Measuring Viscoelastic Properties of Silicone Gel Coatings on MEMS-based Sensors

Introduction

A pressure sensor is an electronic device used for measuring the pressure of gases or liquids. As one of the applications for MEMS-based devices, pressure sensors are gaining popularity and have been widely used in the automotive, petroleum, electronics and medical industries[1]. Pressure sensors usually operate in a variety of extremely harsh environments and therefore entail specific manufacturing design requirements to ensure sensor performance and reliability. For example, an automotive pressure sensor needs to perform well at temperatures ~40°C to 80°C, and must also offer exceptional resistance to vibration, impact, shock, moisture, dust, dirt and other environmental contamination. A protective gel compound is normally applied on top of the MEMS device to form an encapsulating barrier between the device's sensing element and the harsh environment. The use of soft silicone to encapsulate and provide reliable, long term protection for sensitive electronic components becomes more critical as device complexity increases.

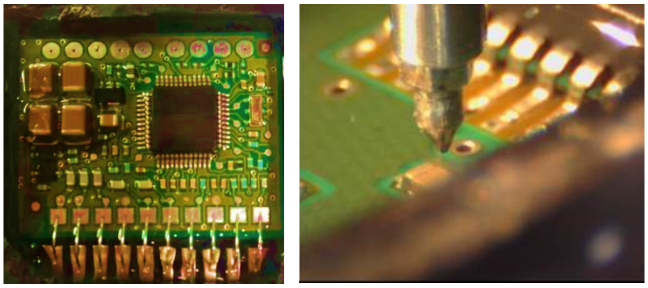

Figure 1. A typical pressure sensor IC device covered by a silicone gel coating (left); a KLA Nano Indenter® measuring the silicone gel coating (right).

In processing the heat cure encapsulation gel, the gel is typically dispensed at a lower viscosity to ensure complete coverage of the IC parts. This application is then followed by a heat treatment to cure the gel in order to achieve the desired viscosity for MEMS protection. To further the design, development and production phases of gel encapsulation, it is necessary for the process engineer to characterize the gel's mechanical properties and use the results as measurable output. In this work, a KLA Nano Indenter® was used to measure the localized Dynamic Mechanical Analysis (DMA) modulus on silicone gel.

Experimental Method

Two automotive pressure sensor samples were received, with Sample 1 marked as "pass" and Sample 2 marked as "fail". The nanomechanical analyses of the silicone gel coatings were performed using a KLA Nano Indenter configured with a flat-ended cylindrical punch tip with a diameter of 100µm. A test method based on the ProbeDMA™ technique was used with the input values summarized in Table 1. The ProbeDMA technique turns the indenter into a localized DMA instrument, allowing for the measurement of storage modulus, loss modulus and loss factor as a function of frequency on atypical sample geometries and small volumes of material. The ProbeDMA modulus is often used as the primary screening parameter for small samples as a pass/fail criterion for product compatibility and durability issues. Compared to a conventional DMA tester, the sample preparation is simpler, requiring only a test surface that is flat relative to the test scale to be performed. Due to the indenter geometry, the test is a spatially-resolved measurement that enables property mapping over the surface. ProbeDMA takes advantage of Continuous Stiffness Measurement (CSM) and the precision of the KLA actuators to provide quantitative results that match traditional DMA testing. Each ProbeDMA test of the gel included the following steps:

1. Engagement: the probe tip automatically moves toward the target area;
2. Approach: with the probe tip positioned over the gel, the actuator moves down until contact with the gel is sensed by a shift in phase angle;
3. Pre-test compression: the actuator drives the probe tip into the surface by 10µm;
4. Test: the probe tip is vibrated in contact with the gel at the target frequency to measure the contact stiffness. This contact stiffness is then converted to the DMA modulus (storage modulus).

Four locations were randomly selected on Sample 1 with 10 tests performed at each location. Five locations are selected on Sample 2 with nine tests performed at each location. All tests were performed at temperature of 23°C and humidity of 41%.

