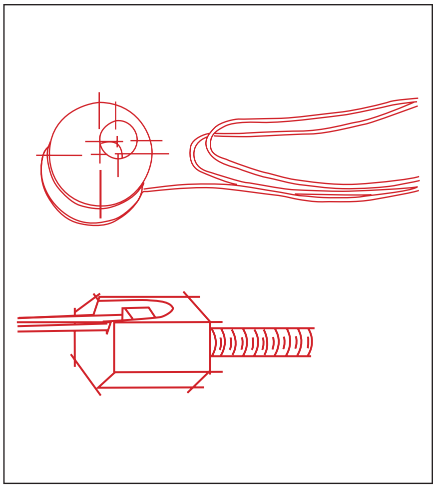
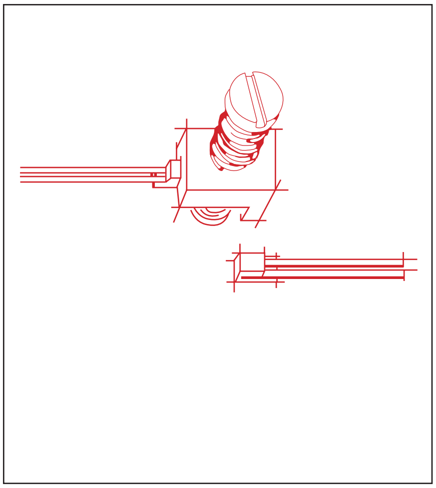
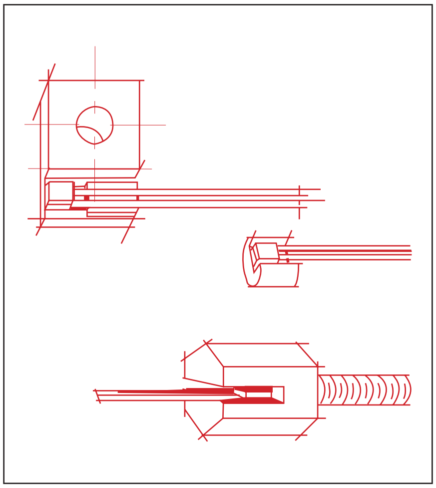
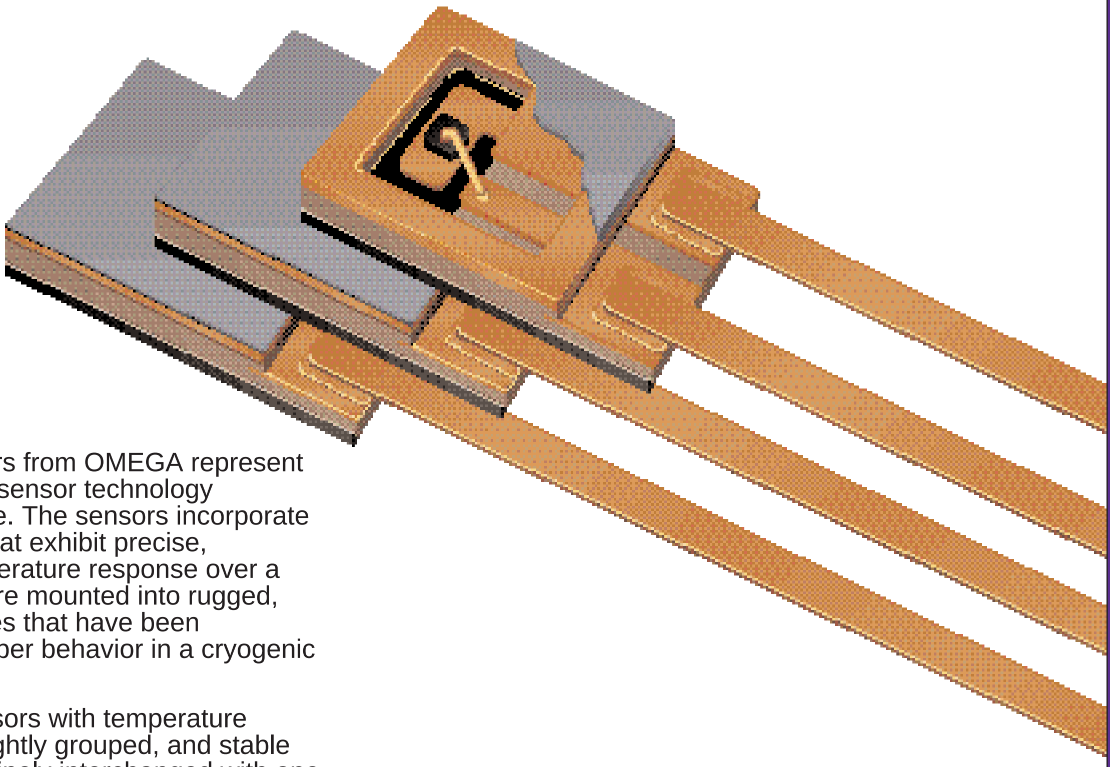
Cryogenic Temperature Sensors

