metal between conductors, and act as a design tool due to their excellent electrical properties. Selection of a conformal coating depends on the specific application. Typically, the dielectric properties, abrasion, solvent, and thermal resistance, and ease of application of the coating are considered. Coatings are applied in thin layers of a few mils to a fraction of a millimeter.

The environmental and mechanical protection afforded by conformal coatings can prevent short circuits and corrosion of conductors and solder joints, significantly extending the life of the components and circuitry. Other technologies used to protect electronics from harsh environments include potting, sealing, and overmolding. "Although conformal coatings are an older technology, it is my opinion that they are of immense importance to the electronics industry—an industry in which product reliability is crucial,"

says Brad Solensky, global product manager—circuit board protection, with the electronics group at Henkel. "Conformal coatings are a simple method of harnessing a strong protective barrier to shield sensitive modern electronics devices and interconnections," he adds.

Five different types of resins serve as the base materials for conformal coatings: acrylics, epoxies, urethanes, silicones, and parylenes. Each type of resin has different properties, application issues, and performance characteristics associated with it. The choice of coating material depends on the environmental and operating conditions that will be present.

Acrylic coatings, which have traditionally been solvent-based formulations, provide tough, hard, transparent coatings that exhibit good pot life, low moisture absorption, and relatively short drying times. They have good electrical and physical properties, resist fungal growth, and do not shrink. They do lack stress-relieving capabilities, and some versions may have associated environmental, health, and safety concerns. Because they are solvent-based, acrylic resins are easily removed if repairs are necessary. Some formulations are now available that contain no volatile organic compounds (VOCs). A few waterborne acrylics and urethane-acrylic hybrids are also on the market, but these coatings are not as easily removable.

Conformal coatings based on epoxy resins are also hard. Excellent water, chemical, and abrasion resistance of epoxy coatings is balanced with instability under fluctuating temperatures. They also shrink while curing and are very difficult to remove for repair of the PCB. Urethanes also make hard conformal coatings that are resistant to solvents, moisture permeability, and abrasion while maintaining flexibility at low temperatures. However, they cannot be used in high-temperature applications, air-cured formulations can take days to fully cure, and they are very difficult to remove. Both epoxies and urethanes have some health and safety issues associated with them as well.

Silicone-based conformal coatings can be either tough, abrasion resistant, or soft, stress-relieving materials, depending on the formulation. They are most recognized for their stability over a wide temperature range and during temperature cycling. These conformal coatings provide good moisture and corrosion resistance and are available as both solvent-based and 100% solids formulations. The 100% solids materials can be cured with heat, moisture, or UV. Removability is typically not an issue as chemical strippers are available that enable this process. As with epoxies and urethanes, there are some handling issues with silicone coatings.

Parylene coatings are applied in a vacuum using vapor deposition techniques in order to achieve very thin, uniform coverage. They are costly and very sensitive to contamination, and must be applied in a batch operation. Conformal coatings based on parylene resins are hard, transparent, and biocompatible. They exhibit excellent dielectric properties and provide protection against most solvents, contaminants, and moisture. Generally, these coatings are recognized as the top performing material, but their applicability is limited due to their high cost and difficult removability.

Conformal coatings are traditionally applied by dipping, spraying, or flow coating. Select coating or robotic dispensing is becoming more common. Manual application by brushing is still done for very small volume operations or sometimes during repair work. However, it is difficult to get a uniform coating. Handheld spray guns used with low-viscosity coatings are appropriate for slightly larger volumes, but they require masking to protect parts of printed circuit boards that should not be coated, such as contacts, connectors, heat sinks, LED lenses, speakers, terminals, etc. Consistency is an issue with this method, as application of the coating is often operator dependent. Overspray of coating material is also a concern.

Immersion or dipping of the PCB is used for complete component coverage and higher volume applications. It is more common with PCBs populated with through-hole components. The viscosity of the formulation can significantly impact the results with this technique, and masking can be difficult. Flow coating is also used for complete board coverage where high profile components need to be left uncoated. Screen application is often used for ceramic/PTF substrates.

High volume coating today is often done with automated dispensing systems, which allow for selective application of the conformal coating and provide consistent results and minimal waste. As a result, these automated systems achieve labor savings, reduced material usage, and decreased environmental management costs.

