Increased Performance Requirements Are Driving New Applications for Ceramic Sensor Components

By Megan Maguire

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As demand grows for more sophisticated, connected devices, many appliances are being outfitted with various types of sensors in order to detect, monitor, and improve performance. Engineers are consistently being presented with new challenges in developing sensors that don't interfere with the core purpose of the device, while driving advancements in efficiency, reliability, and connectivity. In small and micro-applications, there is the additional challenge of creating intricate sensor components that can be replicated at high volumes.

Advances in material science are addressing these challenges, and technical ceramics are stepping in to replace metals and polymers where durability must be combined with acute thermal management, electrical insulation, and corrosion resistance. Extraordinary material properties make technical ceramics the ideal materials for critical sensor components—providing reliable and repeatable performance in demanding environments.

Technical ceramics are extraordinarily versatile. Hundreds of ceramic formulations with varying material properties provide design engineers with numerous options. Materials such as high-purity alumina, steatite, and zirconia toughened alumina each have different material qualities, and major manufacturers offer variable grades of each material to meet exacting requirements in a given system, both in terms of performance and budget.

Engineered ceramics have long been used in the manufacture of sensors for automobiles. The average late model vehicle is outfitted with 60 to 100 sensors, including pressure, temperature, proximity, and particulate sensors, driving performance in applications ranging from engine management to air conditioning.

The challenges for developing sensors in appliance applications are much the same as in automobile manufacturing, though on a different scale. Though most appliances have lower operating temperatures, the cyclical demands are still present. System sizing is a major factor, as appliance packages in general are considerably more restrictive. For smaller sensors used in medical applications, mini or even micro components are necessary, as is biocompatibility.

To address the issue of restricted space, there are numerous manufacturing technologies available to form and shape ceramics with varying degrees of dimensional control. Extremely tight tolerances are achievable in the as-fired state, with many pre-sintered forming methods. Secondary processes provide additional options to achieve even greater precision.

Alumina (aluminum oxide) is a general purpose ceramic displaying excellent mechanical, thermal, and electrical properties.

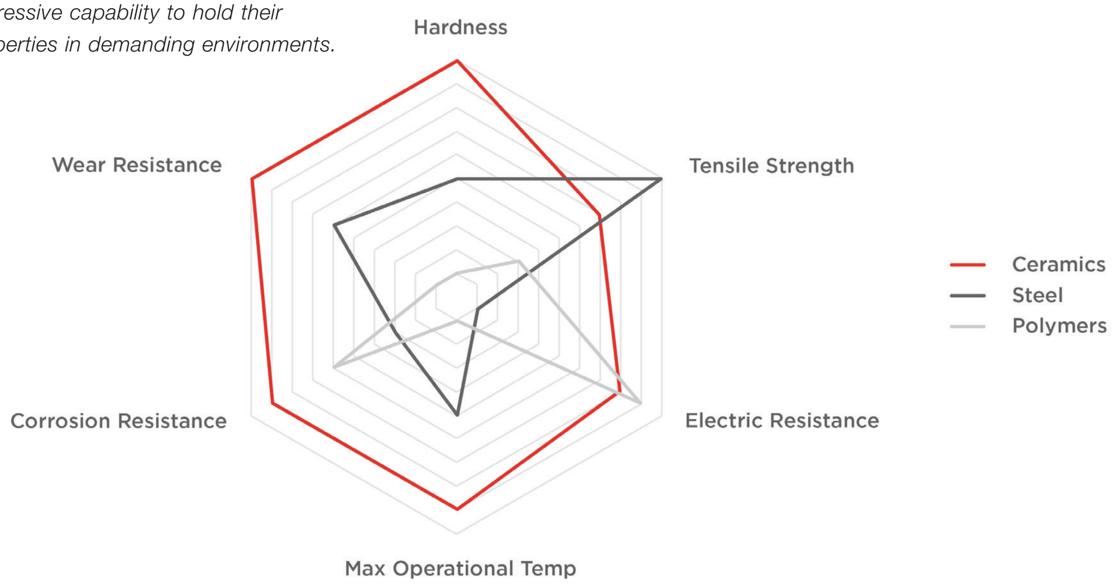
"Today's ceramics have evolved into materials of choice for many sensor applications," says Nathan Pauls, a process engineer with CoorsTek. "Few materials have the right combinations of electrical, mechanical, thermal, and chemical properties to help accurately and repeatably measure pressure, temperature, position, etc. And technical ceramics are in no way a one-size-fits-all solution. There are literally hundreds of formulations designed to meet individual specifications, so you can start with the most demanding of requirements and work your way back into finding the material you need."

