# Application note

## Conductive silicones in elevated temperatures

As the level of sophistication increases for applications, the ability of the material supplier to aid the manufacturer in choosing an appropriate material remains more crucial than ever. Whether an application requires a conductive or merely static dissipative material, the operating temperature of the application can greatly affect conductivity. With silicone's insulative nature and large Coefficient of Thermal Expansion (CTE), sustaining conductivity as temperatures rise requires a special understanding of silicone chemistry and filler technology. Conductivity can be maintained by adjusting the type, amount, and the particle size and distribution of filler in the silicone matrix. This Application Note discusses the trade-offs one should expect when customizing silicone to remain conductive in elevated temperatures and help explain why changes occur.

### WHY CHOOSE A SILICONE?

A legacy derived from decades of use in aerospace and other harsh environments that commonly experience temperature extremes is why most choose silicone for many applications. Siloxane-based polymeric systems are unique polymers, as compared to standard, organic-based materials. Cured silicones are typically low modulus, which absorb stresses during thermal cycling and do not degrade at continuous operating temperatures up to 250°C. Other attributes of silicones are:

- Typical dielectric strength > 500 V/mil
- Volume resistivity > $10^{11}$ ohm·cm
- Biologically inert
- Low moisture absorption < 0.4% ( 85°C/85 RH/168 Hrs )
- Low modulus
- Versatile - Can be filled with various conductive fillers

### FROM INSULATIVE TO CONDUCTIVE[1]

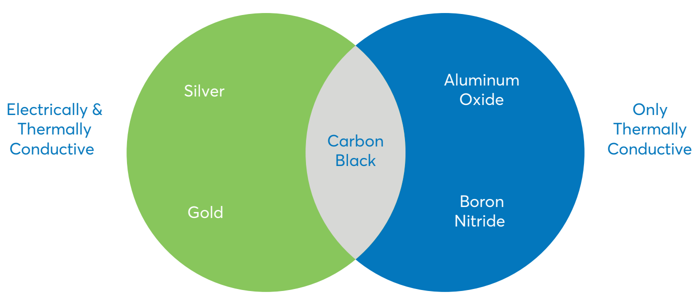
Before deciding which product or filler to choose, it is important to understand the degree of conductivity a particular application requires. Although naturally insulative, silicone can be optimized to achieve varied conductivity.

- Insulative (Insulator)
  - >$10^{11}$ ohm·cm
  - Prevents or limits the flow of electrons across its surface or through its volume
- Static Dissipative
  - ($10^{4}$-$10^{11}$) ohm·cm
  - Electrons flow across or through the material and are controlled by the volume or surface resistance. The transfer of charge will typically take longer than a conductive material
- Conductive
  - <$10^{4}$ ohm·cm
  - Low electrical resistance, and electrons flow easily across its surface or volume

### CONDUCTIVE FILLERS

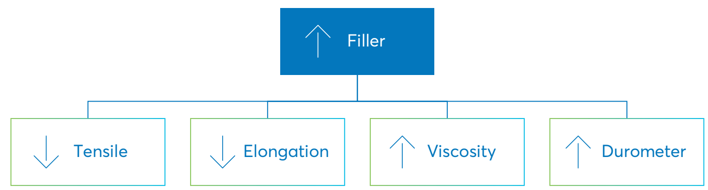
Due to silicone's large free volume and "polar nature" compared to carbon-based polymers, various fillers can be used to optimize silicone's conductivity. Filler technology is also a rapidly growing enterprise in which fillers with various particle sizes and shapes can be added to silicones to impart key properties such as maintaining conductivity at elevated temperatures. Caution should be used when considering filler for a specific conductive property. While some only impart one type of conductivity - such as Boron Nitride to increase thermal conductivity — others, like silver, increase thermal conductivity, as well as electric conductivity concurrently. In general, there are three main types of filler: electrically insulative ceramic filler that contributes thermal conductivity only; carbon filler that contributes electric conductivity and, to some degree, thermal conductivity; and, finally, metal filler that contributes greatly to both electric and thermal conductivity. The following are examples of fillers, what property they target and a description of filler shapes to consider:

| Filler Shapes | Attributes |
|---|---|
| Amorphous | Solid structures that form aggregates of various shapes |
| Spherical | Good Point-Point Contact |
| Flake | Better Aspect Ratio |
| Fibers | Best Aspect Ratio |