Application of conformal coatings occurs as the last step in the production process of PCBs. While some board manufacturers do apply conformal coatings themselves, much of this work is completed by independent processors at separate facilities. Each conformal coating application must be developed according to the shape of the board and the

Leading Suppliers of Conformal Coatings

Dow Corning
Dymax
Emerson & Cuming (ICI)
GE Silicones, Emersion
Henkel
HumiSeal
Lord Corporation

PC boards can be dipped into silicone-based conformal coating materials to protect the boards and their chips. Typically used for medium- to high-volume production, dip coating can assure complete coverage of a circuit board. *(Photo courtesy of Dow Corning Corp.)*

pieces on it because the configuration of the PCB has a large impact on the coatings, according to Michael D. Brown, vice president of The ChemQuest Group, Inc., a management consulting firm located in Cincinnati, OH. "As a result, this step isn't integrated with the rest of the board manufacturing process," he notes.

In general, ChemQuest sees the conformal coatings market as being an overlooked segment of the coatings industry. Because there is a blurring of the lines between conformal coatings, potting compounds, and other electronic coatings, it is difficult to pinpoint the actual market size for conformal coatings alone. In North America, ChemQuest estimates the conformal coatings market to be valued at approximately $45 million and growing at around 6% per year. The largest portion of the market, however, is located overseas, because most circuit boards today are manufactured in Southeast Asia/China. "The modest growth rate can be attributed to the increasing use of higher performance electronics such as circuit board technology in more corrosive and harsh environments," says Mr. Brown. The shrinking size of electronic devices is also leading to a shift away from encapsulation and towards conformal coatings for some applications, according to Lord Corporation's global marketing manager John Hiel.

Conformal coatings were first introduced in the 1960s. For many years the major market for these protective barriers was in the U.S. electronics industry, according to Jerry Donahue, sales manager for the HumiSeal Division of Chase Specialty Coatings. "The original military specification was written in December 1968 and served as the dominant standard of performance for anyone hoping to obtain a market position in conformal coatings," he notes. Conformal coatings have widespread applications in the defense industry because there are electronics in these applications that must maintain performance or lives are placed at risk. Today, specifications from the U.S. Military (MIL), Underwriters Laboratories (UL), and the private industry council (IPC) establish the necessary performance levels for conformal coatings.

As it turns out, conformal coatings still provide the same protective function today that they did 20–30 years ago. The level of protection has improved during that time, however. Additional advances in technology have and continue to focus on making the application process more user friendly, which includes modifying the physical and chemical properties of the formulations as well as addressing environmental, health, and safety (EH&S) issues. While the basic resin materials have remained the same, new formulations and curing techniques have been developed. "Speed of processing, reliability in ever-increasing harsh environments, environmental friendliness, and process flexibility and efficiency will remain paramount issues for conformal coating suppliers over the next several years," says Marjorie Dwane, global market manager, electronics board & module protection with Dow Corning Corporation.

The need to reduce cost has been a major driver in the conformal coatings market as with most other segments of the coatings industry. Reduced cost has been achieved by developing improved application processes that minimize waste, such as the automated spray systems. Technologies that allow for very rapid curing (UV methods in particular) have enabled increased turnover for applicators of conformal coatings and complement the automated coating systems. Development of waterborne, 100% solids, and non-VOC solvent-based formulations have begun to address the ES&H concerns of the past.

Several other technology developments are improving the application process for conformal coatings. "One hundred percent solids coatings that can be selectively applied to small areas of circuit boards and components have been a significant improvement," says Mr. Hiel. "R&D efforts are now focused on developing low temperature or ambient cure systems that allow for very thin coating coverage," he says. "Conformal coating suppliers must work with their customers to ensure reliability of the customers' printed circuit boards and to conform to efficient processing that works with the individual customer's process flow," adds Ms. Dwane.

The last major development in conformal coatings technology was the emergence of UV-curing technologies, according to Mr. Solensky. "This method is extremely process-friendly, being able to cure conformal coating material in 20 seconds or less, which is a dramatic contrast to previous curing times of around 10 minutes," he explains. Kevin Zoeller, electronic program manager with Dymax, estimates that UV-curable conformal coatings account for about 3–5% of the global market. "Although the total market share is small, the use of UV-curing is growing rapidly," he notes.

There are limitations associated with UV curing for conformal coatings. PCBs with shadow areas require a secondary moisture or heat cure following UV-processing to ensure complete curing of the entire coating. The higher cost of UV-curable coatings is also an issue for some PCB manufacturers. However, when the hidden costs associated with traditional coatings systems are considered, the cost of UV-curable conformal coatings can be competitive. Hidden costs include loss of solvent through evaporation and the associated environmental management issues, added time and labor for handling, levels of waste, and more frequent equipment maintenance.

Because the main benefit of UV curing is increased cure speed, many small operations that are not impacted by slower curing rates will not have use for this technology. The initial upfront investment in equipment can be prohibitive for medium sized companies who might benefit from the increased cure times. Thus, mostly larger companies that can recover the initial capital investment and have high volume throughput have taken advantage of the UV-curing technology.

