# *Extraction Method for Thermal Resistance*

## *Bipolar-Arbeitskreis*
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# Outline

- Teststructures for temperature measurement
- Example
- Evaluation of recent RTH-extraction method
- Results
- Conclusions
- References

# Temperature Measurement

Dependent on the extraction method used different requirements arise:

- DUT and separate sensor
  - some distance from DUT
  - usually requires calibration
  - example : diode
- DUT merged with sensor
  - requires special layout
  - and calibration
  - see example
- DUT as sensor
  - uses regular device
  - best choice

# Example (1)

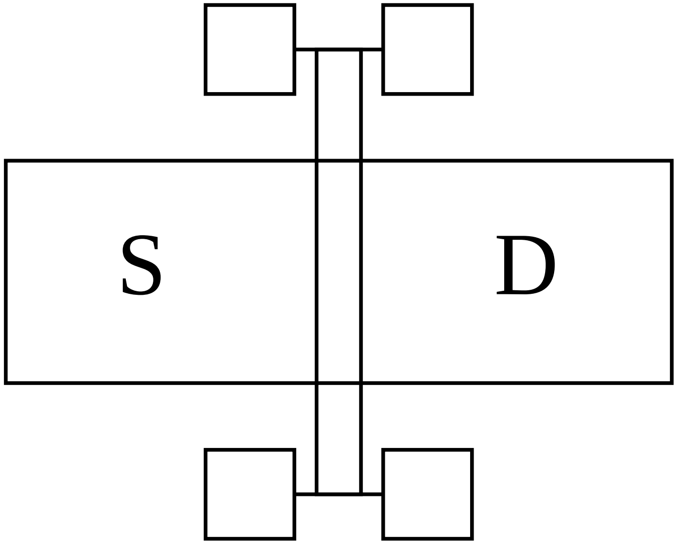

Figure 1: top view of experimental teststructure for temperatue measurement

Principle of teststructure for temperature measurement in SOI MOSFET's after [1].

The gate is configured for four-point resistance measurement with calibration in off-state of the MOS.

During operation of the MOS this resistance serves as temperature sensor.