Cost considerations can present a barrier to engineers interested in using technical ceramics for sensor components given the higher price point vs. many metals and plastics, but in certain applications ceramics can be the only materials capable of meeting the severe-duty requirements of certain devices. Price has traditionally meant that technical ceramics are only found in critical duty sensor applications for industrial and medical devices, but increased demands for higher performance in consumer appliances have lead designers to view ceramics in a new light. High-end consumers have also demonstrated a willingness to pay a premium for luxury appliances with smart connectivity and functionality. Efficiency gains in ceramic manufacturing methods, as well as volatile markets for other materials such as metals, are making ceramics an increasingly attractive option.

Electrical circuitry for sensor components is generally built upon thick film ceramic substrates manufactured through processes that include injection molding, dry-pressing, roll compaction, or tape casting. For pressure sensing applications, ultra-sensitive thin ceramic membranes can be used to detect minute environmental changes. Technical ceramic membranes have added strength, heat and corrosion resistance, and hardness, making them much more durable than easily damaged metal diaphragms.

Fabrication

Roll compaction is a method of fabricating continuous thin sheets of ceramic materials by compacting flowable ceramic powders in a rolling mill. This fabrication technology allows parts to be manufactured to precise dimensional specifications, yields two identical working surfaces, *While materials such as steel and polymers excel in specific arenas, advanced ceramics have an impressive capability to hold their properties in demanding environments.*



and tighter thickness control.

Tape casting is a widely used forming technique for developing ceramic tapes and sheets used for substrate applications. A ceramic powder is mixed with solvents and binders, then cast onto a moving belt. A scraping, or doctor blade, is used to remove excess slurry and to form an even layer of ceramic which is then dried and sintered. The thin layers can then be used to form single layers or can be stacked and laminated into multi-layered capacitors and ceramic packages. This fabrication method allows for exceptionally flat surfaces with virtually no surface imperfections. Manufacturers can produce thick film substrates for sensor applications at thicknesses ranging from .254 mm to 3.556 mm.

Both tape cast and roll compacted substrates are then laser machined, scribed, or annealed to create machined holes, slots, scribing lines and other necessary markings and cuts to meet the design requirements.

Ceramic injection molding is the process of injecting ceramic powder mixed with a binding agent into a pre-formed mold to form the green, pre-fired shape. Thanks to advances in process controls, this forming technique has gained a lot of popularity in developing smaller, complex shapes and geometries. With tightly controlled shaping, ceramic injection molding can eliminate the need for secondary machining. Near net shape parts can be produced and replicated at high volumes, making it a cost-effective process for sensor and other small electronic components.

Material Properties

Corrosion Resistance/ Biocompatibility

Technical ceramics are inherently inert, guaranteeing against corrosion and providing a lifetime of compatibility even when minute changes in environment occur. Corrosion is most often a factor in fluid environments but can also present in high-humidity arenas. Many medical-grade ceramics are also bioinert and capable of meeting the stringent demands for surgical, implant, and other medical devices.

