Sensors for precision thermometry in the range from < 10 mK to 8 K

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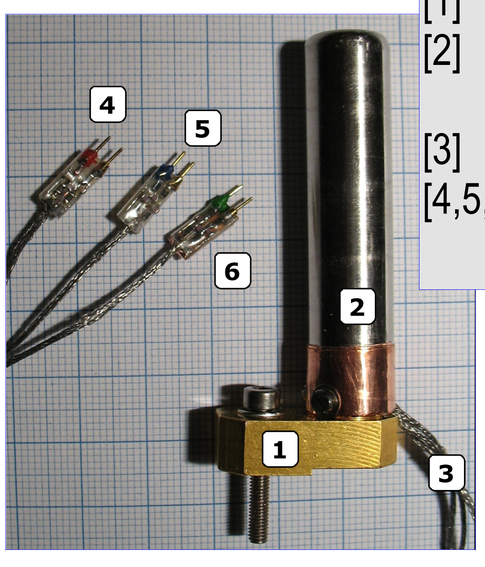
Introduction

The SRD1000 sensor offers up to 13 superconductive reference points for precision thermometry on the PLTS-2000 and ITS-90 in the range from 15 mK to 8 K.
A CMN1000 sensor was developed to support continuous thermometry in the range from < 10 mK to 3 K alongside the SRD1000.
The MIDS20x series of mutual inductance detection electronics allows precision reading of both types of sensors.

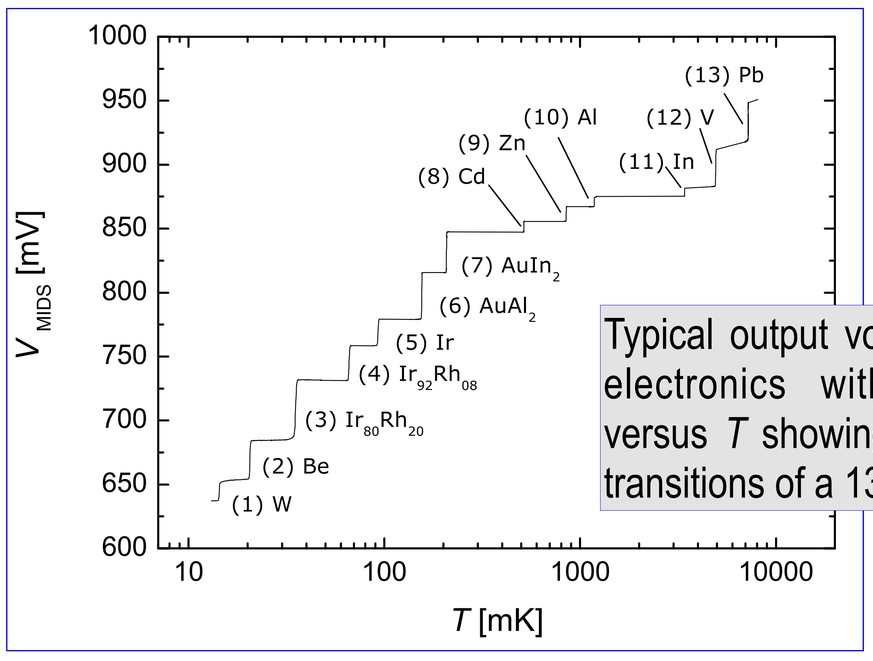
SRD1000 superconductive reference point sensor



Constructional details:
[1] thermal plate / mounting adapter;
[2] sensor body with Cryoperm / Nb magnetic shielding;
[3] shielded twisted pair leads;
[4,5,6] connections with rf-filters of the primary, secondary and field compensation coils.

#	material	T_C [mK]	W_C [mK]	U_C [%]
1	W	15	< 0.2	< 0.26
2	Be	21	< 0.3	< 0.28
3	$Ir_{80}Rh_{20}$	30	< 0.5	< 0.34
4	$Ir_{92}Rh_{08}$	65	< 0.5	< 0.16
5	Ir	98	< 0.5	< 0.10
6	$AuAl_2$	145	< 0.5	< 0.06
7	$AuIn_2$	208	< 1	< 0.10
8	Cd	520	< 1	< 0.04
9	Zn	850	< 2	< 0.05
10	Al	1180	< 4	< 0.06
11	In	3400	< 4	< 0.02
12	V	4900	< 20	< 0.08
13	Pb	7200	< 6	< 0.02

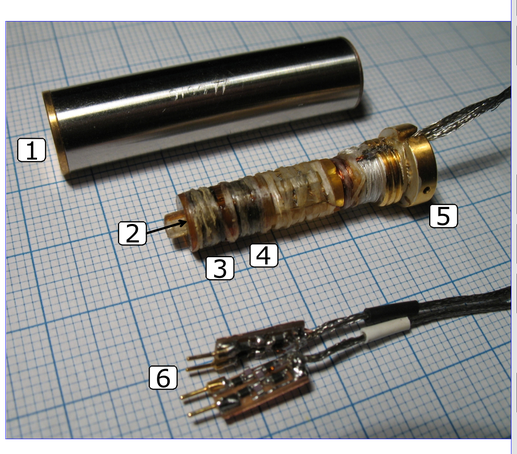
List of the reference points with typical values for:
- transition temperature T_C;
- width of the transition W_C;
- uncertainty of the realisation of the reference point U_C.



