Manual

CBT Sensor H3L3

v1.0

This manual describes the handling and assembly of CBT sensor provided by Aivon Oy, Finland.

Further information:

Aivon Oy
Tietotie 3, FI-02150 Finland
tel. +358-400-265501
email: info@aivon.fi

Updates to this manual found at: www.aivon.fi

This manual applies to the following products:

Sensor type	Description	Temperature range
(C1) H3L3	CBT sensor unit, no magnet, bobbin, Cu screw	40 mK[&] – 1 K
(C1) H3L3m	CBT sensor unit, magnet, bobbin, Cu screw *	40 mK[&] – 1 K

*=neodymium magnet, diameter 5 mm, height 2 mm, theoretical maximum holding strength 0.65 kg, max. temperature 80 C. The sensor H3L3m is used in cryogenic setups without external magnetic field or with field less than 50 mT. Sensor H3L3 is used when the cryostat is exposed to external magnetic field larger than 50 mT.

[&]=lowest temperatures achievable only with properly thermalized and filtered wiring.

Drawings

Dimensional drawings can be found in Appendix I at the end of this manual.

Figure 1: The sensor H3L3 consists of two gold-plated copper parts, lid and holder. From left to right: Opened sensor, sensor H3L3, sensor H3L3m with magnet, and bobbin B1. The sensor wire is 30-cm long phosphor bronze twisted pair.

Unpacking and handling

The sensor is delivered in ESD (**E**lectro**S**tatic **D**ischarge) package to prevent the sensor from electrostatic shocks. After removal from the original package the sensor should always be handled carefully taking into account proper **ESD practices** such as grounded wrist wraps, shoes, desks, tools, etc.

The sensor H3L3m contains strong permanent magnet on top of the sensor package. Due to magnetic forces the sensor can move suddenly if magnetic objects e.g. tools are in close proximity. Please use **nonmagnetic or plastic tools** when working with these sensors.

Please keep the package in case you need to transport or return the sensor.

The user is encouraged to measure the room-temperature resistance of the sensor from the loose wire ends of the twisted pair sensor wire. **Use measuring current not exceeding 0.01 mA. Make also sure that you do not expose the sensor to voltages exceeding 5 V.** If the resistance is not between 40 kOhm – 70 kOhm, please contact Aivon.

Do not open the sensor. Warranty is not valid if the cover is removed. If the lid detached from the holder, please attach it carefully on top of the holder and observe that the wire is fed thru one of the grooves on the lid. Contact Aivon for further assistance and possible replacement.

Assembly

Clean the surfaces and apply suitable thermally conducting paste such as Apiezon N to improve thermal contact between sensor and substrate. Attach the sensor with a M4 screw to the substrate. A copper screw is provided. Also other screw materials can be used provided that thermal contraction is taken into account.

In order to improve thermal anchoring of the 30-cm long sensor wire, the user should attach bobbin B1 either on top of the sensor (using same mounting hole and screw) or nearby the sensor. The wire should be tightly wrapped around the bobbin and attached using varnish or suitable epoxy (e.g. Stycast).

Solder the loose end of the sensor wire to your setup using standard lead-free or leaded solder using temperature not exceeding 320 degrees C for short time not exceeding few seconds.

Wiring recommendations

All sensors need only two wires to measure the resistance. The sensor resistance is approximately 60 kOhms and thus a 100-Ohm wiring resistance yields only 0.17 % error in resistance reading. Obviously, the wiring resistance can be compensated to make error even smaller. You can also make four-wire measurements by attaching two wires per one sensor wire by soldering.

If properly mounted by the user, the sensor described in this manual cover temperature range 40 mK – 1 K.

Ultra low temperature operation

If the sensor is operated below 100 – 200 mK, poor wiring can prevent the sensor from following the cryostat temperature. Thus it is recommended that the wiring has the following properties:

- **thermal anchoring**. The sensor twisted pair is not thermally anchored. Thus, the user must thermalize the wiring to the same temperature stage that is being measured by the sensor. The use of bobbin B1 is recommended (see Assembly)

- **rf filtering**. At lowest temperatures, a tiny radio frequency (rf) power can heat up the sensor and give incorrect readings. It is thus recommended to ensure rf tightness of the whole cryostat. It means that all room temperature connectors have to be filtered at radio frequencies. It might be important to use auxiliary low temperature filters such as powder filters close to the sensor.

