## *Ceramic Capacitor Encapsulation for High Voltage Applications – Selection Overview*

## INTRODUCTION

Use of ceramic capacitors in the manufacture of high voltage systems rated for 800 VDC and above, mandates the use of an encapsulate to insure proper isolation and functionality of the device. Given the seemingly endless number of options available, it becomes incumbent on the designer to have a clear understanding of the characteristics of any potting material being considered and how it might impact the capacitor and / or assembly, prior to any selection being made.

Depending on the material chosen, epoxies and sealants can provide superior environmental protection from moisture, humidity, temperature extremes and chemicals that might otherwise damage or compromise the performance of the device. Epoxies can also offer mechanical protection in situations where the capacitor may be exposed to high levels of vibration or shock, where handling might be a concern, and where lead flexure might impart stress to a solder joint, or directly to the ceramic itself. Epoxies might also offer increased electrical isolation in high voltage applications, where termination to termination distances have been designed at a minimum, or where the capacitors may be placed in close proximity to other components that are operating at a different voltage potential. Finally, coatings are often used for purely cosmetic reasons, where they may provide a more appealing finish than if the part were offered with exposed components and solder joints.

Unfortunately, those characteristics of an encapsulation that provide seemingly desirable benefits can often introduce other unintended consequences. The ability of a material to provide a superior seal for example, is tied to how well it adheres to the surrounding surfaces, but if that bond is too good, the material may under certain conditions, impart a high level of mechanical stress to the capacitor, which in turn can introduce ceramic fracturing and ultimate failure.

With countless options available, a clear understanding of the electrical, mechanical and chemical properties of any epoxy, coating or sealant being considered, how it might affect the assembly in which it is being used and how it might be influenced by, or in turn influence the environment in which it is intended, is critical in ensuring the design achieves its desired result. With that in mind, this application note is intended to provide a level of insight into some of the key questions that should be considered during the material selection process. It should however, in no way be considered a guarantee against adverse results and Calramic Technologies strongly recommends that the engineer contact the material manufacturer and solicit further recommendations on which encapsulate might best suit their specific application.

## GENERAL CONSIDERATIONS

Depending on their size and form factor, ceramic capacitors are typically available as either surface mount chip style components, or for larger configurations, as a leaded device. If the required part is a leaded capacitor, the designer may have the option of selecting a finished part that has been pre-coated prior to delivery. With radial leaded capacitors for example, CalRamic Technologies can eliminate the guess work by providing the finished capacitor with a conformal coating already applied. This material has been specifically engineered by CalRamic Technologies for use with ceramic capacitors and it offers a highly reliable coating that is ideally suited to high voltage environments.

Although CalRamic Technologies highly recommends the selection of a pre-coated device wherever possible, that option will not always be available and in those cases, the choice of a suitable encapsulation becomes the responsibility of the end user who is integrating the capacitor into their system. To aid with the selection process, CalRamic Technologies has offered some recommendations at the end of this document, which should hopefully narrow the search and help provide the basis for a reliable encapsulation process. That said, these options as well



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as the possible selection of a pre-coated capacitor, may not prove satisfactory for all situations, and as such should in no way imply a guarantee for reliable performance. Consequently, it becomes the engineer's responsibility to contact the material supplier for additional recommendations, confirm all results and make adjustments where necessary to accommodate specific conditions and design requirements. With that in mind, listed below are several factors that can influence the final outcome and they should all be carefully considered when establishing a suitable encapsulation or sealant material:

- **Coefficient of Thermal Expansion (CTE) –** Depending on the intended application, capacitors are normally expected to operate in an environment where the ambient temperature can vary from anywhere between -55 and +125°C. Transitioning between temperatures results in a dimensional change in the capacitor, where increases in temperature cause the capacitor to expand in size and subsequent reductions causes the part to contract. This measurement of change is defined as the "Coefficient of Thermal Expansion" and typical measurements for ceramic capacitors range anywhere from $9\times10^{-6}$ to $11\times10^{-6}$ ppm/°C. Considering that ceramic chip capacitors that are soldered to substrate are already placed under stress due to differences in their CTE, the addition of an epoxy encapsulant can impart additional stresses on the ceramic. With that in mind, the designer needs to recognize that the CTE values for epoxies or sealants can vary significantly, that they are different than those for ceramic bodies and that it is extremely important to first verify the compatibility of any material being considered.