# Example (2)

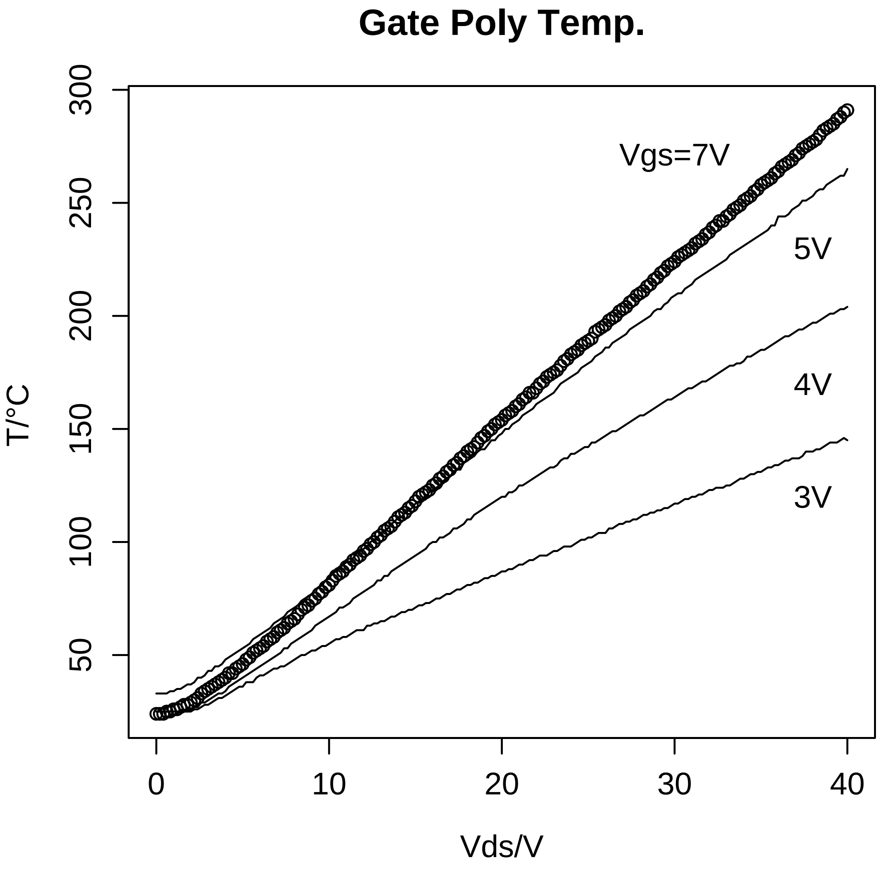

Figure 2: experimental results of SOI NMOS, w=$320 \mu m$

# ***RTH-Extraction Method***

There are several extraction methods suitable for regular devices [2, 3, 4, 5]. Of particular interest is the method from [5], which allows the extraction of thermal resistance in dependence on ambient temperature.

Thermal conductivity changes with temperature ($\alpha \sim 1.5$) :

$$\kappa(T) = \kappa_{ref} \left( \frac{T}{T_{ref}} \right)^{-\alpha} \tag{1}$$

Since thermal resistance is inversely proportional to the thermal conductivity, we should expect as claimed in [5] :

$$R_{TH}(T) = R_{TH,ref} \left( \frac{T}{T_{ref}} \right)^{\alpha} \tag{2}$$

# RTH-Extraction Method

Total temperature change caused by ambient and power dissipation [4]:

$$\Delta T = R_{TH}(I_C \Delta V_C + \Delta I_C V_C) + \Delta T_A \tag{3}$$

$$\Delta I_C = TC_F(I_C) I_C \Delta T + \frac{\Delta V_C}{V_A} I_C \tag{4}$$

Keeping $V_C$ constant :

$$\begin{aligned} \Delta T|_{\Delta V_C = 0} &= R_{TH} V_C \Delta I_C + \Delta T_A \tag{5} \\ &= \frac{\Delta T_A}{1 - TC_F(I_C) R_{TH} I_C V_C} \tag{6} \end{aligned}$$

Keeping $T_A$ constant :

$$\begin{aligned} \Delta T|_{\Delta T_A = 0} &= R_{TH}(I_C \Delta V_C + \Delta I_C V_C \tag{7} \\ &= \frac{I_C R_{TH}(1 + \frac{V_C}{V_A}) \Delta V_C}{1 - TC_F(I_C) R_{TH} I_C V_C} \tag{8} \end{aligned}$$

# RTH-Extraction Method

Variation of $I_C$ :

$$\Delta I_C = \frac{\partial I_C}{\partial T}\Delta T \tag{9}$$

$$= TC_F(I_C)I_C\Delta T \tag{10}$$

$$= TC_F(I_C)I_C(\Delta T|_{\Delta V_C=0} + \Delta T|_{\Delta T_A=0}) \tag{11}$$

$$= \frac{TC_F(I_C)I_C}{1 - TC_F(I_C)R_{TH}I_CV_C}(\Delta T_A + I_CR_{TH}(1 + \frac{V_C}{V_A})\Delta V_C) \tag{12}$$

Extraction of $R_{TH}$ :

$$\frac{\frac{\Delta I_C}{\Delta V_C}|_{\Delta T_A=0}}{\frac{\Delta I_C}{\Delta T_A}|_{\Delta V_C=0}} = I_CR_{TH}(1 + \frac{V_C}{V_A}) \tag{13}$$

$$R_{TH} = \frac{I_C(V_C + \Delta V_C, T_A) - I_C(V_C - \Delta V_C, T_A)}{I_C(V_C, T_A + \Delta T_A) - I_C(V_C, T_A - \Delta T_A)}\frac{\Delta T_A}{\Delta V_C}\frac{1}{I_C(1 + \frac{V_C}{V_A})} \tag{14}$$

This is eq. 3 of [5] using $I_C$ instead of $I_B$ as sensored signal.