One possibility to arrange adequate wiring is to use so-called thermocoax (www.thermocoax.com). In this case thermocoax cable is fed from room-temperature rf tight connector down to lowest temperatures. The cable should be thermally anchored in several stages to ensure negligible heating power along the cable to the sensor. A good overview of the wiring techniques is found in Ref. 5.

<u>Low temperature operation above 200 mK.</u>
At higher temperatures the requirements for wiring are less stringent. A moderately thermally anchored (to e.g. 4K, 1K and sample temperature) twisted pair is adequate. Suitable resistive materials for twisted pair wire are phosphor bronze, constantan or manganin. Also rf filtering can be lighter. Noise heating of 4 pW at 200 mK would imply an error less than 1% from the actual temperature.

Operation

The operation of Coulomb Blockade Thermometer is based on tunneling of current-carrying electrons in small metallic tunnel junctions or arrays of junctions [1]. The differential conductance depends on voltage bias and electron temperature of the sensor as depicted in Figure 2, where the conductance is normalized by G_T, the conductance at high bias voltages (G_T ~ (60 kOhm)$^{-1}$).

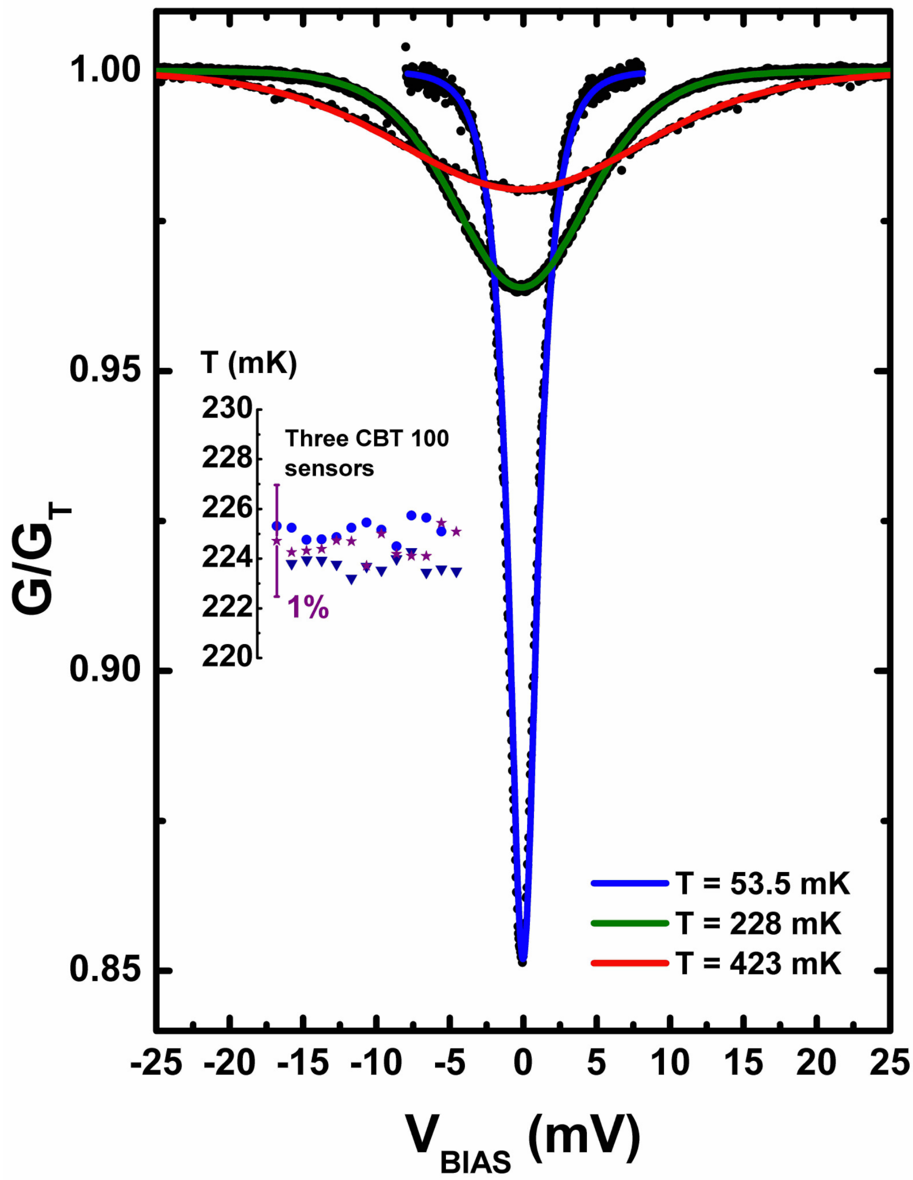

Figure 2: Normalized conductance curves at different temperatures. Fits are based on full theory (Ref. 4.)