Table 1. Summary of Experimental Input Data

Input	Value	Units
Punch diameter	100	μm
Poisson's Ratio	0.5	None
Pre-test Compression	50	μm
Target Frequency	145	Hz
Phase Change for Contact	0.5	Degrees

Results and Discussion

The measured properties of the silicone gel coating are summarized in Table 2. The storage modulus is a measure of the elastic response of the material and is proportional to the stored energy during loading. The average DMA modulus of Sample 1 extracted from the measurement lay in the range between 4.6kPa to 7.0kPa, agreeing very well with the reference value obtained by conventional DMA test (~5.2kPa)[2]. By contrast, Sample 2 shows a relatively low value of average DMA modulus, ranging from 2.16kPa to 3.07kPa. An obvious difference between Sample 1 and Sample 2 can also be seen by comparing the average contact stiffness values.

The Student t-test analysis was used to compare the data between Sample 1 and Sample 2. At a 95% level of confidence, there is sufficient evidence to conclude that the DMA modulus of Sample 1 is different from Sample 2. The resulting variation in modulus value could be caused by solvent crystallization, curing time, network structure, gel content, heat flow temperature, etc., during the manufacturing process. The KLA Nano Indenter has proven the capability to detect these types of manufacturing process changes, based on changes to the modulus. The reference Young's modulus obtained by conventional DMA measurement is ~5.2 kPa, consistent with the data collected from Sample 1. Figure 2 shows the ProbeDMA results graphed as a function of location across the surface. Within Sample 1, Young's modulus at Location 4 has ~45% higher value than moduli measured at the other locations. Within Sample 2, Young's modulus at Location 5 has ~40% higher value than data from the other locations. These high moduli were measured in the small square region of both samples that is noticeably different from the other locations. As such, the KLA Nano Indenter is sensitive enough to detect the within-sample variations calculated from testing at different locations.

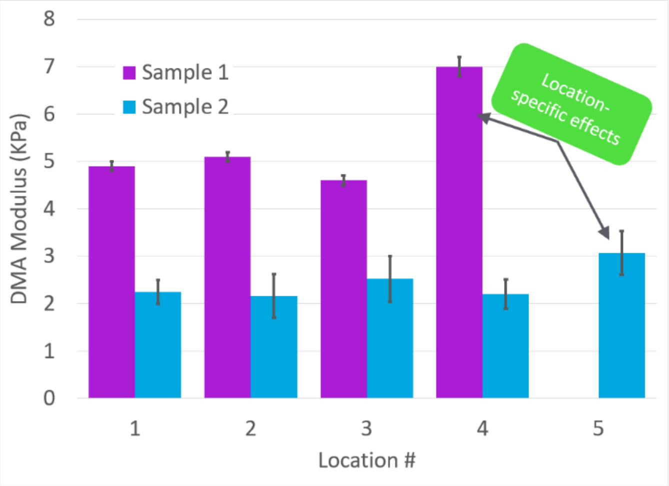

Figure 2. The measured DMA moduli for Sample 1 and Sample 2.

Table 2. Summary of ProbeDMA Results

Sample ID	Sample 1		Sample 2	
Location	Average DMA modulus (kPa)	Average Contact Stiffness (N/m)	Average DMA modulus (kPa)	Average Contact Stiffness (N/m)
1	4.9 ± 0.1	2.6 ± 0.07	2.24 ± 0.25	1.19 ± 0.13
2	5.1 ± 0.1	2.7 ± 0.12	2.16 ± 0.46	1.15 ± 0.24
3	4.6 ± 0.1	2.4 ± 0.10	2.52 ± 0.48	1.35 ± 0.26
4	7.0 ± 0.2	3.7 ± 0.10	2.20 ± 0.31	1.17 ± 0.17
5			3.07 ± 0.46	1.64 ± 0.25

Conclusion

In the process of design and development of MEMS-based assemblies, typical gels are selected based on the desired final product properties. It is essential to verify the quality of both the dispensed and cured silicone gel. This application note demonstrates the use of the KLA Nano Indenter equipped with ProbeDMA to characterize the mechanical properties of a silicone encapsulation gel applied to MEMS-based pressure sensors. The nanoindenter system is sensitive enough to measure this soft material down to 1kPa. The ProbeDMA technique is key to characterizing nanoscale polymers and polymer films that are not well-served by traditional dynamic mechanical analysis (DMA) test instruments.

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