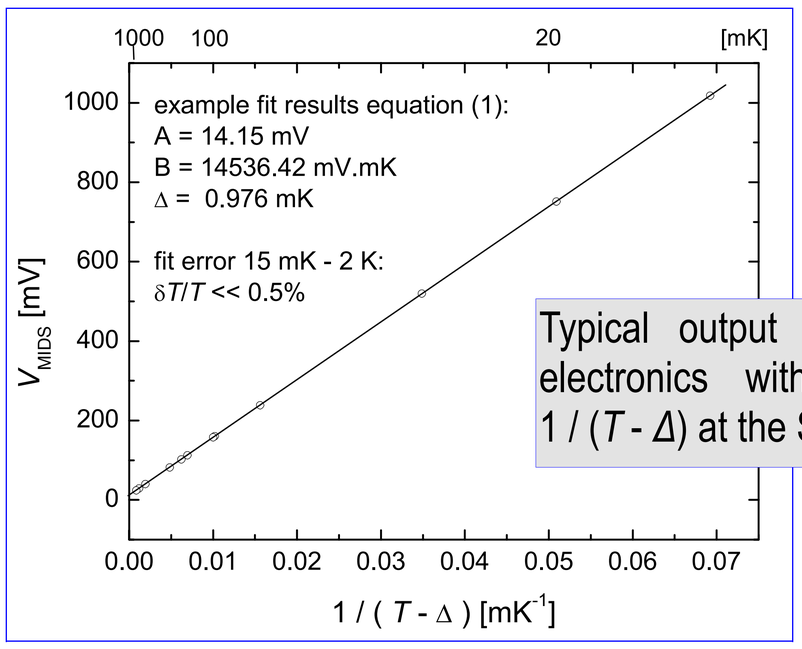
Typical output voltage of the MIDS20x electronics with SRD1000 sensor versus T showing the superconductive transitions of a 13-point sensor.

Recent developments and results:
- samples of In, V and Pb were characterized and implemented to support the range 3 K to 8K;
- three times better signal-to-noise ratio of the 15 mK W transition is achieved by focusing the magnetic flux of the detection coils;
- a gold-plated copper shield inside the Cryoperm shield improves the thermal and mechanical stability of the sensor on thermal cycling.

CMN1000 paramagnetic susceptibility sensor



Constructional details:
[1] protective cylinder with Nb shield;
[2] sealed capsule (ø 3 x 3 mm) with powdered cerium magnesium nitrate (CMN) sample and silver-foil thermal link;
[3] detection transformer;
[4] compensation transformer;
[5] base for mechanical and thermal connection;
[6] shielded twisted pair leads (primary and secondary coil connections) with rf-filtered terminals.



Typical output voltage of the MIDS20x electronics with CMN1000 sensor versus $1 / (T - \Delta)$ at the SRD1000 reference points.

Signal characteristics:
- the susceptibility X of CMN follows the Curie-Weiss law below approximately 3 K: $X_{CMN} \sim C / (T - \theta)$, with C the Curie-constant and T the temperature; θ is related to the magnetic ordering temperature of CMN at around 1.8 mK;
- the output voltage V_{MIDS} of the MIDS20x electronics is proportional to the susceptibility X, so approximately: $V_{MIDS}(T) = A + B / (T - \Delta)$ (1);
- constants A, B and Δ of (1) need to be calibrated for each sensor.

Recent developments and results:
- span <10 mK to 3 K is covered within one range of the MIDS20x electronics;
- signal-to-noise related resolution varies between 4 mK at 2 K, 0.2 mK at 500 mK and << 10^{-4} mK below 10 mK;
- reproducibility is better than 0.5 % after cycles to room temperature;
- thermal relaxation time is < 5 s at 10 mK and smaller at higher temperatures;
- the sensor is well suited for temperature control down to < 10 mK.

Acknowledgements

We would like to thank the Fine Mechanics and Electronics departments of LION for their support in preparing essential parts of the sensors and measurement electronics. The Dutch Metrology Institute VSL generously supplied a calibrated RhFe thermometer and related instruments for the measurements above 3 K.

Further information

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