

Effects of Silica Filler on the Material Properties of Underfill

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Background Information:

The electronic industry is one of the fastest growing industries in the world today. As this market continues to grow, so too does the demand for packaging processes which require the minimum cost and maximum efficiency possible. Electronic packaging has four major functions which include providing electrical pathways that power up integrated circuits (IC), reallocating signals to and from the IC chips, removing the heat generating form circuits, and protecting the chips form the outside environment. In first-level packaging, an interconnect is established between an IC chip and a module. One interconnection technique is flip-chip technology, in which a chip is flipped with its active side facing a substrate, and then connected to the substrate by solder joints.

For many years, the substrate on which the chip was mounted was made of inorganic materials due to the low difference between each material's respective coefficient of thermal expansion (CTE). However, inorganic materials are expensive and thus undesirable in industry applications. Organic substrates are therefore preferable, yet also have drawbacks. The difference in CTE between chips and organic substrates is much larger. This results in a greater amount of strain on the solder joints, which decreases the mechanical life of the unit.

However, this strain was greatly reduced with the application of underfill, which is an adhesive between the substrate and chip. Low CTE and high modulus of the underfill are critical to achieve high interconnect reliability. Organic resin on its own does not yield the required low CTE and high modulus. To meet these requirements, silica filler is incorporated into the resin. The purpose of this project is to observe the material properties of underfill when silica is added in order to eventually determine the effects of its addition on thermal mechanical reliability.

Sample Preparation:

First, a large quantity of underfill was prepared that would later be mixed with varying amounts of silica filler. To prepare this underfill, a catalyst was added to an epoxy liquid (EPON828) and then dissolved by being stirred on a hotplate for about 30 min at a temperature of 90° C. The mixture was allowed time to cool, and then a hardener (HMPA) was incorporated. The epoxy, hardener and catalyst were combined in a weight ratio of 100:76:1, respectively. The silica filler itself had a diameter of 3 micron. It was placed in a 120°C oven for 2 hours to remove the absorbed moisture. The filler was then added to the mixture in amounts as indicated in the table below. To mix the filler and the underfill, a high speed blender was used. The resulting mixture was then stored at a temperature of -40°C. The material was allowed to return to room temperature before experiments were conducted. The table below shows the formulation of each sample.

| <u>Sample Name</u> | <u>Resin (g)</u> | <u>Desired Weight of Filler (g)</u> | <u>Desired Amount of Filler (wt%)</u> | <u>Actual Amount of Filler (wt% from TGA)</u> |
|--------------------|------------------|-------------------------------------|---------------------------------------|---|
| 00 | 15 | 0 | 0 | 0 |
| 01 | 15 | 0.79 | 5 | 5.027 |
| 02 | 15 | 1.67 | 10 | 8.653 |
| 03 | 15 | 3.75 | 20 | 18.67 |
| 04 | 15 | 6.43 | 30 | 28.31 |
| 05 | 15 | 10 | 40 | 38.05 |
| 06 | 15 | 15 | 50 | 47.91 |
| 07 | 15 | 22.5 | 60 | 59.54 |

Measurement Tools and Techniques:

Modulated Differential Scanning Calorimeter (MDSC, TA Instruments, Model 2920)

This device was used to determine the curing behavior of each sample. About 10mg of the sample (in a liquid state) was placed into a hermetic aluminum pan. The machine was then set for a dynamic scanning experiment with a ramping rate of 5°C/min from room temperature to 300°C. The peak temperature of the curing heat flow was recorded. The curing heat from the reaction was integrated. The sample was cooled down to room temperature, and then reheated to 250°C at 5°C/min in a modulated mode. The glass transition temperature (DSC Tg) could then be found by finding the inflection point in the transition step.

Rheometer (TA Instruments, Model AR-1000)

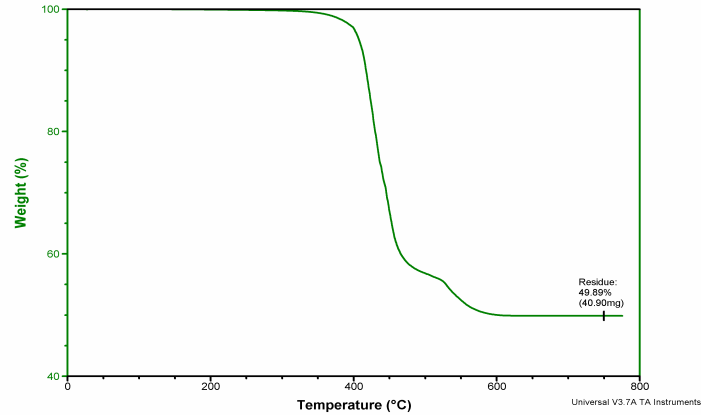
This device was used to find the viscosity of each sample. Each sample was measured with a shear rate of 1/s at room temperature (25°C).