CY7 Series Silicon Diodes









MADE IN USA

The new CY7 Series Sensors from OMEGA represent the first truly new cryogenic sensor technology introduced in the last decade. The sensors incorporate uniform sensing elements that exhibit precise, repeatable, monotonic temperature response over a wide range. The elements are mounted into rugged, hermetically sealed packages that have been specifically designed for proper behavior in a cryogenic environment.

The result is a family of sensors with temperature responses so predictable, tightly grouped, and stable that the sensors can be routinely interchanged with one another.

A New Proprietary Silicon Diode Chip

The key to the sensor's temperature response lies with the basic sensing element itself. The small silicon chip in each sensor has a temperature characteristic that is so stable, so predictable, and conforms so well from chip to chip, that the CY7's sensors are the first mass-produced, interchangeable cryogenic sensors.

As shown on the graph on page Z-93, the temperature response profile of a CY7 is comprised of two distinct elements. With their inherent dual sensitivity, CY7 sensors can cover a wide temperature range (up to 475 Kelvin) and at the same time exhibit high sensitivity for critical low temperature measurement.

Precise thermal response of the sensing element itself is of little benefit if thermal errors generated in installing and using the sensor swamp out its capability. It is in minimizing these frequently unsuspected errors that the CY7 excels.

A Sensor Package Designed for Cryogenics

Sensors for higher temperatures fall far short for cryogenic use. The complex thermal link between the sensing element and its entire environment must be taken into account, as must the effect of any measurement-induced self-heating of the sensor, if one is to achieve accurate results. In addition, the package must also withstand repeated cycling to low temperatures without mechanical failure.

Cryogenic Temperature Sensors

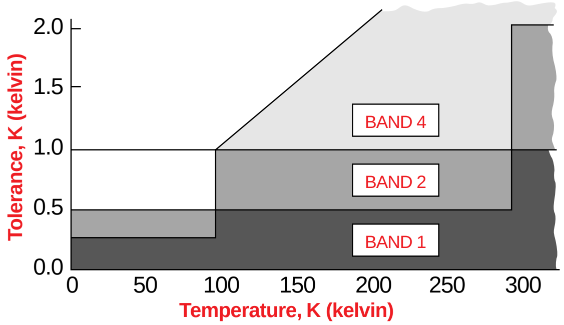
CY7 Series

The development of the CY7 Series has included the design of unique sensor packages to solve many of the problems encountered in low temperature thermometry. For example, the CY7 hermetic package incorporates a sapphire substrate for high electrical isolation yet good thermal conductivity. The base bottom is metallized for easy anchoring to a sample. Large strong leads form an integral part of the package and are thermally sunk into the substrate. This simplifies making connections to the sensor and at the same time helps reduce measurement errors that could be caused by heat conduction along the leads.