Advances in EH&S friendliness of conformal coatings have benefited all users of these materials. "With continually increasing pressure from the environmental regulatory agencies, conformal coating manufacturers are being forced to develop 'greener' products that address the issues of VOCs and hazardous air pollutants (HAPs)," notes Mr. Donahue. "Companies have responded by reducing the level of hazardous and toxic solvents that were traditionally used to manufacture conformal coatings," he adds. According to Mark Privett, an application engineer with Henkel, the level of VOCs has been reduced from around 65% to 6–12% in most solvent-based conformal coatings today.

While conformal coating manufacturers have been investing in R&D efforts to improve the user friendliness of their coatings, they have also been faced with challenging market conditions. The higher cost of lower VOC- and HAP-bearing solvents has resulted in reduced margins for coatings producers, according to Mr. Donahue. "Increasing raw material costs and declining prices are also contributing to the margin squeezes for some suppliers," says Mr. Hiel. Increased drying times associated with reduced solvents has also been a concern for many suppliers of conformal coatings, according to Mr. Solensky. A larger issue is the potential for replacement of conformal coatings by other, disruptive technologies.

Main Conformal Coatings Technologies

- Acrylics
- Epoxies
- Urethanes
- Silicones
- Parylenes

For Dymax, one of the biggest challenges is keeping up with the changes that occur in the electronics industry. "We need to know about different substrates, fluxes, solder pastes and masks, and other components," says Mr. Zoeller. "As these technologies evolve, so must the conformal coatings applied to protect them." Globalization, the rise of offshore competition in China and India, and the shifting of production to Asia are also changing market dynamics that must be addressed by conformal coating manufacturers.

Many companies have a positive attitude despite these concerns. "These commercial and technological challenges can be converted into opportunities for those companies that can find innovative solutions," adds Mr. Hiel. Mr. Solensky notes that the popularity of conformal coatings, primarily among automotive manufacturers worldwide, relates to the fact that the industry has succeeded in eliminating many of the manufacturing and EH&S issues previously associated with it. "The technology is comprehensively accepted as a secure and reliable method of protecting electronics material across the industry. It is proven and highly cost-effective, and this is why manufacturers are reluctant to look elsewhere," he explains.

Silicone-based conformal coatings have received increased attention as electronics are being placed in harsher environments, particularly where temperature extremes and/or excessive vibration are present. "Dow Corning coatings are particularly useful for protecting circuitry in severe service environments, while maintaining a low-stress environment for components and connections. These severe conditions range from everyday temperature and humidity extremes seen in consumer electronics, to the harsher automotive underhood applications, up to the extremes demanded in military or industrial applications," says Ms. Dwane.

Dow Corning has worked to reduce solvents in its conformal coatings products, and offers a wide selection of formulations that can be cured at room temperature or with heat. The company's product range includes solventless room-temperature vulcanized (RTV)

elastomeric, solventless heat-cure, and RTV elastoplastic conformal coatings. "Dow Corning uses our proven and leading-edge product development, material equipment integration, and supply chain capabilities and partnerships to help achieve the reliability and peace of mind our customers want," Ms. Dwane notes. Recently the company introduced four new solvent-free, room-temperature-cure conformal coatings, Dow Corning® HC-1000, HC-1100, HC-2000, and HC-2100, designed for use around relays and high tolerance devices. Varying viscosities of the products enable different application methods. Dow Corning's Fast Formulation program helps customers upgrade from standard offerings, including such modifications as cure schedule, modulus, viscosity, color, and adding or removing inert intermediates.

Main Application Techniques for Conformal Coatings

Brushing
Hand-held spray gun
Dip coating or immersing
Flow coating
Screen application
Automated spray systems
Vapor deposition (parylenes only)

"Dow Corning has also invested in material and equipment integration, launching its External Equipment Provider Alliance with nine leading equipment suppliers worldwide. By taking advantage of these partnerships, we have reduced the time, risk, and cost for our customers to enter their markets by insuring an optimum integration of material and processing," explains Ms. Dwane. Dow Corning also offers early evaluation of conformal coating performance by producing prototype coated boards or test patterns. The company also conducts a wide range of analyses and tests to monitor customer quality, assist with trouble-shooting, or simulate accelerated service conditions, according to Ms. Dwane.

Lord Corporation offers low temperature, fast cure, one-component silicone conformal coats for both high build and low thickness coatings. The company has recently commercialized SC-323, a low-viscosity, high performance, one-component heat-cure product. Emerson & Cuming offers one-component, solventless urethane, silicone, and acrylate conformal coatings that meet the requirements of the military and UL specifications.