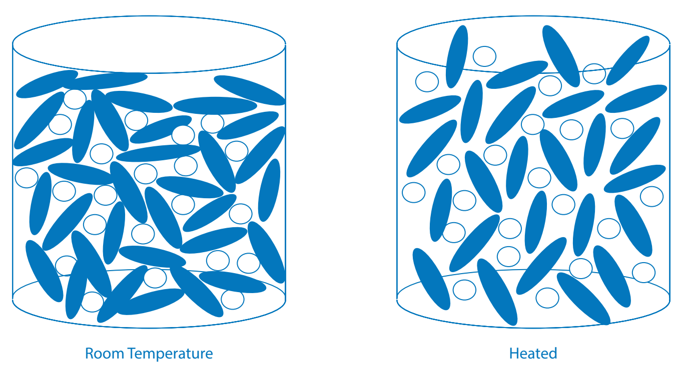

## Physical Affects on Silicone with the Addition of Filler

Filler shape and size significantly affect a material's rheology, mechanical properties and conductivity. Physically, the amount of filler that can be added is governed by the interaction between the polymer and the filler. It is also important to understand that, while maximum loading gives the best conductivity, changes to the silicone's physical properties - durometer, elongation, etc. - are common. As a general rule, the following changes should be expected in the physical properties of a material:




## Effects of CTE on Conductivity

Silicone is naturally insulative; therefore point-to-point contact of the filler is crucial to maintain conductivity. This requirement becomes a challenge; however, when you consider the large CTE that silicone exhibits (120-1000 ppm/°C) and the CTE mismatch between the filler and silicone. The main considerations when maintaining the point-topoint contact as silicone expands are particle size and distribution. Along with what type of filler is being used, the size and shape of the filler is going to dramatically dictate how conductive a silicone is and at what temperature it ceases to conduct.




## COMPARISON OF FILLERS

In an effort to evaluate the performance of different fillers, a study was performed comparing their conductivity at various elevated temperatures: 28°C, 80°C, 100°C, 125°C, 150°C, 175°C and 200°C. In the study, traditional fillers, such as carbon black and silver spheres, were evaluated.

## Testing Method

- Volume Resistivity, ASTM D 257 (ASTM D 4495)
- Cured per the Design Specification onto coupon, open face
- 4 wire
- Agilent 34401A digital Multimeter
- Blue M Convection Oven
- Measured VR at 28 °C, 80 °C, 100 °C, 125 °C, 150 °C, and 250 °C

$$VR = R\frac{W(T2 = T1)}{L}$$

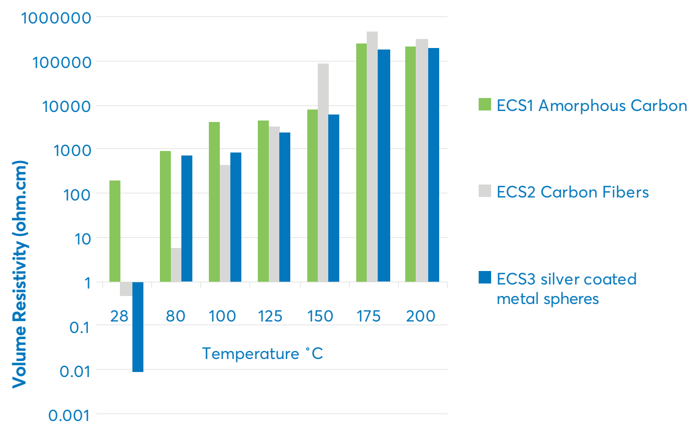
Where VR = Volume resistivity in ohm.cm

R = resistance reading from multimeter in ohms
W = Average width of sample in cm
T2 = Average thickness of sample and coupon in cm
T1 = Average thickness of coupon in cm
L = Distance between inner copper strips on coupon in cm

