PROPER SELECTION OF GR-200A GERMANIUM RESISTANCE TEMPERATURE SENSING ELEMENTS FOR USE FROM < 0.05 K to 4.2 K APPLICATION NOTE

Considerations for the proper selection and specification of 30, 50, and 100 ohm GRT's.

Increased interest in temperatures below 1 Kelvin has resulted in a dramatic increase in requirements for Germanium Resistance Temperature Sensing Elements (GRT) for use from below 30 mK to 1 K.

Historically, GRT's for this use have been designated 30 ohm, 50 ohm, or 100 ohm resistors, indicating their approximate resistance at 4.2 K. It was thought that such a simple measurement would provide sufficient information to predict approximate R(T) below 4.2 K. Fortunately, this has proven to be the case for $1 < T < 4$ K, but is not so below 1 K. Thus, for resistors below 1 K:

1. The resistance value of a GRT at 4.2 K has little or no value in determining the GRT characteristic below 1 K, in short, "Caveat Emptor."
2. Only an appropriate calibration can guarantee the characteristic of the GRT at the required use temperature.
3. a) Modest guarantees of performance can be made if the resistance ratio of the GRT at 1.5 and 4.2 K is known.

   b) More precise guarantees of performance can be made if the resistance ratio of the GRT at 0.3 and 4.2 K is known, and if several resistors from the same crystal have also been calibrated.
4. GRT's have a useful range for acceptable sensitivity of about two orders of magnitude in temperature. This is true both above and below 1 K. A change of only 2 to 3 parts in 10^{16} of arsenic doping is the difference between a 1000 ohm GRT and a 30 ohm GRT.
5. Manufacturing technique must be carefully controlled to assure quality.

How to order a GRT for use in the range of < 0.05 to 4.2 K.

General: As Figure 1 demonstrates, the GRT should not be expected to have optimum sensitivity over much more than one order of magnitude of temperature change.

For 30 ohm GRT's: Lake Shore Cryotronics will only supply 30 ohm GRT's with a calibration (Type .05A, 0.05 to 6.0 K). As Lake Shore will not calibrate below 0.05 K, we request that you specify:

a) Lowest temperature that you intend to use the the GRT, if known.
b) Maximum resistance that your system can read out with accuracy.
c) Minimum resistance that will be acceptable.
d) Any unusual technical point you may wish to advise us of.

Note that the greater the spread between (b) and (c), the faster we will be able to supply the GRT.

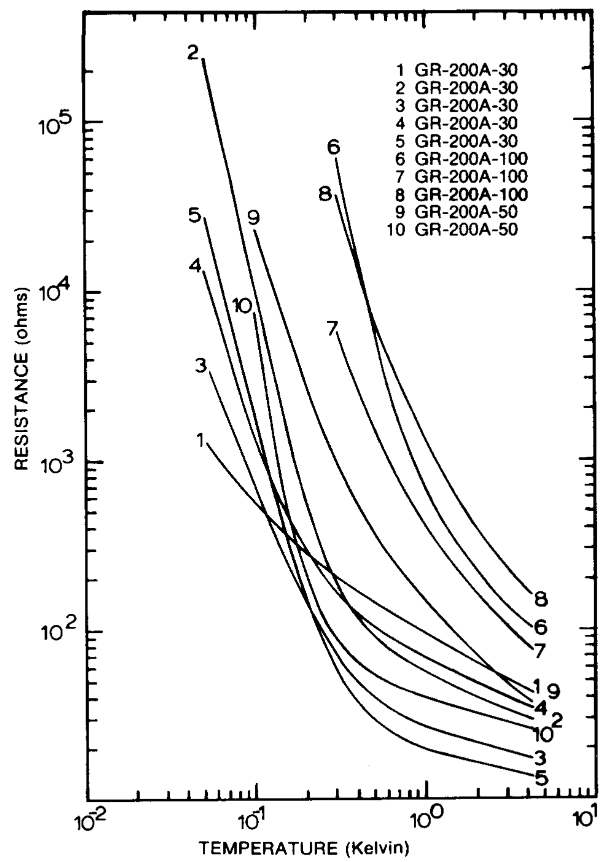

FIGURE 1. Typical Resistance vs. Temperature

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For 50 ohm GRT's: We recommend 50 ohm GRT's for use down to 0.1 K with the comments as above. Calibration is recommended for use below 1 K.

