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Thermal Conductivity of CuCrZr Alloy

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Abstract

Non alloyed copper is widely used for construction of cryogenic devices where high thermal conductivity and low thermal capacity are needed. Mechanical properties of pure cooper are sometimes limiting for design or machining of mechanical parts. Using of copper alloys is often restricted by unavailability of experimental data on thermal properties of these materials. We present measurement of thermal conductivity of CuCrZr alloy in the temperature range 5 K up to room temperature. This material is commercially available and may be used as an alternative to the materials like tin bronze or brass. Studied material is characterized by its composition, state, Brinell hardness and measured RRR.

Motivation

The Group of cryogenic at the ISI Brno has long term experience in design and construction of cryogenic devices. The use of various materials is often conditioned by the knowledge of thermal conductivity at low temperature. Sometimes as we need to make parts with high thermal conductivity and good strength we choose to use as alternative to the pure copper and aluminium the chromium copper (CuCrZr). The using of this material in cryogenic was suggested by Woodcraft [1]. The CuCrZr is being applied used in nuclear fusion research [2-5] at high temperatures.

Alloy samples

Raw material

Supplier: Kovohute Rokycany a. s., Czech Republic

Samples: 1.5 mm wide strips were cut from a 0.8 mm cold rolled sheet.

The lengths of measured strips was 200 mm.

Thermal treatment

Chromium copper is precipitation hardening alloy.
CuCrZr-X - as received from the producer in hardened state
CuCrZr-A - solution annealing at 980°C
CuCrZr-H - hardening (annealing, rapid cooling, ageing at 480°C)
Thermal treatment was done in He atmosphere to avoid oxidation .

Application of CuCrZr

Fig. 1 Sample holder
Threads M8, M3, M1.6,
lapped backside

Tab. 1 Composition of the CuCrZr alloy (from supplier's certificate)

Cr	Zr	Fe	Si	Cu
0.71 %	0.23 %	0.01%	0.02 %	Balance

Tab. 2 Measured Brinell hardness and electrical properties of the samples

	Units	**CuCrZr-X**	**CuCrZr-A**	**CuCrZr-H**
Brinell hardness	HB	236	56	128
Electrical resistivity ρ (at 295 K)	Ω.m	$2.30\ 10^{-8}$	$5.26\ 10^{-8}$	$2.22\ 10^{-8}$
Electrical resistivity ρ_0 (at 4.2 K)	Ω.m	$4.56\ 10^{-8}$	$3.61\ 10^{-8}$	$4.48\ 10^{-8}$
RRR = ρ / ρ_0 referred to 300K	1	5.04	1.46	4.95

Device

Design based on [6].