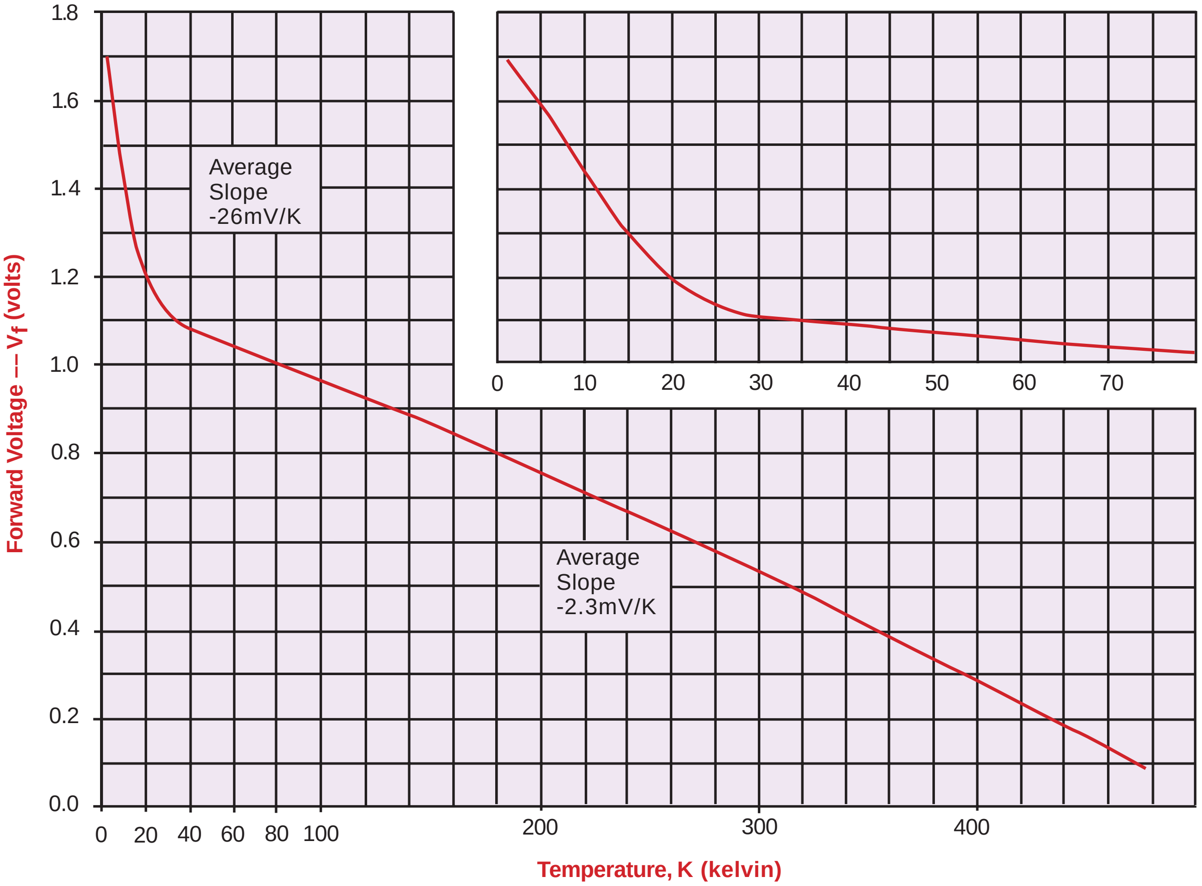
10 Microampere Excitation Current

Key to the achievement of error-free measurement is low excitation current. The lower the current, the less power is dissipated in the sensor and the less self-heating occurs.

One measure of the effectiveness of a cryogenic sensor's thermal design is the variation in reading obtained between operation in a vacuum at liquid helium temperature and immersion directly in the liquid. In a field where discrepancies of a degree or more have been reported, OMEGA® CY7 sensors exhibit variations as low as 5 millikelvin.



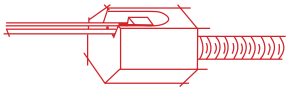
Tolerance Bands for CY7 Series Sensors allow selection of appropriate (and economical) accuracy levels for a given application.



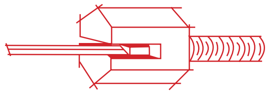
Standard Temperature Response (Curve 10) for CY7 Series Sensors. All Sensors Track this Curve Within Specified Tolerance Bands.