--- Since the rest of the experiments required a solid sample of specific geometries, portions of the samples were cured for 2 hours at 180°C. The resulting solid samples were then polished and cut into specific shapes as needed for the different machines.---

Thermogravimetric Analyzer (TGA, TA Instruments, Model 2050)

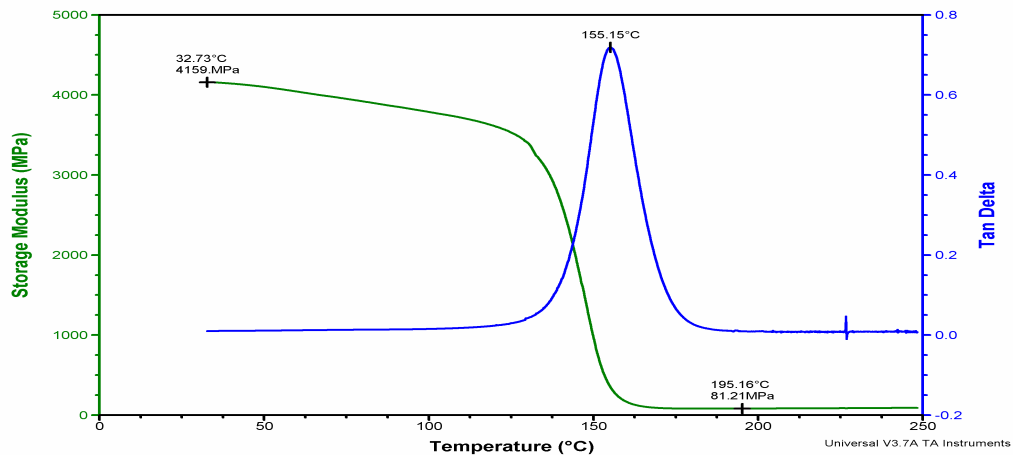
This instrument was used to find the actual silica filler content in each sample to account for human error by observing in change in weight as a function of temperature. The experiment was done in the atmospheric environment of air. As the resin of the underfill was burned off, the

resulting residue was the equivalent of the silica filler content, thus it was possible to see the actual filler loading of each sample. A typical TGA graph is shown below.



Dynamic Mechanical Analyzer (DMA, TA Instruments, Model 2890)

This instrument was used to determine the dynamic mechanical properties of the different samples. The DMA T_g was found by examining the peak temperature of tan δ curve. The experiment was done using a ramping rate of 3°C/min from room temperature to 250°C. The oscillation frequency was 1Hz. The storage modulus at 30°C of each sample was recorded. An example of a typical DMA graph is shown below.



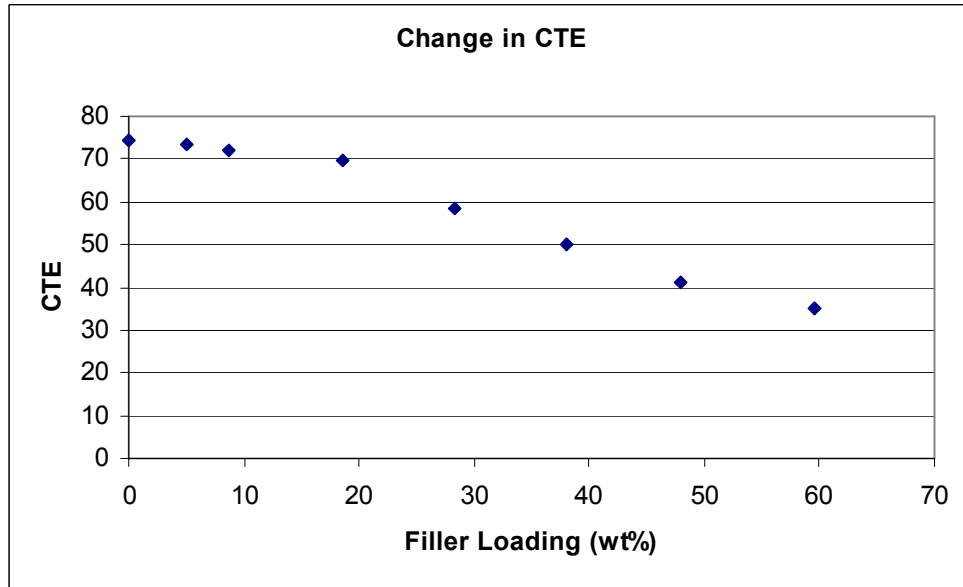
Thermomechanical Analyzer (TMA, TA Instruments, Model 2940)

This instrument measures the thermal expansion behavior of the material. Each sample was heated at a ramping rate of 5°C/min from room temperature to 250°C. The CTE was then calculated by the software and recorded.

