Si and Ge NTC High Temperature Thermistors

In the very significant market for NTC (negative temperature coefficient) thermistors, which are thermally-sensitive resistors whose resistance decreases as the temperature rises, there is clear potential for a readily - manufacturable sensing technology that would further extend the market opportunities for NTC thermistors by providing a wider temperature range, higher sensitivity, greater interchangeability, and a smaller form factor at an attractive price.

AdSem, Inc. has developed and offers the first silicon and germanium high-temperature NTC thermistors that significantly improve the performance of conventional ceramic NTC thermistors. These thermistors do not require individual calibration in the working temperature range of –40°C - + 500°C (Si) and -100 °C - +300 °C (Ge), and offer compelling benefits, compared to conventional NTCs, such as: a wider temperature range; higher thermo sensitivity; a very high degree of interchangeability; high stability; ease of manufacturing and ability to be more cost-effectively produced; smaller form factor; resilience to negative environmental conditions (e.g., moisture/humidity); versatility of device configuration; and compatibility with semiconductor and microelectronic packaging. Moreover, employment of semiconductor Si and Ge as a thermistor material creates the opportunity for development of the new generation of multi-functional sensing devices on the same chip (for example, pressure and temperature sensors, acceleration and temperature, etc.

All other manufacturers of commercial NTC thermistors use basic ceramic technology that continues today much as it has been for seven decades. Thermo-sensitive ceramic materials for thermistors are made of a composition of different metal oxides (MnO, CoO, NiO, etc.). In the basic process, a mixture of two or more oxide powders is combined with a suitable binder, and then formed into a desired geometry with following processing at elevated temperature to achieve solid phase chemical reactions. The result is a ceramic material that has an electrical conductivity value that changes exponentially with temperature variance. Thermistor's thermo sensitivity depends on oxides employed, their composition, treatment temperature, environment, etc. Ceramic NTC thermistors can provide greater sensitivity to temperature change than RTDs (resistance temperature detectors), thermocouples, or semiconductor temperature sensors based upon p-n-junctions. They are also inexpensive relative to these temperature sensors. However, ceramic NTC thermistor element generally has an upper temperature limit ~300 degrees C, and is sensitive to environmental condition. Ceramic technology is not a highly reproducible with final results depending upon permanent control of many variables. Interchangeability of ±0.1% can be reached at quite narrow working temperature range of 0 - +70°C only by body trimming which involves manual labor leading to substantial price increase of the product, and there is no standard resistance versus temperature R (T) characteristics established for ceramic NTC thermistors. Each ceramic thermistor supplier provides their own resistance-temperature look-up tables based on the type of employed oxides and in-house production technology. For instance, due to the severe degree of fragmentation of the ceramic thermistor industry, the development of an integrated digitizer has not been feasible; it would force IC designers to provide variety of R (T) curves and still limit compatibility of the ICs to few thermistor production lines.

The starting semiconductor material for our thermistors is crystalline silicon or/and germanium utilized in electronic industry. Si or Ge wafers are subject to special treatment. Then wafer cutting is followed by chip assembly into usable device with wire leads attachments and packaging similar to those used for ceramic thermistors. Due to employment of Si and Ge as thermistor materials, we can also utilize various microelectronic packaging techniques that are well developed, automated and miniaturized in the modern semiconductor industry.

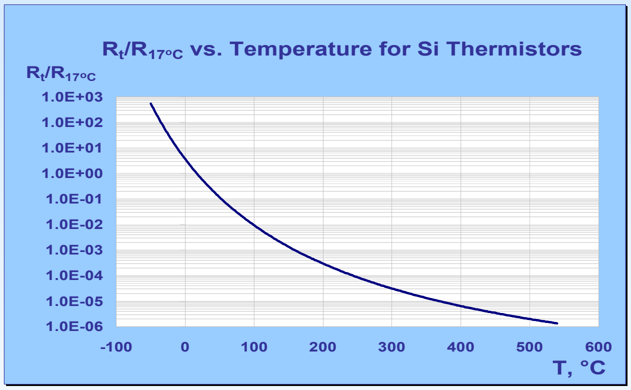
There are fundamental scientific reasons for our Si and Ge thermistors to be the most sensitive and interchangeable in a wider temperature range. Due to large activation energy of conductivity in Si and Ge, their resistivity is a sharp exponential function of temperature. Large activation energy value ensures large thermo sensitivity and expands operating temperature range for Si and Ge thermistors.