- **Moisture absorption –** Some encapsulation materials have a tendency to absorb moisture (hygroscopic) which could have an adverse effect on the overall performance characteristics and / or the reliability of the device. The presence of moisture can have an adverse effect to electrical characteristics like Insulation Resistance or leakage current, may exacerbate conditions related to silver migration or tin whisker growth and certainly, the presence of moisture can overtime, contribute to an overall physical deterioration of certain materials utilized during manufacture.

- **Chemical Resistance** – A candidate potting material needs to be able to withstand exposure to any chemicals it might be subjected to during subsequent processing steps and / or in its actual intended application. Failure to properly analyze how the chosen epoxy might react could result in a situation where the material is compromised, physically, mechanically and / or electrically.

- **Fungus –** Fungus limitations are often defined by Military specifications and should be addressed when considering encapsulations for most applications.

- **Outgassing Characteristics –** Outgassing refers to the release of gas that may be trapped within an encapsulant, even after it has presumably reached full cure. If not properly addressed, outgassing can become problematic in those high vacuum environments often associated with spacecraft, whereby condensation onto critical components like optical elements or solar cells may impede their ability to function properly. This characteristic can also impact other applications, like those in the medical field that rely on maintaining a sterile environment.

- **Volts per Mil Breakdown Characteristics** – Whether an epoxy or coating is chosen for environmental, electrical, mechanical or simply cosmetic reasons, it is important to ensure that the volts per mil breakdown characteristics of the material do not compromise the parts ability to function at its intended voltage. As the heading implies, the amount of voltage that can be sustained is due in large part to the thickness of the coating, but obviously that figure is also tied to the makeup and resulting resistance of the material itself.

- **Surface Resistivity –** Similar to V/mil breakdown through the material, the design engineer needs to insure that the material has a high surface resistivity to minimize risk of arc over.

- **Dielectric Constant** – Like all insulators, epoxies and coatings are characterized as having a dielectric constant and resulting capacitance value that may impact and change the anticipated results for lower capacitance requirements needed for precession circuitry (ie. COG / NPO designs). In these instances, the design engineer may be required to tweak the capacitor value somewhat to compensate for the added capacitance.

- **Adhesion** – When considering an encapsulation it is important to select a material that provides sufficient adhesion without resulting in a situation where the material's shear strength can pull apart the ceramic when exposed to changing temperature gradients. An increase in the resin content may help to achieve a better bond to surrounding surfaces, but may also result in an excessive TCE mismatch and the likelihood that microfracturing of the ceramic may occur through thermally induced stress conditions.

- **Curing Characteristics –** If you bear in mind that the temperatures used in firing processes for ceramic capacitors are typically in the range of 1100°C or more, decisions related to whether to use a room temperature or high temperature cure epoxy becomes less to do with the capacitor itself and much more to do with final characteristics of the encapsulation and how curing temperatures might affect other components utilized in the assembly. Most epoxies, even if cured at room temp to reduce shrinkage or expansion will need to be exposed to, or conditioned at higher temperature to fully cure and achieve full performance characteristics. That said, care needs to be taken to ensure that exposure to the higher temperature does not damage other components. In addition, although exposure to a higher temperature may not necessarily damage the capacitor itself, the parameters of the curing cycle would need to be such that the capacitor is not subjected to thermal shock during the ramp up or cool down steps in the procedure.

- **Material Application** - Certain materials, even those with less than desirable results, can be utilized in certain situations where the cross section of material is kept to a minimum. A thin cross section offers less restraint to the ceramic during temperature transitions, reducing its shear strength, limiting the consequences of an excessive CTE mismatch and reducing the possibility that the material might damage the capacitor surface.