Dymax has capitalized on the growing interest in UV-curable conformal coatings. The company offers UV-curable, solvent-free, low and high viscosity conformal coatings in both soft and rigid formulations. While its products are used in many different application areas, Dymax has a very strong presence in the military, telecommunications, and automotive sectors.

Henkel has taken the approach of investing in alternative technologies to the conformal coatings currently available. Specifically, the company is focusing on overmolding, a technique that will reduce total processing and material costs, according to Mr. Solensky. Henkel is developing two methods of overmolding, one based on thermosetting epoxies and the other on polyamides, which are specifically formulated for lower process temperature molding applications. With the thermoplastic method, which is basically an injection molding process, there is little capital investment and the overmolding is completed at low pressure. Henkel is working with several different partners on this system and has a number of customers producing commercial PCBs with this overmolding process. The thermosetting epoxy overmolding method is in the advanced development phase. According to Mr. Privett, the company expects to have a process commercialized in the near future.

Alongside of these disruptive technologies, Henkel continues to invest R&D efforts on its traditional conformal coatings products. "There are long qualification cycles for the approval and adoption of new technologies because the protected electronic components typically operate costly equipment such as cars and aircraft. The performance of new barrier products must be well demonstrated before the electronics industry is willing to implement such a significant change," Mr. Privett explains. Henkel's conformal coatings research focuses on reducing costs. "We are keen to ensure that customers continue to receive a high level of support in relation to this technology," notes Mr. Solensky. "Our conformal coatings business will continue to back this proven technology with the highest levels of customer support. We are always looking to undertake new industry partnerships and are open to the idea of forming alliances that will drive product development forward to directly benefit our customers," he adds.

Today, HumiSeal Division of Chase Corp. remains the only global supplier of conformal coatings whose only business is the manufacture of these coatings. According to Mr. Donahue, the company was the first to bring a fully qualified (military, private industry counsel, and underwriters laboratory) water-based conformal coatings to the market. "Today, we are continually investigating new technology in an effort to mitigate the issues of VOCs and HAPs," he says. "Since solvent-based conformal coatings are so popular in the industry due to their extreme ease of application and ability to overcome minor surface contamination, we are constantly investigating new solvent technologies. We currently offer solvent-based organic (acrylic, urethane, and epoxy) coatings that are comparable to

many 100% solids coatings in VOC content," he further states.

HumiSeal is also responding to the evolving regulatory requirements such as the current global initiative to develop lead free processes and the European Directive calling for the "Reduction of Hazardous Substances." According to Mr. Donohue, as a result of these challenges, the company is developing several new products and technologies that it expects to launch in the near future.

Sandia National Laboratories (SNL) uses conformal coatings to protect electronic assemblies in a variety of military applications. While not a manufacturer of coatings, the lab does investigate new technologies. "We have a need for a conformal coating that is relatively easy to remove when required in order to repair or upgrade electronic assemblies without causing damage to the board or its components," notes Dr. James Aubert, principle member of the technical staff with SNL. "Additionally, non-damaging removal of the conformal coating is advantageous for surveillance and for dismantlement." To address this need, SNL developed an epoxy-based conformal coating with a very low modulus for the environmental protection and stress relief of electronic devices.

The coating was designed to be removable by incorporating thermally reversible Diels-Alder adducts, particularly those of a maleimide and a furan, into the epoxy resin utilized in the formulation of the coating. "The removability is the unique feature of this coating and was characterized by many different tests," says Dr. Aubert. Thermal, electrical, and mechanical properties have been established through testing on populated boards. The coating was applied with a syringe and cured at room temperature for 16 hours followed by two hours at 60°C. The coating can be removed by raising the temperature to about 90°C, which causes some of the Diels-Alder adducts to open, followed by exposure to a mild solvent such as 1-butanol. Alternatively, furfuryl alcohol can be used as the removal solvent. At 50°C, the alcohol drives the equilibrium of the Diels-Alder reaction in the reverse direction. Using either of these methods, a 10-mil thick coating can be dissolved in about two days without damage to the electronics.

Although only a small segment of the overall coatings market, conformal coatings play an important role in protecting the electronic devices and components that operate the instruments, machinery, and equipment that make much of modern life possible. "The conformal coatings sector is also a hotbed of technology development," says Mr. Brown. The industry has responded to the need for more user friendly and environmentally compliant formulations, and continues to make advances in these areas. The use of UV-cured resins in conformal coatings has been highly successful, too. This technology is now being transferred to other areas of the coatings industry. Despite the many challenges they face, conformal coatings manufacturers continue to leverage their technological expertise in order to further grow the market. CT

Photo courtesy of Henkel.