New smart instrument for thermal characterization of materials

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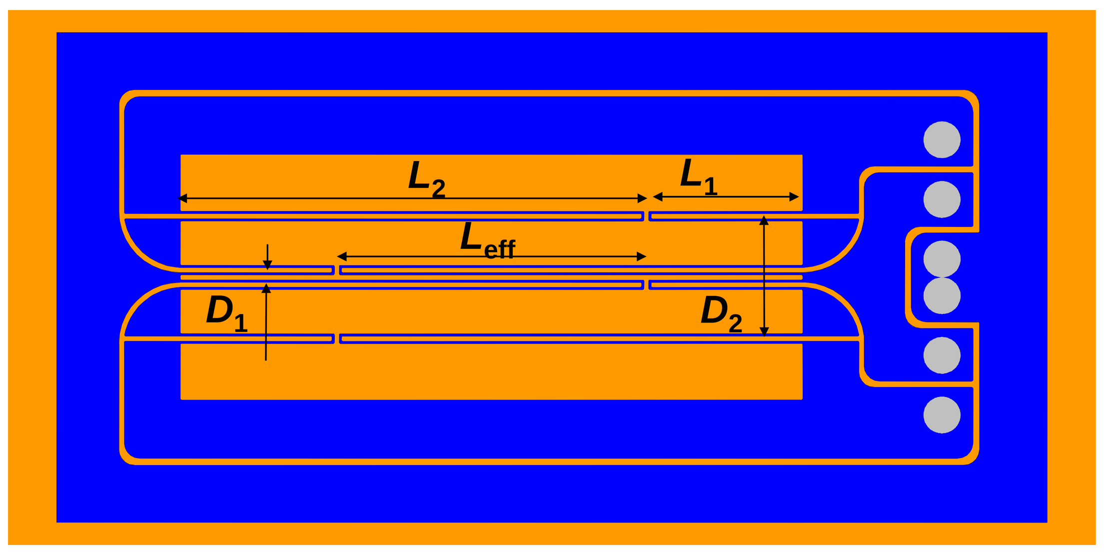
How does it work?



THB-Sensor consists from 5 µm nickel pattern, that is sandwiched between polyimide foils (25 µm Kapton®) and build substantially four hot strips.

It is basically Transient Hot Strip (THS) technique. The Transient Hot Bridge (THB) Sensor makes simultaneously eight THS- experiments and compares their signals by means the Wheatstone bridge circuit of the strips.

The difference of the temperature rises between inner and outer strips is

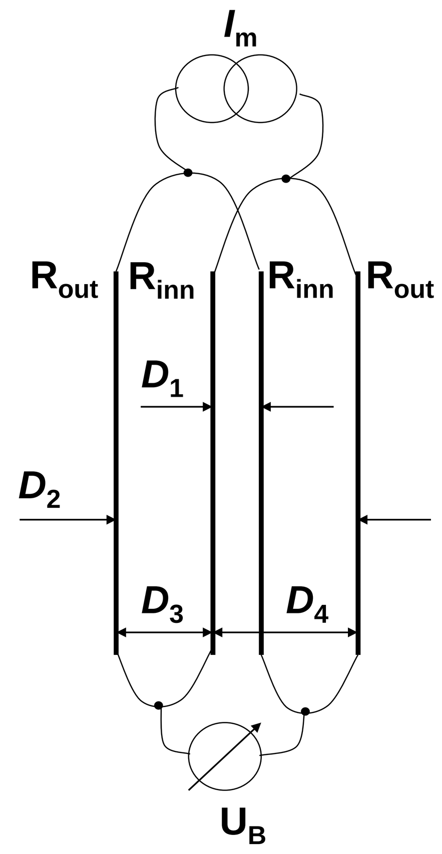
$$\Delta T = T_{inn} - T_{out}$$

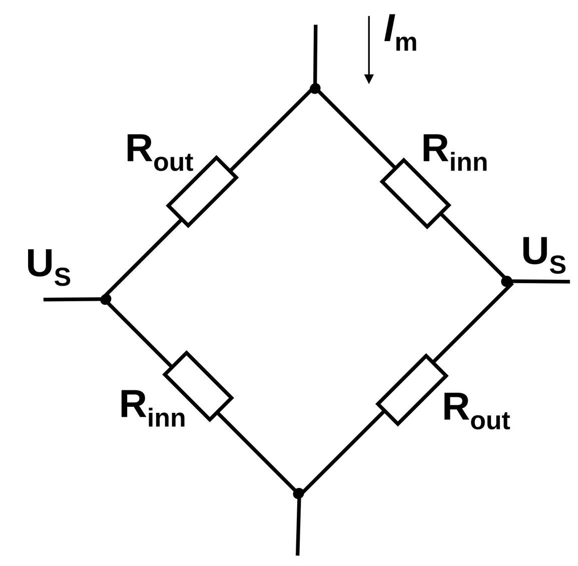
where the temperature rise on the inner and outer strips are the sum of the self heating and from other strips with distance D_i