# RTH-Extraction Method

Measurement conditions :

- DUT : SiGe2_power npn, 4x 19.7 $\mu m$ x 1.3 $\mu m$
- $V_C = 2V, \Delta V_C = 0.2V$
- $I_C \sim 1.5mA$ at room temperature
- $\Delta T_A = 10°C$
- change base drive with temperature to keep power disspation constant

# Results

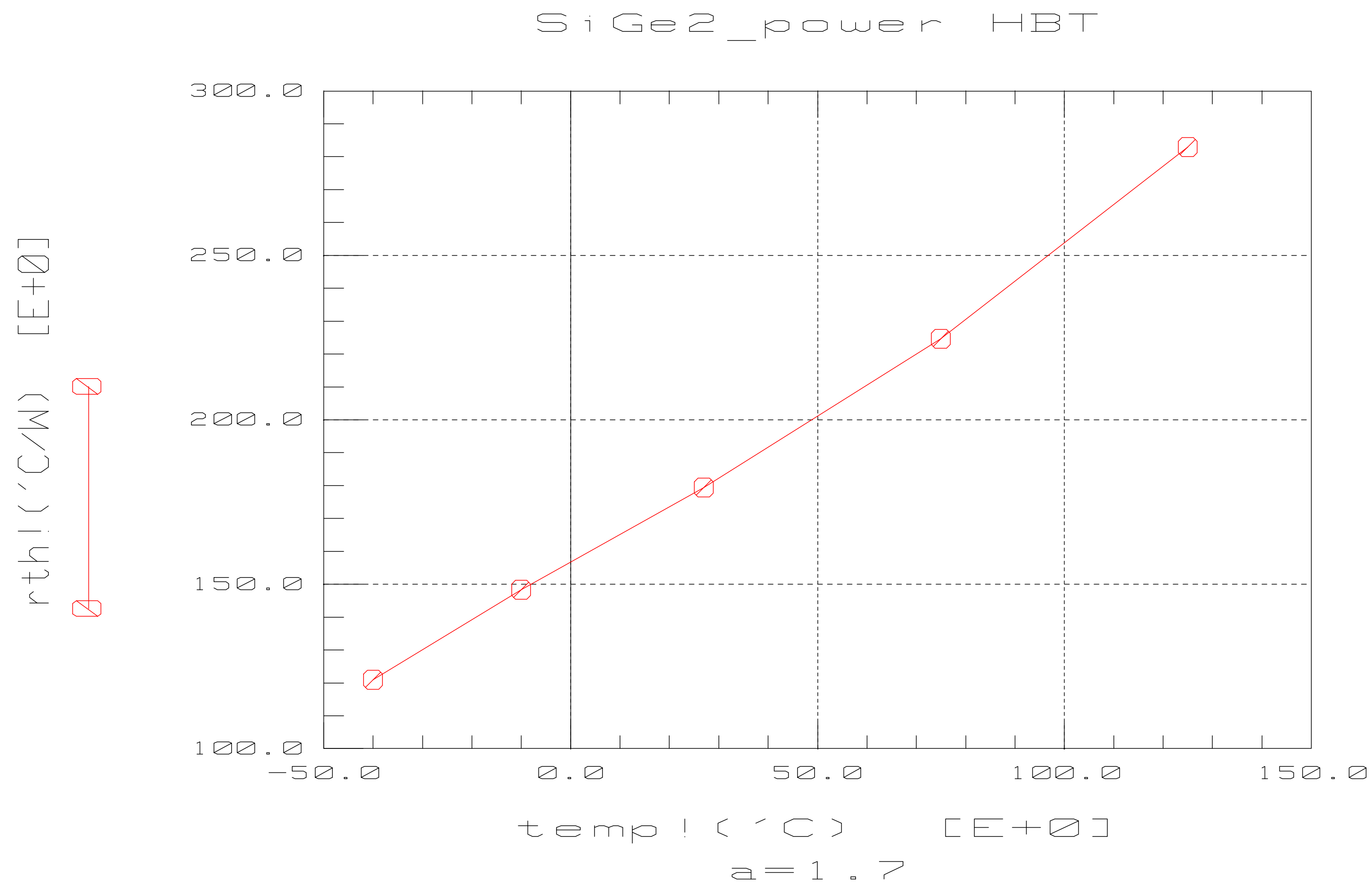

Figure 3: extracted dependence of RTH on ambient temperature