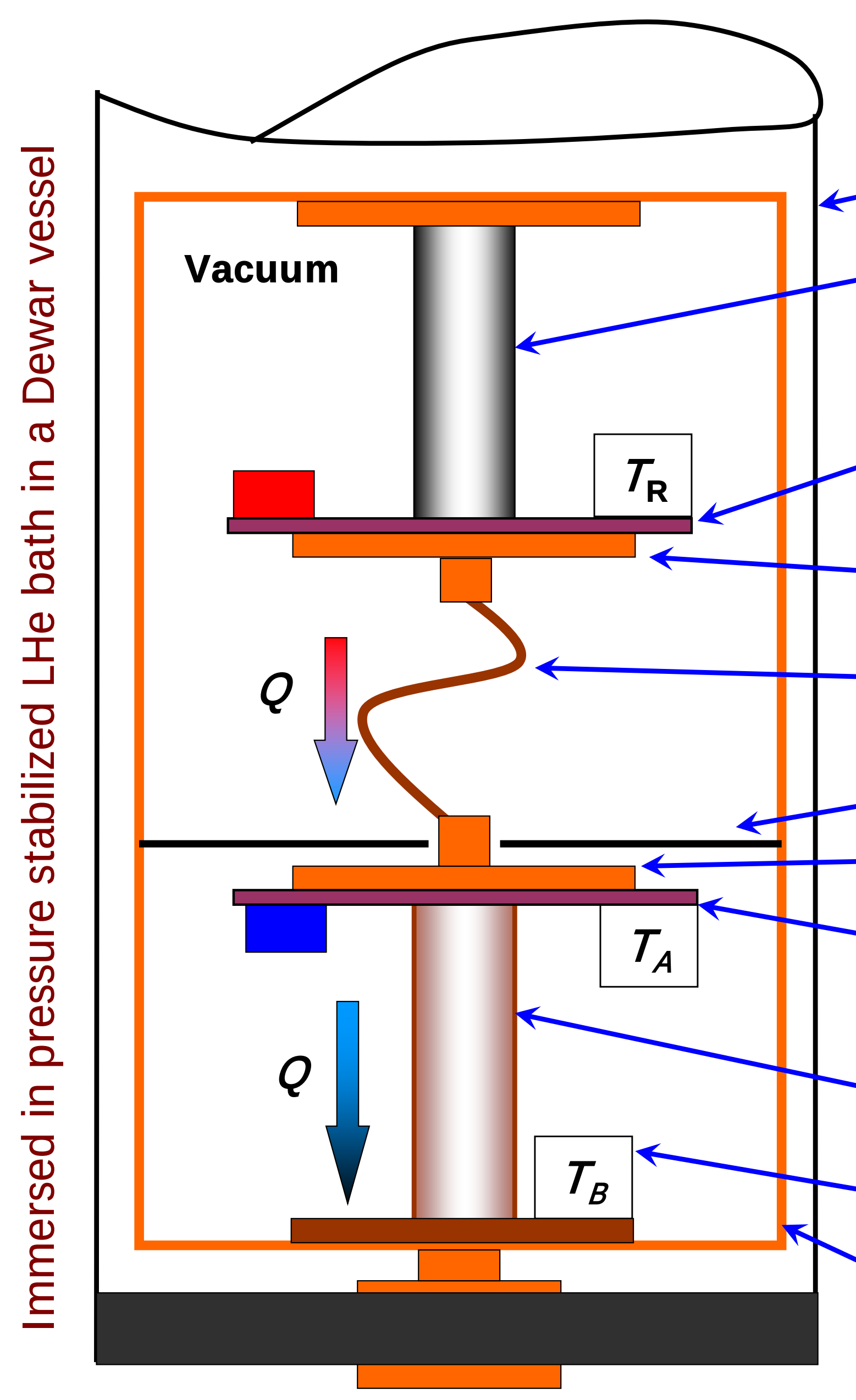

Fig. 2 Schema of the measurement chamber

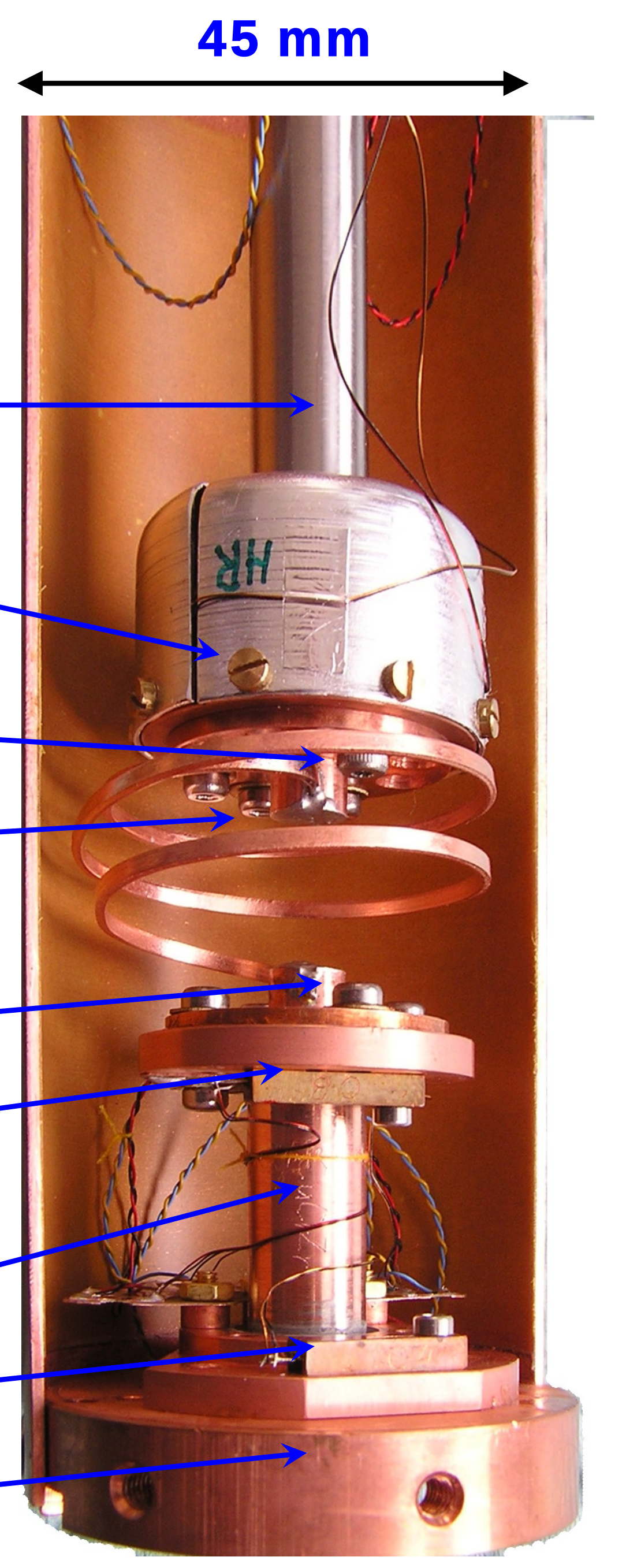

Fig. 3 Measurement chamber opened

Calibration of thermal resistor

Calibration proceeds without sample.

Stepwise heating of the upper end of the thermal resistor.

The temperatures T_A, T_B and electric power are measured in steady states and calibration curve Q (T_A-T_B) of the thermal resistor is created.

Thermal conductivity measurement

Stepwise changing of the temperature of the sample upper end (T_R).

Temperatures T_R, T_A and T_B are recorded and from the calibration curve of the thermal resistor the heat flow Q transferred trough the sample is evaluated.