Select the Sensor Configuration Best Suited to Your Application

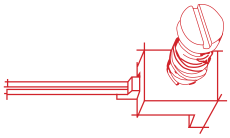
CY7-SD The SD configuration is the smallest package in this series, and is designed primarily for bonding or clamping to a flat surface. Since the sensing element is in best thermal contact with the base (largest surface) of the package, the package should be mounted with that same surface in good contact with the sample. Mounting materials and methods which will not expose the sensor to temperatures above 200ºC are required. Low temperature indium-lead-tin based solder or low temperature epoxy is recommended. The SD package style is usable at temperatures up to 475 K.



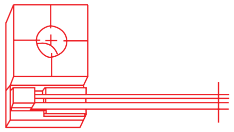
CY7-ET This convenient screw-in package is formed by soldering a basic SD configuration into a recess in one flat of a hexagonal cylinder. The cylinder terminates in a standard 6-32 SAE thread. Thus the sensor can be threaded (finger tight only) into a mounting hole in the sample. A light coating of vacuum grease on the threads further enhances the thermal contact between the sensor package and the sample. The solder used in mounting the SD package to this adaptor constrains the upper useful temperature of this configuration to 325 K.



CY7-MT The MT package is similar to the ET version except the SD package is mounted in a slot in the center of the cylinder and the stud is a 3 mm x 0.5 metric thread.

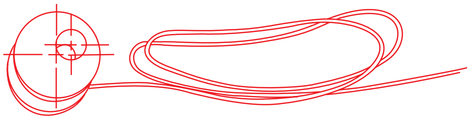


CY7-CO A spring-loaded clamp holds a standard SD sensor in contact with the surface of the sample in this configuration. This allows the sensor to be easily changed or replaced. It also enables the sensor to be used over its full operational temperature range of 1.4 to 475 K. Extra clamps are available to accommodate applications where frequent relocation of the sensor is desirable. The 4-40 brass screw used with this clamp has a formed shoulder so that, once the screw is properly seated, the spring applies correct pressure to the clamp.



CY7-BO In addition to being soldered to the mounting block, the SD sensor in this design has its leads thermally anchored (without epoxy) to the block via a beryllium oxide insert. Since leads can be a significant heat path to the sensing element, and can lead to measurement errors when incorrectly anchored, this configuration helps maintain the leads at the same temperature as the sensor. Mounting of this block is accomplished with a 4-40 screw (not supplied). Usable temperature range of the CY7-BO sensor is 1.4 to 325 K.

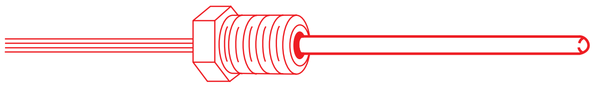
CY7-LR With a CY7-SD sensor mounted on a slightly more than half-round cylinder, this package is designed to be inserted into a 1/8 inch (3.2 mm) diameter hole. Low temperature epoxy can also be used to install the sensor, although the mounting is much more permanent in that case. As with other soldered down sensors, the temperature range of the CY7-LR extends to 325 K.



CY7-CU In this configuration, the SD sensor is epoxied into a flat cylindrical disk and the sensor leads are thermally anchored to that same disk. The unit can be mounted to any flat surface with a 4-40 brass screw (not supplied). The CU style sensor is wired in a four-lead configuration with the leads comprised of a 36-inch length of OMEGA's color coded cryogenic wire. Temperature range is 1.4 to 325 K.

CY7-D1 This is a two-lead version of the the CY7-CU.

CY7-CY Some applications are best served by a relatively large, robust sensor, and the CY7-CY fills that bill. It is very similar to the CU style except that the disk has a larger center diameter with the mounting hole directly in the center. The CY sensor has 36-inch heavy duty (30 AWG, PTFE coated) leads. Special attention must be paid to thermally anchoring the leads to prevent heat leak induced measurement error.



Probes The flexibility of the CY7 series sensors makes them ideal candidates for incorporation into various probes and thermowells. However, the individualized nature of these applications usually demands customized designs.

Cryogenic Temperature Sensors
CY7 Series

Polynomial Representation

Curve #10 can be represented by a polynomial equation based on the Chebychev polynomials which are described below. Four separate ranges are required to accurately describe the curve, with the parameters for these ranges given in Table 1. The polynomials represent Curve #10 on the preceding page with RMS deviations on the order of 10 mK.