# Results

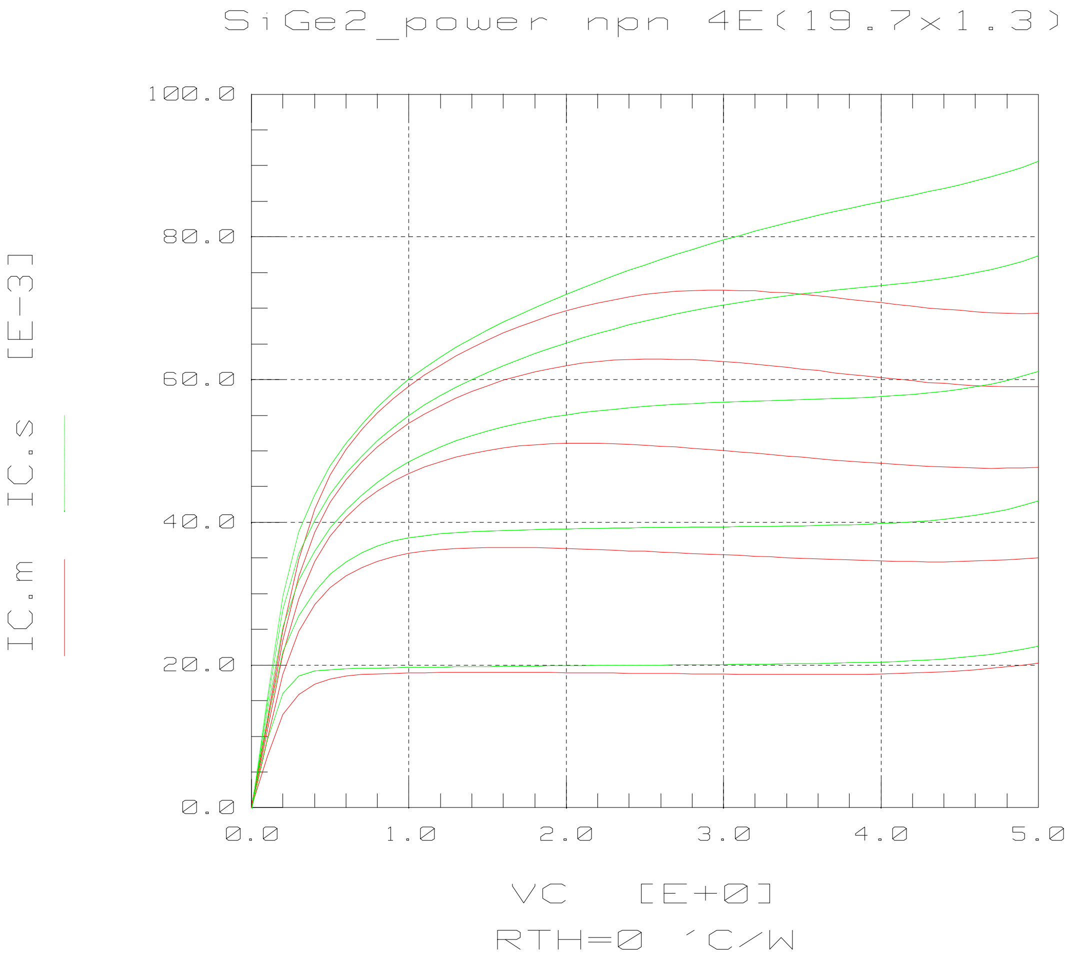

Figure 4: output characteristics of HBT w/o. selfheating

# Results

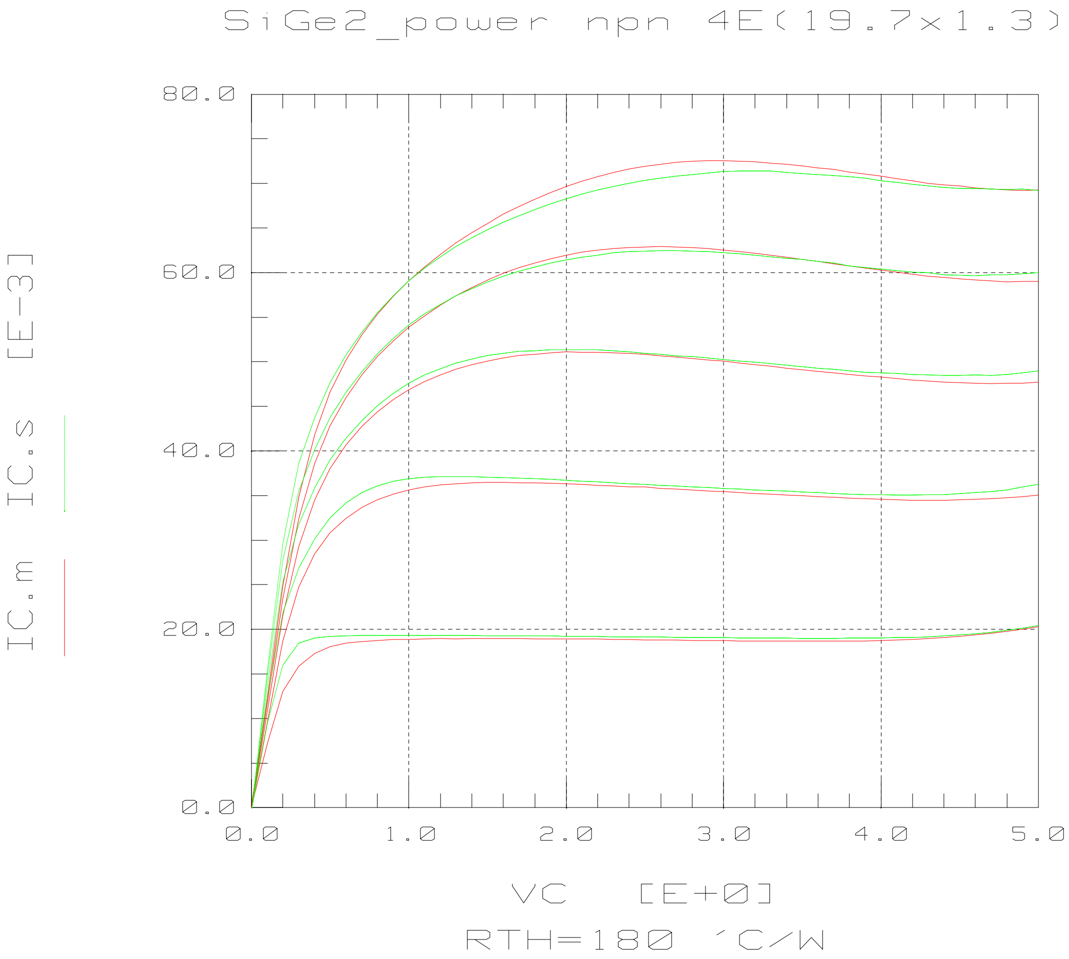

Figure 5: output characteristics of HBT including selfheating

# Conclusions

- Most recent method for R_TH extraction has been verified
- Thermal resistance depends on temperature
- Therefore selfheating (SH) becomes nonlinear
- Can be handled by Kirchhoff-Transformation [7]
- Models having SH should take that into account

# Literature

## References

[1] L.T. Su *et.al., T-ED*, Jan. 1994

[2] H. Tran *et.al., BCTM*, 1997

[3] S.P. Marsh *,T-ED*, Feb. 2000

[4] D.T. Zweidinger *et.al., BCTM*, 1995

[5] J.C.T. Passchens *et.al., BCTM*, 2004

[6] M. Reisch *,Solid-State Electronics*, pp. 677-679, 1992

[7] K. Poulton *et.al., JSSC*, Oct 1992