It has been shown [1] that the full width at half maximum $V_{½}$ of the conductance curve is proportional to temperature by

$$V_{½} = 5.439 \times N k_B T / e,$$

where N=100 is the number of series tunnel junctions in the array, Boltzmann constant $k_B = 1.38x\ 10^{-23}$, and electron charge $e = 1.609 \times 10^{-19}$ C. This equation is valid within 5% at temperatures above 40 mK. Thus, by measuring the full width $V_{½}$ one obtains primary temperature T_{pri} from

$$T_{pri} = eV_{½} / (5.439 \times N k_B) = 21.44 \times V_{½}\ [K/V].$$

The normalized depth of the conductance curve dip $g = G_0/G_T$ at zero bias voltage is inversely proportional to temperature,

$$g = Cal / T,$$

where Cal is a sensor-specific calibration constant. By once measuring the primary temperature T_{pri} and the corresponding dip depth $g_{pri} = G_0/G_T$ at the same temperature, one can obtain unknown temperature T by measuring g and using the following equation:

$$T = T_{pri} \times g_{pri}/g.$$

Since G_T depends only slightly on temperature one can make fast measurements on temperature T_{fast} by measuring the zero-bias conductance G_0 only and by using the equation

$$T_{fast} = T_{pri} \times G_{0pri}/G_0,$$

where G_{0pri} is G_0 measured at T_{pri}. The above formula is accurate if the temperature T_{fast} does not deviate too much from the previously obtained T_{pri}. The advantage of measuring only the zero-bias conductance instead of full conductance curve is that it heats the sensor several orders of magnitude less due to absence Joule heating from dc voltage bias.

Further studies of the theory and measurements on CBT's are found in references [2] – [3] in the References section of this manual.

Practical instructions

A) The operation of the sensor is based on normal-state electron transport. If you are using sensor without magnet H3L3 please apply an external magnetic field when the temperature is below the superconducting transition temperature of aluminum (~ 1K).

B) To obtain reliable G_T, use wide enough sweep for dc voltage bias. A rule of thumb: $-2.5 \times V_{½} < V_{dc} < 2.5 \times V_{½}$. Use figure 2 to estimate the voltage bias range needed.

C) To measure the conductance dip accurately, use small enough ac excitation (probe) voltage. A rule of thumb: $V_{ac} < V_{½}/10$. Use figure 2 to estimate the ac voltage needed. Too small probe voltage yields noisy readings.

References

[1] J. P. Pekola, K. P. Hirvi, J. P. Kauppinen, and M. A. Paalanen, Thermometry by Arrays of Tunnel Junctions, Phys. Rev. Lett. 73, 2903 (1994).

[2] K. P. Hirvi, J. P. Kauppinen, A. N. Korotkov, M. A. Paalanen, and J. P. Pekola, Arrays of normal metal tunnel junctions in weak Coulomb blockade regime, Appl. Phys. Lett. 67, 2096 (1995).

[3] J. P. Pekola, J. K. Suoknuuti, J. P. Kauppinen, M. Weiss, P. v. d. Linden and A. G. M. Jansen, Coulomb Blockade Thermometry in the Milli-Kelvin Temperature Range in High Magnetic Fields, Journal of Low Temperature Physics, Vol. 128 (5-6), (2002).

[4] M. Meschke, J. P. Pekola, F. Gay, R.E. Rapp, and H. Godfrin, Electron thermalization in metallic islands probed by Coulomb blockade thermometry, Journal of Low Temperature Physics, Vol. 134, 1119 (2004).

[5] F. Pobell, Matter and Methods at Low Temperatures, 3rd Edition, Springer-Verlag.

Appendix I: Drawings and dimensions

(All drawings and dimensions are subject to change without prior notice.)