The Chebychev equation is of the form

$$T(x) = \sum_{n=0} a_n \, t_n \,(x) \qquad (1)$$

where T(x) represents the temperature in kelvin, $t_n(x)$ is a Chebychev polynomial, and a_n represents the Chebychev coefficients. The parameter x is a normalized variable given by

$$x = \frac{(V-VL)-(VU-V)}{(VU-VL)} \qquad (2)$$

where V is the voltage and VL and VU designate the lower and upper limits of the voltage over the fit range.

The Chebychev polynomials can be generated from the recursion relation

$$t_{n+1}\,(x)=2xt_n(x)-t_{n-1}(x),\ t_o(x)=1,\ t_1(x)=x. \qquad (3)$$

Alternately, these polynomials are given by

$$t_n(x)=\cos[n * \arccos(x)]. \qquad (4)$$

The use of Chebychev polynomials is no more complicated than the use of the regular power series, and they offer significant advantages in the actual fitting process. The first step is to transform the measured voltage into the normalized variable using equation (2). Equation (1) is then used in combination with equation (3) or (4) to calculate the temperature. Programs 1 and 2 give sample BASIC subroutines which will take the voltage and return the temperature T calculated from Chebychev fits.The subroutines assume that the values VL and VU have been input along with the degree of the fit, Ndegree. The Chebychev coefficients are also assumed to be in an array A(0), A(1), ...,A(Ndegree).

An interesting property of the Chebychev fits is evident in the form of the Chebychev polynomial given in equation (4). No term in equation (1) will be greater than the absolute value of the coefficient. This property makes it easy to determine the contribution of each term to the temperature calculation and where to truncate the series if the full accuracy is not required.

TABLE 1. Chebychev fit coefficients

2.0 to 12.0 K

A(0) = 7.556358 VL = 1.32412
A(1) = -5.917261 VU = 1.69812
A(2) = 0.237238
A(3) = 0.334636
A(4) = -0.058642
A(5) = -0.019929
A(6) = -0.020715
A(7) = -0.014814
A(8) = -0.008789
A(9) = -0.008554

12.0 to 24.5 K

A(0) = 17.304227 VL = 1. 11732
A(1) = -7.894688 VU = 1.42013
A(2) = 0.453442
A(3) = 0.002243
A(4) = 0.158036
A(5) = -0.193093
A(6) = 0.155717
A(7) = -0.085185
A(8) = 0.078550
A(9) = -0.018312
A(10) = 0.039255

24.5 to 100.0 K

A(0) = 71.818025 VL = 0.923174
A(1) = -53.799888 VU = 1.13935
A(2) = 1.669931
A(3) = 2.314228
A(4) = 1.566635
A(5) = 0.723026
A(6) = -0.149503
A(7) = 0.046876
A(8) = -0.388555
A(9) = 0.056889
A(10) = -0.116823
A(11) = 0.058580

100 to 475 K

A(0) = 287.756797 VL = 0.079767
A(1) = -194.144823 VU = 0.999614
A(2) = -3.837903
A(3) = -1.318325
A(4) = -0.109120
A(5) = -0.393265
A(6) = 0.146911
A(7) = -0.111192
A(8) = 0.028877
A(9) = -0.029286
A(10) = 0.015619

PROGRAM 1. BASIC subroutine for evaluating the temperature T from the Chebychev series using equations (1) and (3). An array Tc(Ndegree) should be dimensioned.

```
100     REM Evaluation of Chebychev series
110     X= ((V-VL)-(VU-V))/(VU-VL)
120     Tc(0) = 1
130     Tc(1) = X
140     T = A(0) + A(1) *X
150     FOR I = 2 to Ndegree
160     Tc(I) = 2*X*Tc(I-1)-Tc(I-2)
170     T = T + A(I) *Tc(I)
180     NEXT 1
190     RETURN
```

PROGRAM 2. BASIC subroutine for evaluating the temperature T from the Chebychev series equations (1) and (4). ACS is used to represent the arccosine function.

```
100     REM Evaluation of Chebychev series
110     X = ((V-VL)-(VU-V))/(VU-VL)
120     T = 0
130     FOR I = 0 to Ndegree
140     T = T + A(I)*COS(I*ACS(X))
150     NEXT I
160     RETURN
```

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