Test measurement

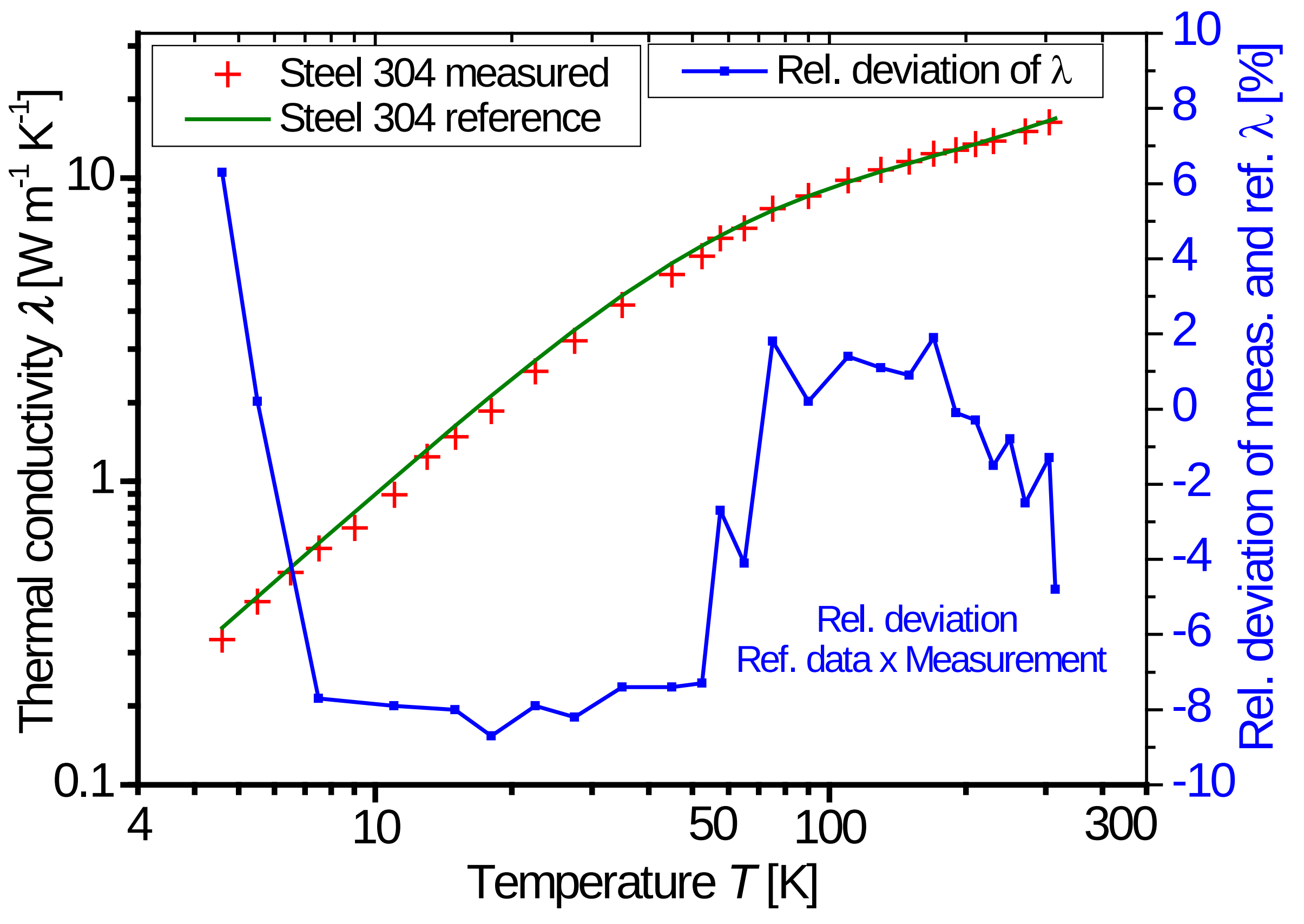

Fig. 4 Test measurement of stainless steel (bar D=3 mm, L =43 mm). Reference data from [7]