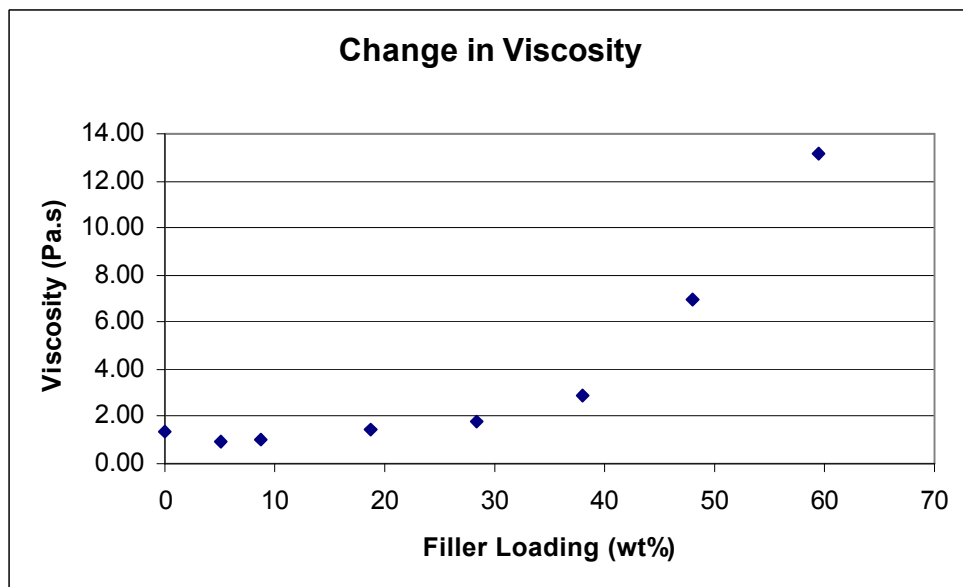
Experiment Data:

| <u>Sample Name</u> | <u>Curing Peak Temp (°C)</u> | <u>DSC Curing Heat</u> | <u>DSC Tg</u> | <u>Storage Modulus (MPa) at 30°C</u> | <u>DMA Tg</u> | <u>Viscosity (Pa.s) at 25°C</u> | <u>CTE (50°C-100°C)</u> |
|--------------------|------------------------------|------------------------|---------------|--------------------------------------|---------------|---------------------------------|-------------------------|
| 00 | 158.53 | 336.5 | 137.2 | 2305 | 146.48 | 1.39 | 74.43 |
| 01 | 160.82 | 335.9 | 136.4 | 2265 | 148.62 | 0.95 | 73.68 |
| 02 | 154.32 | 335.8 | 138.2 | 2339 | 147.20 | 1.00 | 71.98 |
| 03 | 164.47 | 312.2 | 130.0 | 2905 | 149.02 | 1.41 | 69.73 |
| 04 | 168.59 | 317.5 | 130.7 | 3173 | 150.19 | 1.78 | 58.63 |
| 05 | 163.66 | 325.6 | 133.5 | 3759 | 149.75 | 2.86 | 50.28 |
| 06 | 156.43 | 314.5 | 137.4 | 4159 | 155.15 | 7.00 | 41.37 |
| 07 | 172.30 | 312.4 | 138.4 | 5370 | 152.43 | 13.15 | 35.09 |

