Gel Dispense for Encapsulation of MEMS Pressure Sensors

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AS THE MEMS-BASED SENSING industry grows, the environmental conditions in which these sensors must perform grow with it. Pressure sensing is one application of MEMS-based sensing where particularly harsh environments can be present. Examples of common challenging environmental conditions include automobile exhaust, fuels, refrigerants and atmosphere with moisture and ice. Unlike previous technology, which used large mechanical assemblies and welded or soldered interconnects in the fluid path, the MEMS-based technology offers the ability to place the microscopic sense element and wire bond interconnects directly in the fluid path. As a result of the harsh environment and exposed assemblies, it is often necessary to protect the sense element and interconnects with products such as encapsulation gels.

The first step in the process of protecting exposed MEMS-based assemblies is to select the proper gel for the design intent of the product and for the environment in which it will serve. Protective gels have come a long way in recent years with a virtually endless selection of silicone dielectric encapsulation gels. Typically encapsulation gels are selected based on desired final product properties, such as viscosity after cure and chemical properties best suited for the end-use environmental conditions. The manufacturing procedures for using gel are often overlooked in the initial design process, and must be reconciled by the process engineering team.

Once the design is complete, a process is developed by the engineering team to properly apply the correct amount of gel to best serve the end-use application without creating unintended consequences. These requirements compel the satisfaction of four critical factors during the application process: 1) complete gel coverage of critical components, 2) elimination of all air voids in the gel, 3) proper and complete cure, and 4) a controllable process with a measurable output.

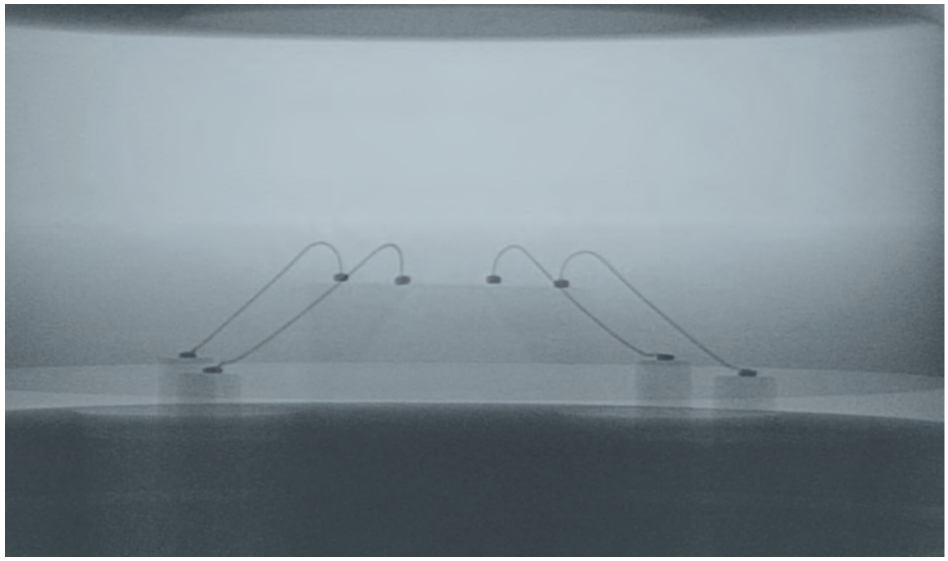


Figure 1. X-ray of die and wire bonds after gel dispense.

Attaining and maintaining complete gel coverage over all critical components seems like a straightforward process. Verification of the gel dispense process ensures coverage of all critical components, but with shrinking product packages and complex layouts, an unobstructed view of critical areas is not often obtainable. At SMART Microsystems, analysis techniques, such as acoustic microscopy and 3D X-ray, are used to develop and validate gel dispense procedures during the initial design process (see Figure 1). These tools allow inspection inside of the part after dispense, confirmation that the product is properly protected, and verification that the gel dispense parameters have achieved the desired result.