Results

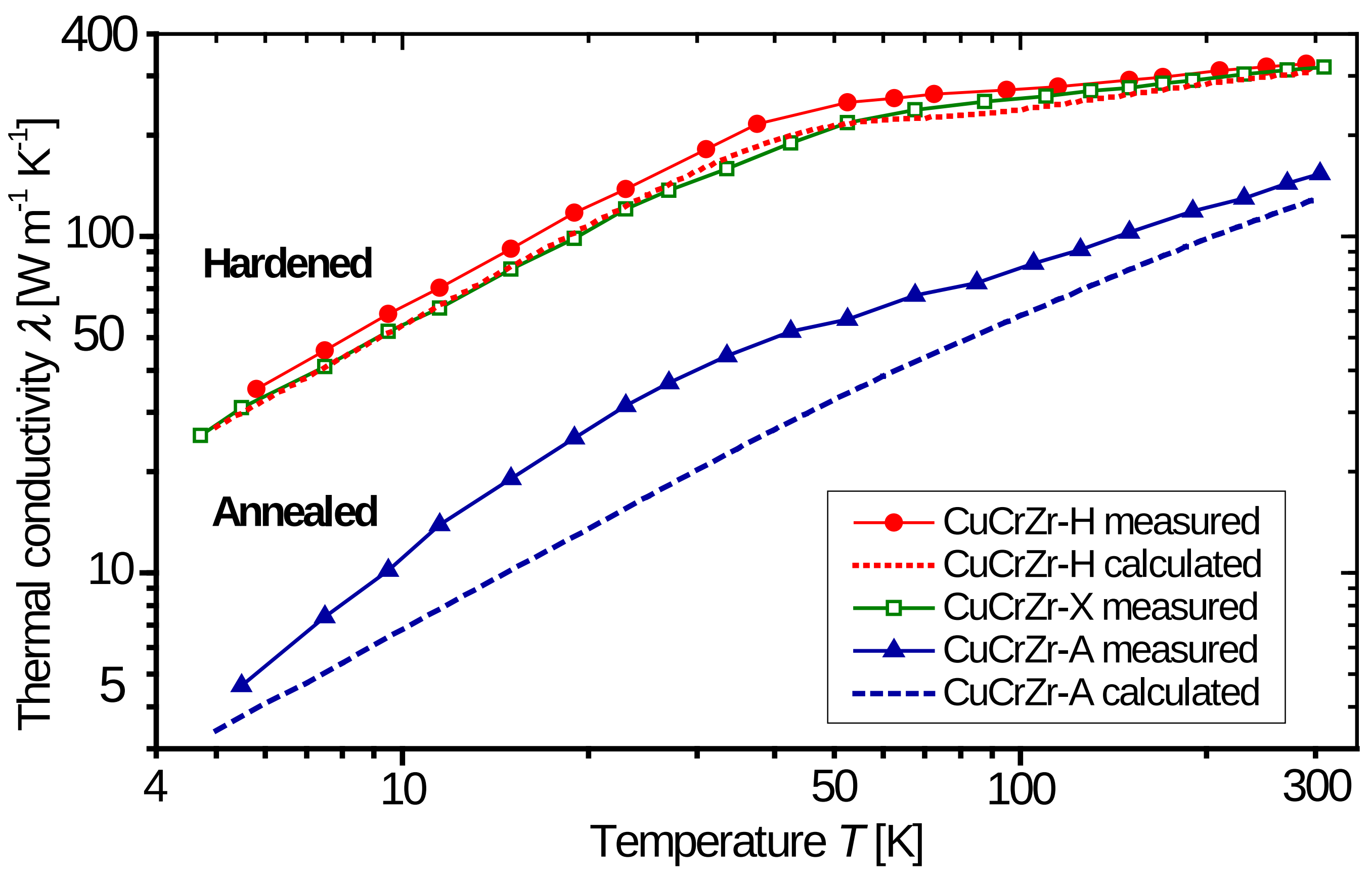

Fig. 5 Measured and calculated [8] *thermal conductivity of CuCrZr*

Comparison

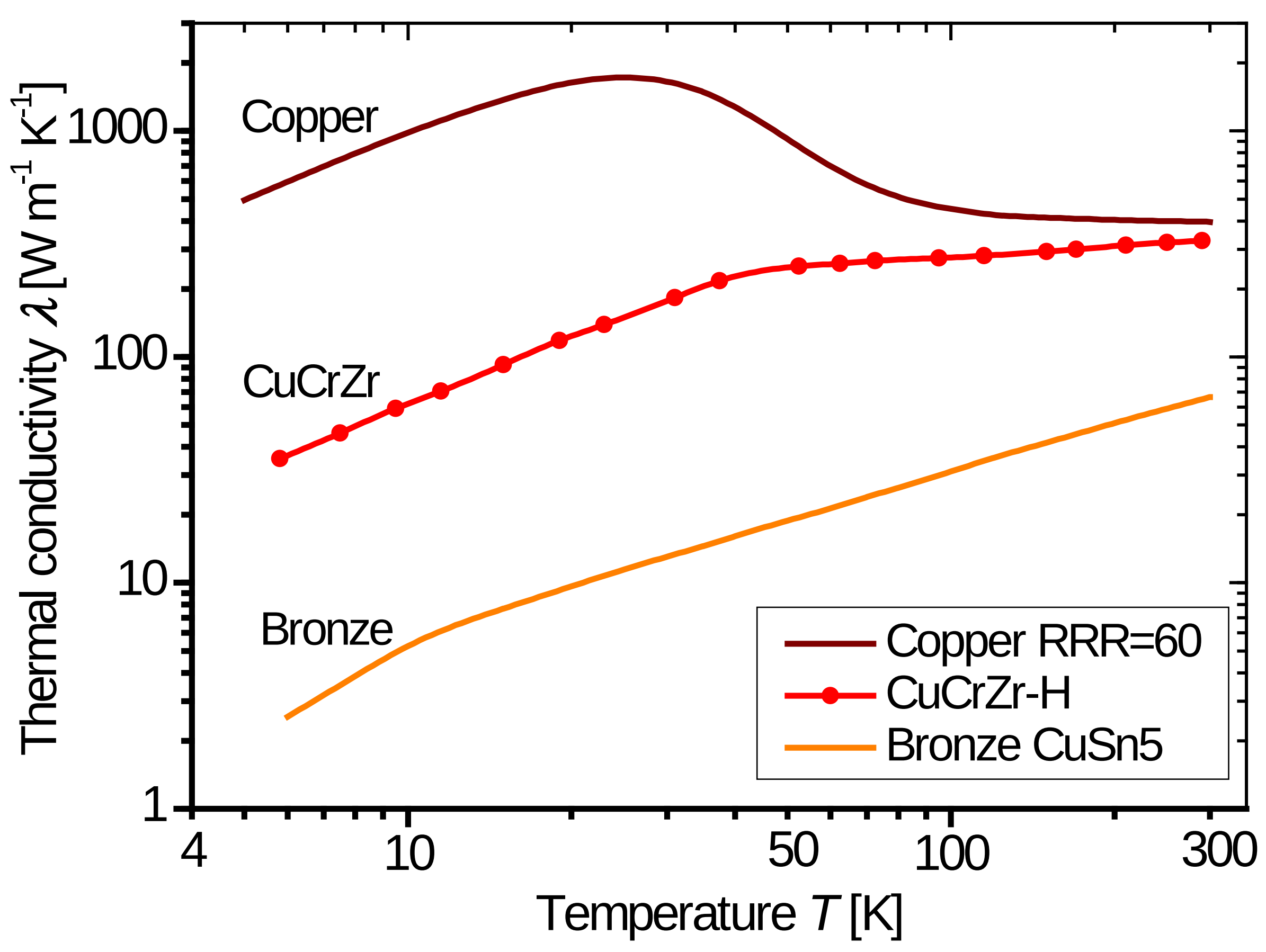

Fig. 6 Thermal conductivity of CuCrZr, Cu and Bronze

Evaluation

The thermal conductivity integral $K(T_A, T_R)$, derived from the Fourier law (1), is measured as (2). The integral is calculated from measured data in every measurement point.

If the T_A is kept constant, the thermal conductivity is estimated by differentiation of $K(T_A, T_R)$ with respect to the T_R (3).

In this measurement the temperature T_A rises slightly as the T_R rises.

With good thermal contacts and T_B constant, the second term in equation (3) doesn't exceed 1 % of the measured conductivity.

$$Q = A\lambda(T)\frac{\mathrm{d}T}{\mathrm{d}x} \qquad (1)$$

$$K(T_A, T_R) \equiv \int_{T_A}^{T_R} \lambda(T)\,\mathrm{d}T = Q\frac{L}{A} \qquad (2)$$

$$\frac{\mathrm{d}}{\mathrm{d}T_R} K(T_A, T_R) = \lambda(T_R) - \lambda(T_A)\frac{\mathrm{d}T_A}{\mathrm{d}T_R} \qquad (3)$$

Calculation from electrical conductivity

Fig. 5 shows thermal conductivity of CuCrZr calculated from the electric resistance measured at 4.2 K. Formula based on physical models of electric and thermal conductivity elaborated by Hust [8] was used.

Conclusions

Precipitation hardened CuCrZr alloy represents an alternative to copper in that cases, where higher mechanical properties and also sufficiently high thermal and electrical conductivity are required. Mechanical properties of precipitation hardened CuCrZr are higher than those of copper and approximately equivalent to those of tin bronze.

By comparison to tin bronze, the studied CuCrZr alloy has thermal conductivity an order of magnitude higher. Observed stability of thermal conductivity of hardened CuCrZr during several thermal cycles
(4 K - 300 K) was better than 2 %.

We tried to verify the Woodcraft's [1, 9] idea to assess the thermal conductivity of precipitation hardened copper alloys from the electrical properties. Thermal conductivity of the hardened CuCrZr alloy predicted from its 4.2 K electrical resistivity agreed with the measured conductivity within 14 % over a temperature range from 5 K to 300 K.

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Acknowledgement

The work was supported by the Grant Agency of the Academy of Sciences of the Czech Republic under grant No. IAA100650804 and by Academy of Sciences of the Czech Republic under grant No. AV0Z20650511.