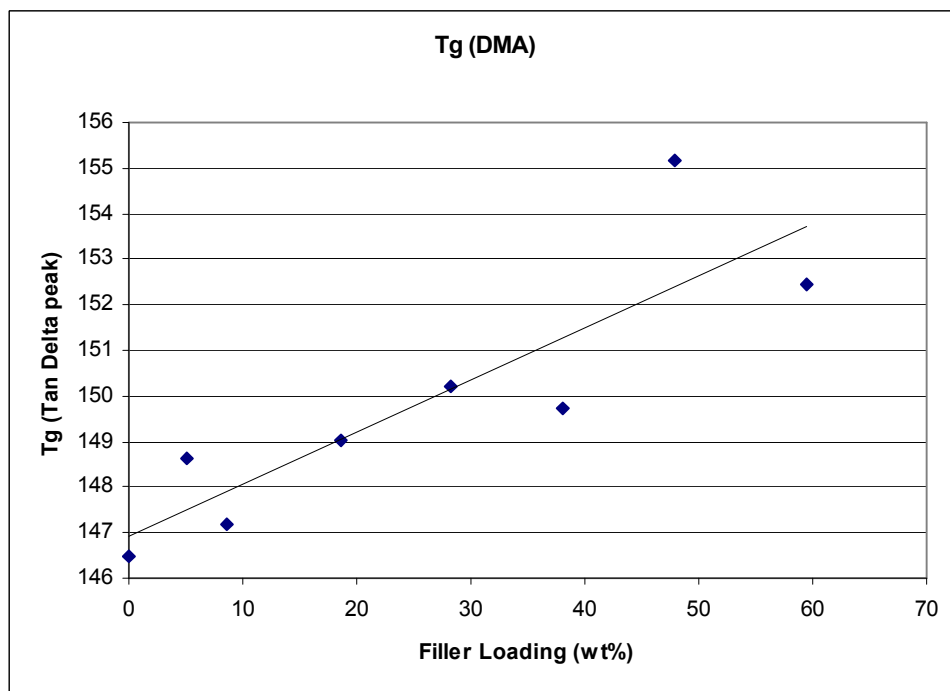
Data Analysis:



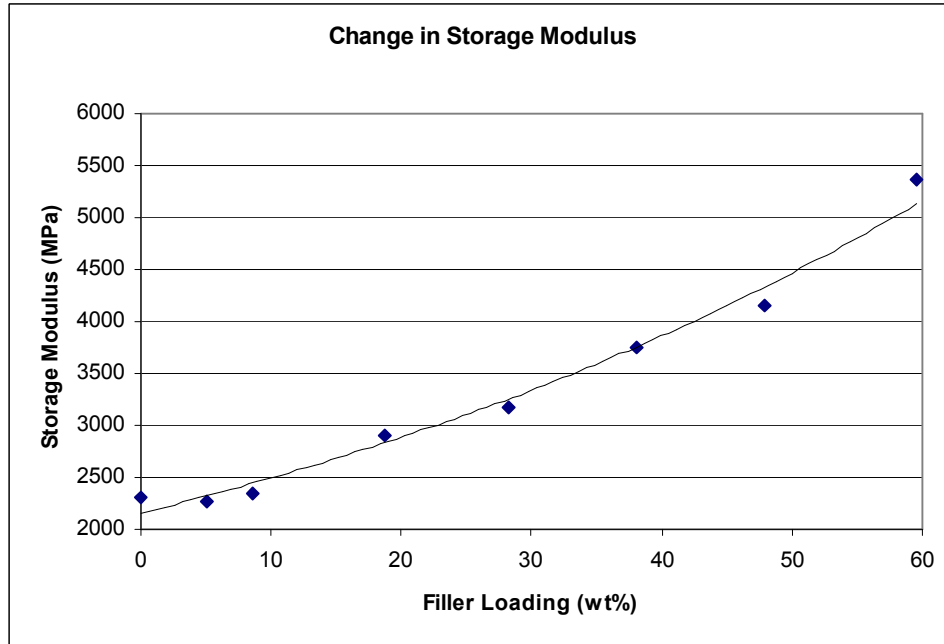
After determining the CTE of the different samples of underfill, it can be seen that as the amount of silica filler increases, the CTE decreases. Before a weight percentage of about 20, the decrease in CTE is very small. However, after this the decrease is more dramatic. As previously stated, low CTE is desirable in flip-chip applications, thus the mechanical reliability would be better with a greater amount of silica filler. However, problems do arise in terms of viscosity.



The change in viscosity graph shows that increasing the amount of silica filler in each sample results in the increase of viscosity as well. This is undesirable for flip-chip applications because it makes the dispensing of underfill more difficult, as well as augmenting the potential for voids.



As the filler loading increase, so did the Tg in a somewhat linear fashion. This increase, however, was not dramatic. The impact of Tg on flip-chip reliability is yet to be determined.



The modulus of the samples at room temperature increased as more silica filler was added. Unlike the increase in T_g , however, the increase was an extremely dramatic one, as the storage modulus of the 60%wt sample more than doubled compared with the unfilled sample. High modulus is desirable for mechanical reliability, thus this is a positive observation.

Conclusion/Discussion:

The effects of silica filler on the material properties of resin were observed. It was found that the increase in the amount of filler resulted in the decrease of CTE and increase of modulus in the samples. The T_g was found to increase slightly, yet not dramatically. This viscosity of the sample also increased with the addition of filler. Low CTE and high modulus are desirable for flip-chip applications, yet high viscosity undesirable for underfill processing. Thus, while the addition of silica filler has positive effects on the material properties of resin in flip-chip applications, a major drawback is the increase in viscosity which must be further investigated.

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