$$T_{inn} = T(D_0) + T(D_1) + T(D_3) + T(D_4)$$

$$T_{out} = T(D_0) + T(D_2) + T(D_3) + T(D_4)$$

Finally is $$\Delta T = T(D_1) - T(D_2)$$





Each hot strip consists of a short and long segment, the length L_1 or L_2. The eight segments of the strips are connected in the Wheatstone Bridge against each other so, that each of the voltage drop of a long segment is reduced to those of a short. The output signal Us of the sensor with supply current I_m is formed only from the middle segment of the four stripes. Their effective length is $L_{eff} = L_2 - L_1$, and the associated effective electrical resistance is R_{eff} with temperature coefficient α.

$$Us = \frac{R_{eff} \cdot I_m \cdot \alpha \cdot \Delta T}{2}$$

Easy data reduced signal evaluation including the measurement uncertainty assessment

The temperature rise in a medium with thermal conductivity λ and diffusivity a at the distance D from a linear heat source with constant rate q per unit time and length is described as:

$$T(t) = -\frac{q}{4 \cdot \pi \cdot \lambda} \mathrm{Ei}\left(-\frac{D^2}{4 \cdot a \cdot t}\right)$$

Hence the temperature difference as function of time is

$$\Delta T(t) = \frac{q}{4 \cdot \pi \cdot \lambda}\left[\mathrm{Ei}\left(-\frac{D_2^2}{4 \cdot a \cdot t}\right) - \mathrm{Ei}\left(-\frac{D_1^2}{4 \cdot a \cdot t}\right)\right] = \frac{q}{4 \cdot \pi \cdot \lambda} \cdot f(t)$$

where $$q = \frac{R_{eff}}{L_{eff}} \cdot \left(\frac{I_m}{2}\right)^2$$

Substitute the expressions for q and ΔT in the equation for THB-signal Us we can write

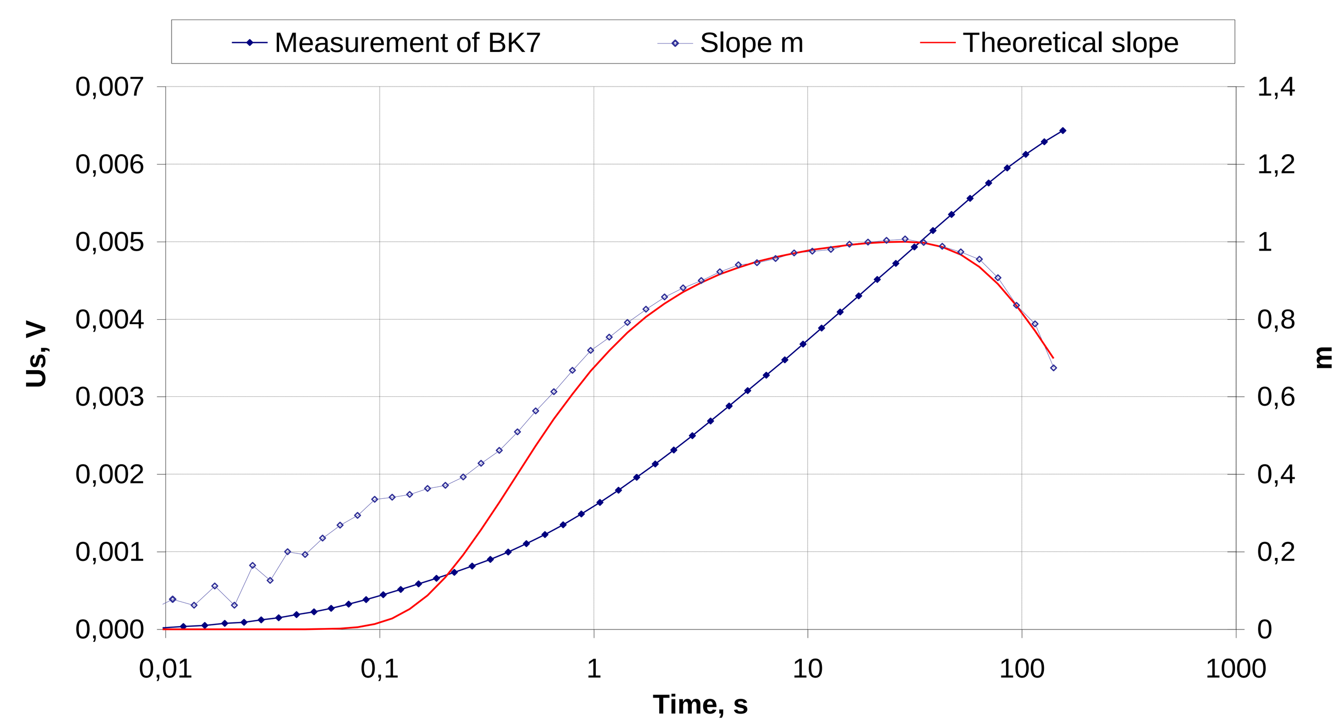
$$Us(t) = \frac{R_{eff}{}^2 \cdot \alpha}{4 \cdot \pi \cdot L_{eff} \cdot \lambda} \cdot \left(\frac{I_m}{2}\right)^3 \cdot f(t) = K_U \cdot f(t)$$