For 100 ohm GRT's: We recommend 100 ohm GRT's for use down to 0.3 K with the same comments as above. Calibration is again recommended for use below 1K.

Notice from the curves in Figure 2 that the values at the lowest temperature recommended for the 50 and 100 ohm resistors do not have as wide a spread as do the 30 ohm resistors.

The availability of the new temperature scales, EPT-76 (0.5 to 30 K) and NBS-CTS #1 (<0.02 to 0.5 K) and the NBS-developed SRM-767 and SRM-768 super-conducting fixed point diodes (which give remarkably accurate and reproducible reference temperatures), allow a sound interpolation calibration for the GRT. The GRT working standards at Lake Shore Cryotronics are checked against the SRM-767 and SRM-768 on a regular, scheduled basis.

Lake Shore calibrates 30, 50, and 100 ohm GRT's in a dilution refrigerator which is mounted on a concrete base and in a screen-room protected area. Resistors are calibrated in this facility from about 44 mK to 1.1 K using a PCB instrument manufactured by SHE.

Self heating and parasitic resistances are tested at 0.05 and 0.1 K. Typical voltage drops across the resistor are limited to 30 μV from 0.05 K to 0.1 K and 100 μV above 0.1 K.

Technical Considerations in GRT Production.

GRT's are manufactured from double-doped germanium crystals. They are available with either "p" or "n" type characteristics with "n" type crystal used below 1 K. The dopants are arsenic and gallium at the 10 atoms per cc. level with arsenic having a slightly higher concentration and providing the "n" characteristics in the compensated crystal. Crystals can be either boat or Czochralski grown.

Control of dopant level is not straightforward for several reasons: the transport co-efficient of the arsenic is approximately three times that of gallium; the vapor pressure of arsenic at the crystal-growing temperature is very much higher than gallium; and these properties, combined with the low dopant levels, require a certain amount of "Black Magic" to successfully grow a useful crystal. Experience has shown that etch pit density (EPD) in the crystal is a further crucial consideration.

After growing the crystal, it is possible to assemble nominal 30, 50, and 100 ohm resistors. This is, of course, a rather simple geometric problem: $R = \rho L/A$. And it is here that the misunderstandings start.

(Un)predictability of GRT Low Temperature Performance.

Our work shows that there is minimal correlation between the nominal value of R at 4.2 K and the GRT's characteristics at or below 1 K. Figure 1 shows R vs. T characteristics of several GRT's. These units were selected from several different crystals and with various R values at lower temperatures. Although it is not necessarily obvious from Figure 1, it is generally possible to preselect GRT's that are useful at low temperatures by determining the ratio of R at 1.5 Kelvin to 4.2 Kelvin. The ratio of R at 0.3 Kelvin to 4.2 Kelvin is even more useful but obviously more expensive to obtain.

After any given crystal's R ratios have been obtained and analyzed, it is very straightforward to discard resistors that either have too high a ratio or too low a ratio. Our experience has shown an essentially 100% accurate rejection process (but not acceptance process). For example, ratios of 1.1 to 2.7 may be obtained from a given slice of 30 ohm germanium material which may include up to 35 resistor elements. Once testing is complete and ratios have been established for yield at lower temperatures, the acceptable ratio range is typically very narrow for a given crystal. For example, 1.4 to 1.6 for 30 ohm resistors, 1.9 to 2.1 for 50 ohm resistors and 3.2 to 3.8 for 100 ohm resistors.