  In addition, uniform and complete coverage is important to prevent mechanical stress risers from setting up, especially for those materials that have a comparatively high Coefficient of Thermal Expansion. Choosing a material where its viscosity allows for adequate penetration around the capacitor will help to evenly distribute the mechanical stress that is inherent with these types of processes.

  Finally, it is important to ensure that the surface is properly cleaned and absent of all contamination prior to coating. Not only can a contaminated surface prevent adequate adhesion, it may also impact the materials ability to reach full cure and depending on the type of impurity, provide for a low resistance electrical path.

- **Dual Encapsulation Systems** – Where the application mandates use of an epoxy or encapsulant that has significant CTE mismatch, the engineer may want to consider a barrier coating over the ceramic surface such as a mold release or parylene coating.

- **Storage / Shelf life / Pot life etc. –** It is important to know and understand the storage and pot life characteristics of the specific material that you intend to use. Following proper instructions will minimize waste of encapsulant, but more importantly, attempting to utilize an encapsulant that is beyond its usable life can adversely affect the performance and / or physical characteristics of the material.

## Material Recommendations

Additional process steps, other components and / or end application itself will in large part dictate the material choice for encapsulation. Calramic Technologies has evaluated / utilized a variety of different materials in the past, some of which are outlined below and in the accompanying table. That said, recommendations are not a guarantee


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of success and it becomes the engineer's responsibility to contact the manufacturers of these materials for further suggestions and fully analyze and qualify any potential candidates prior to approval. With that in mind, these material choices may be a good place to start…

- Parylene C– This system can be used as a barrier coat, as well as a final coat, where excellent moisture and / or electrical breakdown characteristics are needed. Material provides excellent surface resistivity, does not outgas and the vacuum deposition process ensures a complete and uniform coverage in all exposed areas.

- Hysol FP4450 – A high purity, semiconductor grade material, FP4450 is a liquid encapsulant that exhibits good flow characteristics, excellent moisture and chemical resistance and a higher operating temperature range. These benefits along with its ability to provide a high level of mechanical protection to delicate components make this epoxy suitable for a number of capacitor designs and applications.

- Stycast 2850FT – A two part epoxy system, that exhibits good thermal conductivity, good moisture resistance, excellent electrical characteristics, and a low coefficient of thermal expansion. This epoxy has a comparatively high viscosity at room temperature and it is suggested that the assembly be warmed to induce better flow and fill around components.

- Epic S7433 – A two part elastomeric polyurethane system exhibiting a high dielectric strength, this material has been developed for use with electrical components. This system requires high temperature exposure to reach full cure and that characteristic allows for an extremely long pot life.

- Huntsman Araldite DBF / Aradur HY 2966 – Depending on the design and the intended results, Huntsman offers a variety of materials for consideration. Araldite DBF / Aradur HY 2966 for example, is a room cure, low viscosity epoxy that exhibits good heat and chemical resistance characteristics.

| Part No | Parylene C | Hysol FP4450 | Stycast 2850FT (Catalyst 11) | Epic S7433 | Araldite DBF / Aradur HY |
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| Manufacturer | Specialty Coatings Systems<br>(317) 451-8549<br>www.scscoatings.com | Henkel Adhesives<br>(800) 832-4929<br>www.henkelna.com | Henkel Adhesives<br>(800) 832-4929<br>www.henkelna.com | Epic Resins<br>(262) 495-3400<br>www.epicresins.com | Huntsman Advanced Materials<br>(888) 564-9318<br>www.huntsman.com |
| Description | Polymer | Epoxy – 2 part | Epoxy – 2 part | Polyurethane – 2 part | Epoxy resin - Unfilled |
| Performance Characteristics | Contact Manufacturer | Contact Manufacturer | Contact Manufacturer | Contact Manufacturer | Contact Manufacturer |



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