## Examples of Traditional Conductive Materials

Below are examples of current NuSil materials with three different types of traditional fillers: Amorphous Carbon Black (ECS1[2]), Carbon Black Fibers (ECS2[3]) and Silver-Coated Metal Spheres (ECS3[4]). When reviewing the data, one should notice three important facts. First, as expected, the material containing the most conductive filler, ECS3, produces a silicone material with the highest conductivity at room temperature. As the temperature increases, however, at 80°C, the second fact is observed; the material with fibers, having a better aspect ratio, changed the least as temperature increased. This is explained by its ability to maintain its point-to-point contact as the silicone material expanded with heat. While the silver spheres are more conductive, the shape of that filler isn't as forgiving as they are separated from each other as the silicone expands. The third fact — at a certain temperature, shown here around 150°C — traditional fillers all fall to static dissipative and, as the silicone continues to expand with temperature, it will eventually become insulative.

| Material | ECS1 | ECS2 | ECS3 |
|---|---|---|---|
| Filler | Amorphous Carbon Black | Carbon Black Fibers | Siler Coated Metal Spheres |
| Specialization | Tough | Wide Operating Temperatures | Low VR at RT and Flowable |
| Cure System | Addition (Platinum) | Addition (Platinum) | Addition (Platinum) |
| ~% Filler | 4 | 30 | 80 |
| Specific Gravity | 1.04 | 1.2 | 3.41 |
| Durometer "A" | 30 | 75 | 80 |
| Tensile (psi) | 414 | 450 | 440 |
| Elongation (%) | 329 | 83 | 81 |
| Volume Resistivity (25C) | 750 | 1.7 | 0.002 |




## Novel Fillers for Increased Performance

For some applications, the performance shown above is sufficient, and standard technology is able to accommodate their needs. However, some applications are exposed to harsh environments, and thermal or electrical conductivity must be maintained. To accommodate this need, NuSil has developed products using novel fillers described below. ECS4[5] and ECS6[7] both utilize a dynamic filler package making them viable at higher temps. In fact, while ECS6, an addition-cure silicone, is certified to maintain conductivity at $10^{-2}$ ohm·cm in 80°C, ECS4, a condensation-cure silicone, is certified to maintain conductivity at $10^{-3}$ ohm·cm in

200°C. Also, to compensate for the added mass that high levels of filler contribute to a conductive material and an application, NuSil has developed a material with a much lower specific gravity, ECS5[6]. By incorporating lighter spheres coated in silver, we have been able to offer a material a third as dense as similar traditional material.

| Material | ECS4 | ECS5 | ECS6 |
|---|---|---|---|
| Filler | Silver Coated Fibers | Silver Coated Spheres | Silver Coated Fibers |
| Specialization | 0.008 ohm*cm at 200 C | Lower Density | 0.020 ohm*cm at 80 C |
| Cure System | Condensation (Tin) | Addition (Platinum) | Addition (Platinum) |
| ~% Filler | 80 | 55 | 80 |
| Specific Gravity | 3.21 | 1.18 | 3 |
| Durometer "A" | 80 | 91 | 85 |
| Tensile (psi) | 400 | 311 | 440 |
| Elongation (%) | 56 | 55 | 64 |
| Volume Resistivity (25C) | 0.003 | 0.002 | 0.004 |

## The Balancing Act

Determining the best product to choose involves a thorough understanding of applications' requirements. At times, a balance needs to be achieved between changes in physical properties and necessary conductivity. Along with physical changes to the material, one must consider their ability to process the material. NuSil Technology has several standard products, such as ECS1-ECS3, that are designed to work well in many different applications; however, as limits are pushed and applications experience harsher environments, novel solutions must be generated. Steps to solve these challenges have already begun, and a few examples are seen with ECS4-ECS6. NuSil Technology will continue to explore advanced fillers to improve our materials.

## References


1. Electrostatic Discharge Association, "ESD Fundamentals Part 1". 2011. 29 June 2011 www.esda.org/fundamentalsP1.html.
2. Nusil CV-2640 (ECS1)
3. Nusil CV2-2640 (ECS2)
4. NuSil CV-2644 (ECS3)
5. NuSil CV2-2646 (ECS4)
6. Developmental Material (ECS5)
7. NuSil CV2-2644 (ECS6)





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