The root cause for the prevailing gel dispense failure mode which plagues most MEMS-based sensor product designers is air voids trapped in the gel. For pressure sensors with gel in the fluid path, entrapped air in the gel will move under pressure and apply unintended and potentially damaging stress on the sense element and on the interconnects. This can cause premature output shift or product failure. Most silicone gels are hygroscopic in nature—they readily absorb moisture. In typical product designs the hygroscopic gel is placed in the fluid path. The hygroscopic nature of the gel and exposure to the fluid path will cause the gel to collect moisture in any air voids present. The moisture-filled voids immediately become a source of corrosion. For process engineers that have experience in gel dispense procedures, preventing air voids is the primary condition that must be accommodated during product and process design. This requires careful vacuum degas of the gel prior to dispense, with additional centrifuge use as needed due to the intrinsic properties of the gel. A post-dispense degas may also be required due to product design, such as if the product geometry entraps air.

Heat cure encapsulation gels are the preferred choice for many MEMS-based sensor products because they offer a complete cure. Heat cure encapsulation gels are typically dispensed at a lower viscosity to promote flow and complete

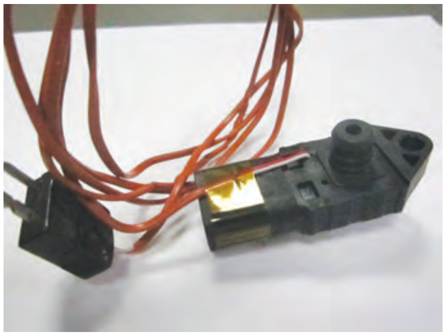
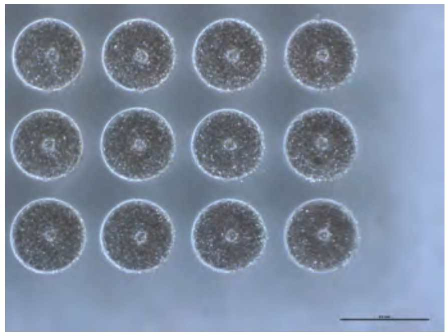


Figure 2. Thermocouple embedded into the gel of a specially modified part.

coverage. After the material has been degassed and dispensed, it must be properly cured to achieve the final viscosity to protect the product. In order to establish the proper cure profile for the gel, as recommended by the manufacturer, it is necessary to characterize the process. A calibrated thermocouple reader and a fine wire thermocouple are used in order to characterize the specific cure oven profile. The fine wire thermocouple is embedded into the gel of a specially modified part (see Figure 2). The thermal gradient of the gel will always lag the thermal gradient of the cure oven. Cure characterization ensures a proper and complete cure of every part every time.

Product specifications and requirements that cannot be measured or quantified serve little purpose. Therefore, a process must be designed which is controllable and which has a measurable output in order to meet product specifications. Gel dispense processes pose unique, but surmountable, challenges to



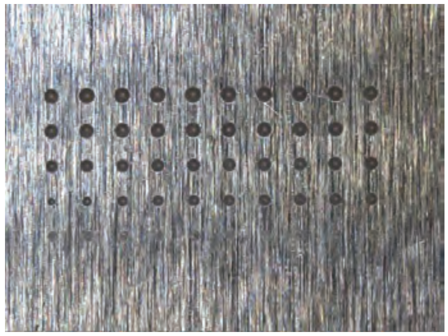


Figure 3. Shot weight test coupon.

quantification. At SMART Microsystems, highly accurate and precise measurement and dispense tools are used in the design, development, and production phases of gel encapsulation. The dispense process is designed using precise mass scales and with accurate programmable dispensing units to deliver a precise shot weight of gel material in every part (see Figure 3). This type of process design provides exceptional results with measurable outputs that can be controlled through statistical process control (SPC).

Not all MEMS sensor designs require dielectric encapsulation gel protection,

SMART's precision automatic dispense equipment.

but many on the front-line of harsh environmental sensing do. It is important to the end-use product viability that the process of protective gel encapsulation is designed and validated properly. Engineers at SMART Microsystems understand from experience that encapsulation gel is not simply a corrective action to a preexisting failure mode. Gel encapsulation is a process which is performed with equal diligence in design and development to wire bonding, die attach, assembly, and many other process crucial to the end-use sensor and the same diligence is observed throughout production.

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