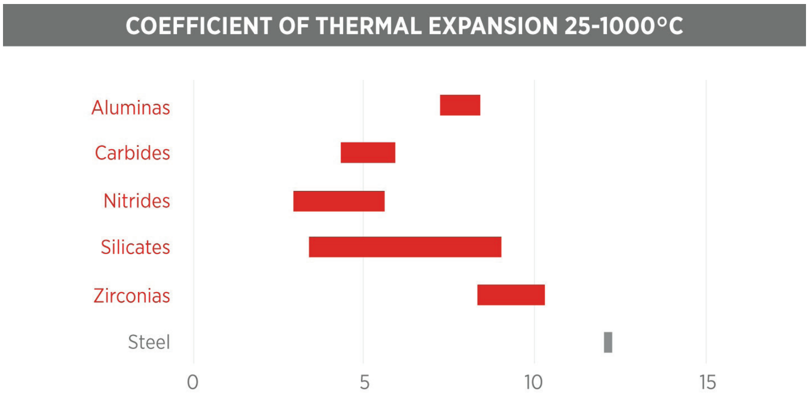
Thermal Stability

With extraordinary thermal properties, ceramics are ideal for high-heat environments where sensors are used. With a low coefficient of thermal expansion and low thermal conductivity many technical ceramic formulations are stable in extreme temperatures.

Electrical Resistivity

Many ceramics are naturally electrically resistant with a low dielectric loss—maintaining high levels of electromagnetic energy with very little, if any, dissipation of that energy. For that reason, ceramic materials provide good electrical insulation for sensors and other electronic devices.

Fatigue Resistance
Elasticity/fatigue resistance presents the ultimate challenge in many sensor applications, as it is necessary for the material to withstand thousands of cycles without weakening. Certain ceramic formulations, such as high-purity alumina have a high modulus of elasticity. For A/C and other applications, technical ceramics are capable of resisting fatigue well beyond metals and plastics, returning to a steady state for each and every cycle.



Technical ceramics have a low coefficient of thermal due to their strong interatomic bonds. The ability to retain material properties in high temperature environments make ceramics a strong choice for sensor components.

Technical Ceramic Materials For Sensors

High purity Aluminum Oxides, or aluminas, are frequently used in sensor applications. A good general use ceramic, the price/performance ratio makes it one of the most affordable options. High-purity aluminas provide exceptional wear resistance, are completely inert, and have high volume resistivity—perfect for sensor components requiring intricate electrical connections.

Steatite is a magnesium silicate ceramic that exhibits good mechanical properties along with low dielectric loss and high dielectric strength. Manufactured from common soapstone and readily formed using a variety of manufacturing methods, it is a lower cost ceramic option for certain appliance sensor applications.

Zirconia Toughened Alumina, or ZTA, is a composite ceramic material with zirconia grains in the alumina matrix. Zirconia toughened aluminas offer increased hardness, strength, and thermal properties when compared to aluminas, but generally at a lower cost compared to full zirconia formulations.

Piezoelectric ceramics are a classification of materials that produce an electric charge when the material is subjected to pressure or tension, making the materials useful for measuring pressure, acceleration, temperature, and more. Piezoelectric sensors are widely used in various applications, including consumer electronics. However, piezoelectric ceramics can only be used for dynamic measurements. They can also be desensitized at high temperatures, and certain crystals in the ceramic structure are water soluble and cannot be used in water or high humidity environments.

Applications

Advanced ceramic components are used in a multitude of appliance applications and can currently be found in variety of industrial and medical appliance sensors such as pressure melt sensors/transducers—instrumentation used to measure melt rates for plastics manufacturing. For high-temperature plastics manufacturing, thermal management is obviously a critical factor and few materials can withstand the necessary temperatures. Ceramics can also be found in many fluid management systems, including level, pressure, and flow sensors used for monitoring crucial fluids for medical diagnostics.

The trend towards interconnectivity is driving increased sensor usage across all appliance platforms, and designers are seeking new and innovative ways to apply these technologies within the constraints of traditional systems. With outstanding material properties and fabrication techniques, ceramics are rapidly becoming the desirable choice over metals and plastics in sensor applications.