GRT Model	Resistance (ohms)			Resistance Ratios			
	at 4.2K	at T*	T(K)*	1.5K:4.2K	0.3K:4.2K	0.1K:4.2K	0.05K:4.2K
GR-200A-30	20.32	1420	0.05	1.38	6.35	34.1	69.9
	17.12	3897	0.05	1.34	3.99	37.7	227.7
	21.72	390.6	0.05	1.27	2.34	9.64	18.0
	41.54	19470	0.05	2.05	9.75	64.6	469
	13.43	26822	0.05	1.27	4.19	118.5	1997
GR-200A-50	37.39	22496	0.1	2.40	24.46	602	----
	26.07	7456	0.1	1.34	3.26	286	----
GR-200A-100	34.23	1396	0.3	2.86	40.8	----	----
	141.3	20786	0.3	3.33	147	----	----
	99.51	58518	0.3	3.14	588	----	----
	140.5	99932	0.3	4.58	711	----	----
	75.19	5488	0.3	2.95	73.0	----	----

*Resistances at other T's omitted for clarity.

TABLE 1.

Table 1 shows ratio values for several 30, 50 and 100 ohm resistors vs. R at selected temperatures. Once again, it is not obvious that useful ratios change from crystal to crystal, or that two resistors with the same ratio and from the same crystal, can have markedly different characteristics. But this is the case!

If the above information is considered in light of the low dopant levels and the difficulties in manufacture of a truly uniform double-doped crystal of germanium, then the above results are reasonable and should be expected.

Other considerations include details of manufacture and tests that relate to quality and reproducibility. All contacts must be ohmic. A good measure of the lead contact quality is the ratio of the two lead to four lead resistance. This ratio should be low and essentially uniform over the use temperature range.

This Application Note is presented to accurately portray the capability of the GRT for use below 1 K and to allow the user to properly specify a GRT for his use. This technical detail represents over five years of analysis of data on many resistors of our manufacture; analysis of eight different crystals used as raw material; and data taken for resistors manufactured by others over the last decade and provided by Prof. J. Gaines of the Physics Department of The Ohio State University.

In addition, in 1979, several resistors were characterized by Prof. A. C. Anderson of the Physics Department at the University of Illinois and by Dr. R. Soulen of the National Bureau of Standards. In the latter instances, Lake Shore Cryotronics had calibrated the GRT's prior to shipping them, and Dr.'s Anderson and Soulen kindly provided calibration checks for our results.

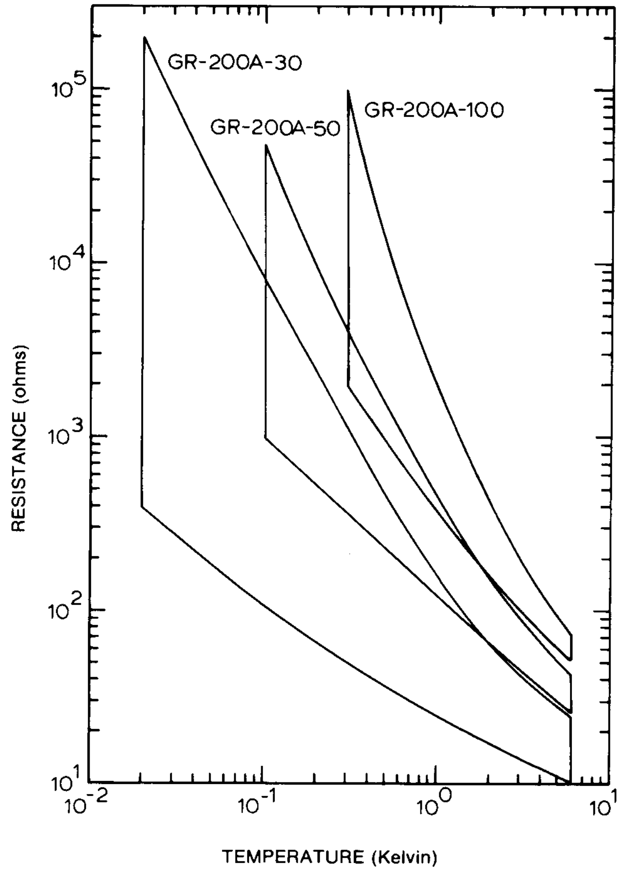

FIGURE 2. Resistance vs. Temperature for GR-200A-30, 50, and 100.