The factor K_U for dimensionless function $f(t)$ depend on sensor parameters, current value and thermal conductivity of sample.

If the signal is recorded with increasing by constant factor f^* integration time, the signal rise dUs can be described as

$$\ln(t_{i+1}) - \ln(t_i) = \ln\left(\frac{t_{i+1}}{t_i}\right) = \ln(f^*) = \mathrm{const}$$

$$\mathrm{d}Us(t) = K_U \cdot \frac{\mathrm{d}f(t)}{\mathrm{d}\ln(t)} = K_U \cdot \left[\exp\left(-\frac{D_1{}^2}{4 \cdot a \cdot t}\right) - \exp\left(-\frac{D_2{}^2}{4 \cdot a \cdot t}\right)\right] = K_U \cdot m(t)$$



The measurement was made with Keithley® Source Meter K2612

The function $m(t)$ has maximum m_{max}, that depend only on sensor parameters D_1, D_2 .
It can be used to estimate simultaneously the thermal conductivity and diffusivity of the sample.

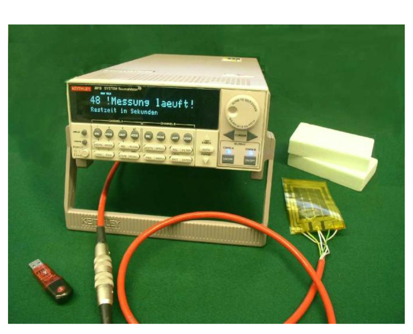
$$\lambda = \frac{\alpha \cdot R_{eff}{}^2 \cdot \ln(f^*)}{4 \cdot \pi \cdot L_{eff} \cdot \mathrm{d}(Us)_{max}} \cdot \left(\frac{I_m}{2}\right)^3 \cdot m_{max} \qquad a = \frac{D_2^2}{4 \cdot t \cdot \ln\left(\frac{1}{1-m}\right)} \quad \text{for} \quad \exp\left(-\frac{D_1{}^2}{4 \cdot a \cdot t}\right) << 1$$

Experimental results

			Polystyrene foam	Plexiglass (PMMA)	Glycerol	Watter	Glass BK7	Stainless steel (1.4301)
THB- Instrument	λ	$(Wm^{-1}K^{-1})$	0,0320 ± 3%	0,196 ± 3%	0,285 ± 3%	0,610 ± 3%	1,09 ± 3%	14,3 ± 8%
	a	(mm^2s^{-1})	0,6 ± 10%	0,12 ± 10%	0,10 ± 10%	0,14 ± 10%	0,56 ± 10%	3,8 ± 10%
Literature values	λ	$(Wm^{-1}K^{-1})$	0,031	0,195	0,286	0,605	1,09	14,7
	a	(mm^2s^{-1})	0,65	0,118	0,095	0,14	0,55	3,75

The measurements uncertainty is evaluated on GUM rules with k = 2

Advantages



- ⇨ Measurement of fluids and solids including anisotropic
- ⇨ No special knowledge and skills need for use
- ⇨ Simply arithmetic signal evaluation without PC
- ⇨ Short measurement time from 10 second to a few minutes
- ⇨ Conventional mass production method for THB-Sensors

- ⇨ Robust film sensor for any industrial application
- ⇨ Lowest possible own thermal capacity of the sensor
- ⇨ Simultaneously control of the sample temperature and drift
- ⇨ Excellent the signal to noise ratio value with conventional electronic
- ⇨ Recognition of disturbances: bad thermal contact and temperature instability

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