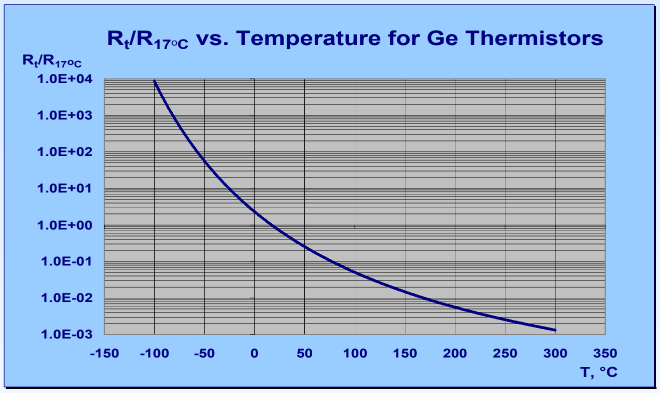
Resistance (R) temperature dependence is the main characteristic of thermoresistors and can be described by expression:

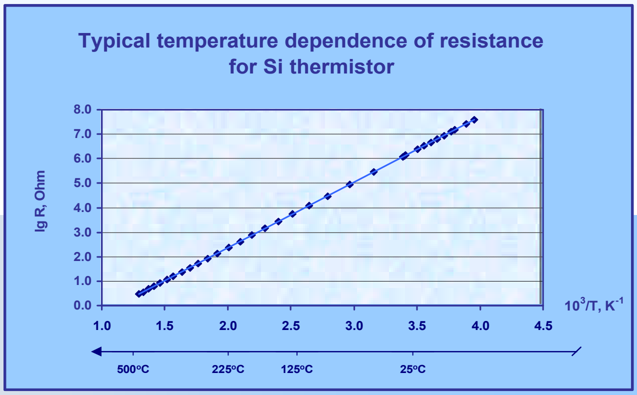
$$R = A \exp [E_a / k T],$$

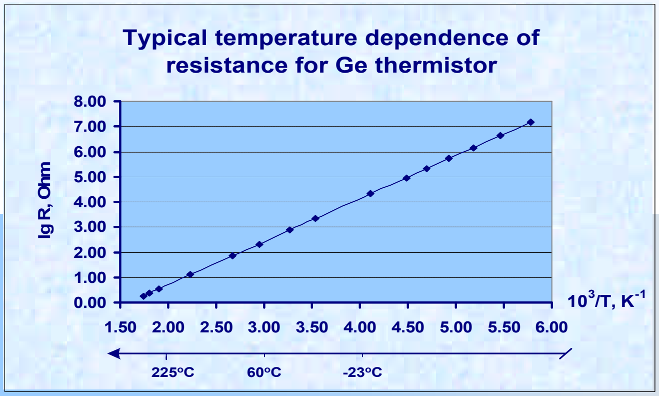
where E_a is activation energy; A and k - constants,
T- temperature.

The fundamental property of both Ge and Si high temperature thermistors is the universality of their resistance-temperature dependence for any thermistor size and any thermistor configuration. In addition, R (T) dependence for Si and Ge is described precisely by the analytical exponential function. Experimental results demonstrate linear dependence of logarithm of resistance versus 1/T over specific temperature range. This means that activation energy for charge carriers is independent from temperature
and thermistor geometry.


$R_t/R_{17^\circ C}$ vs. Temperature for Si Thermistors


$R_t/R_{17^\circ C}$ vs. Temperature for Ge Thermistors


Typical temperature dependence of resistance for Si thermistor


Typical temperature dependence of resistance for Ge thermistor

The universality of R = f (T) dependence, that can be precisely described by analitical exponential functon, allows the development of standard inexpensive integrated electronic digitizer (front end electronics, converting R into temperature data.

