Membrane-based calorimetry for studies of sub-microgram samples

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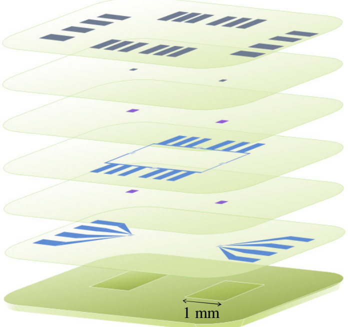
Motivation: development of a tool for thermal studies of mesoscopic samples



6. Al bonding pads
5. Al thermalization layer, 20 nm
4. AlO_x insulation layer, 70 nm
3. Temperature sensor: Ti meanders in bridge configuration, 55 nm
2. AlO_x insulation layers, 55 nm
1. Heaters: Ti resistive meanders, 45 nm
0. Silicon frame with pre-etched dual Si_3N_4 membranes (100 nm)

Use of thin films and membranes:

- low background heat capacity (~nJ/K)
- low thermal conductance (~μW/K)

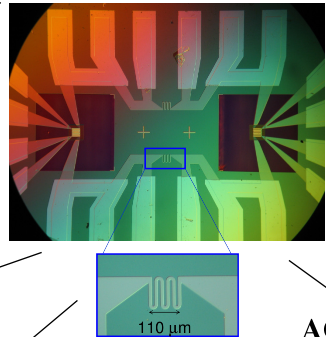
Robust heater and bridge configuration:

- ultrafast temperature control

Advantages

Experimental methods

Layout



Fabrication

- Double layer resist technique
- Photolithography
- E-beam evaporation
- Lift-off (no ultrasound!)

Experimental setup

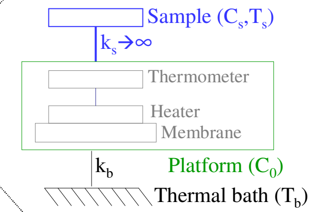
Instantaneous calibration

T_{offs} → 100K

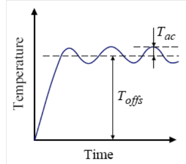
Relaxation

AC steady state

Ac steady state method



- Heater with power: $P(t) = P_{dc} + P_0(1-\cos 2\omega t)$
- Sample temperature: $T_s(t) = T_b + T_{offs} + T_{ac}(t)$



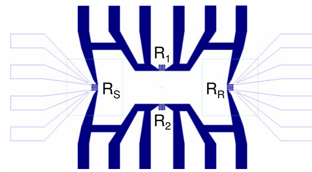
$$T_{offs} = \frac{P_0}{k_b},\ \tau_{ext} = \frac{C_s + C_0}{k_b}$$

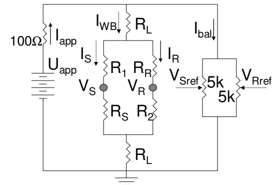
$$T_{ac}(t) = \frac{T_{offs}}{\sqrt{1+(2\omega\tau_{ext})^2}}\sin(2\omega t + \phi)$$

Relaxation method

- Constant power P_0 applied to the heater and turned off $\rightarrow T(t) = T_0 + \Delta T\exp(-t/\tau_{ext})$

Resistance thermometer in bridge configuration:





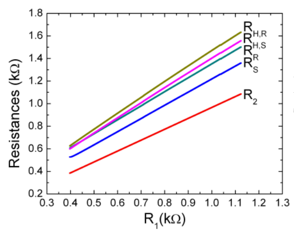
R_S, R_R → T_{offs}

R_1, R_2 → T_{base}

$$U_S^{ac} = V_S - V_{Sref} \rightarrow T_S^{ac} = \frac{U_S^{ac}}{I_S^{dc}\cdot dR_S/dT}$$

$$I_S^{ac/dc} = \frac{I_{WB}^{ac/dc}}{1+\gamma(U_2/U_1)^{ac/dc}},\quad \gamma = (R_1/R_2)|_{RT}$$

Linear beahavior or each resistive meander vs R1



→ Only needed:

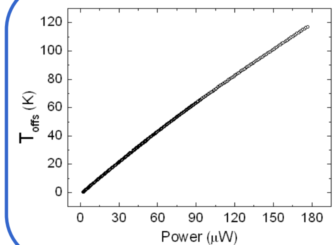
$R_1(T)$, $R_x|_{T1}$ and $R_x|_{T2}$

R_x: all other resistances

T1, T2: two different temperatures

Sensitivity dlnR/dT

300 K	100 K	20 K
$3\cdot10^{-3}$ K^{-1}	$5\cdot10^{-3}$ K^{-1}	→0 K^{-1}



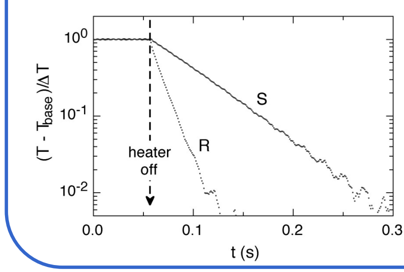
Strong heater:

- ultrafast temperature scanning
- Determination of:

$$k_b = 1/(dT_{offs}/dP)$$

<u>T_b= 68K</u>

High absolute accuracy

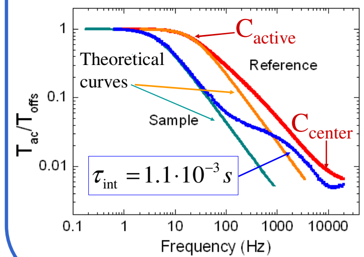


$$\tau_{ext}^S = 4.5\cdot10^{-2}s$$
$$\tau_{ext}^R = 1.36\cdot10^{-2}s$$

$$C_S = 60\ nJ/K$$
$$C_R = 18\ nJ/K$$

<u>T_b= 110K</u>

High resolution: sensitivity to small changes in C



C_{active}: frequency dependent area

C_{center}: 110x110μm^2

Theoretical curves obtained with:

$$\tau_{ext}^S = 3.6\cdot10^{-2}s,\ \tau_{ext}^R = 0.7\cdot10^{-2}s$$

<u>T_b= 68K</u>