Temperature coefficient of resistance alpha (a) and beta value (ß), the parameters that characterize thermo sensitivity of thermistors are higher for our Si and Ge thermistors than corresponding parameters for ceramic thermistors produced by leading manufacturers. The upper limit of operating temperature is also higher for semiconductor thermistors. Our measurements indicate that Si thermistors have operating temperature range from – 40°C to +500°C. Ge thermistors have lower operating temperatures and lower thermo sensitivity in comparison with Si thermistors, which, is nevertheless, higher than vast majority of ceramic thermistors. However, they are ideal for applications in the range of –100°C - +300°C, where micron size (<500 um), high thermo sensitivity and lower (than Si thermistors) resistance value are important.

Comparison data that underline advantages and disadvantages of the various temperature sensors are presented in the Table below. Between them NTC thermistors prevail for implementing customized sensing solutions due to a reasonable combination of sensitivity, accuracy, durability, interchangeability and cost.

Typical characteristics of Si and Ge high temperature NTC thermistors

Dimensions, min..100x100x100 um^3

Temperature Coefficient of Resistance @ 25°C
Si thermistors.......................................-7.3%/°C
Ge thermistors......................................-5.0%/°C

Operating Temperature
Si thermistors …....................................-40 - +500°C
Ge thermistors......................................-100 - +300 °C

Beta Value (B) @ 25°C
Si thermistors…..…………………………6600 K
Ge thermistors....................................... 4700 K

Resistance Range,
Si thermistors…..…………………………1 - 10^8 Ohm
Ge thermistors.. 1-10^8 Ohm

Interchangeability
Si thermistors @ (-40 - + 500 ° C)…..± 0.1 °C
@ (+25 - +200 ° C)…..± 0.05 °C
Ge thermistors @ (-100 - 0 °C)...........± 0.1°C
@ (0 - +200 °C)….......± 0.05 °C

There is no doubt that the need for high quality temperature sensing will continue to grow. Since our Si and Ge thermistors offer better performance in all working temperature range and lower cost, with higher maximum operating temperature, up to 500°C, they are not only advantageous to ceramic thermistors, but, additionally, have a real opportunity to capture significant part of RTD's market.

TEMPERATURE SENSORS COMPARISON

Characteristics	RTD	Thermocouples	NTC Ceramic Thermistors	AdSem Inc. NTC Si & Ge Thermistors
Active Material	Platinum	Two dissimilar metals	Ceramic (metal oxide spinel)	Si or Ge
Changing parameter	Resistance	Voltage	Resistance	Resistance
Themperature range	-200 to +650°C	-200 to +1750°C	-100 to +250°C	-273 to + 500°C
Additional circuitry	Lead compensation	Reference junction	Linearization	Linearization
Sensitivity	0.4%/°C	40V/°C	-4.4%/°C	-7.3%/°C (Si), -5%/°C (Ge)
Accuracy	0.1 to 1.0°C	0.5 to 5.0°C	0.5 to 5.0°C	0.001 to 0.5°C
Response time	Slow, 1 to 50 sec	Fast, 0.1 to 10sec	Fast, 0.12 to 10 sec	Fastest, < 0.1 sec
Stability	Excellent	Moderate	Moderate	High
Cost	High to moderate	Low	Low to moderate	Low
Advantages	Highest stability Linearity	Temperature range Self-powered Durable Low cost	High sensitivity Accuracy Fast response Small size Variety of packages	Highest sensitivity High interchangeability Fastest response Smallest size Ability to employ automated semiconductor micro packages 0402, 0603, 0805…
Disadvantages	High cost Lead resistance error Slow response time Vibration issue Large size Package limitation	Low stability Low accuracy Extension leads	Non-linearity Moisture adsorption Limited temperature range	Non-linearity but universal R = f (T) allowing development of standard integrated digitizer (front end electronics)