Extraction Method for Thermal Resistance

Bipolar-Arbeitskreis

Heilbronn, Nov 2004

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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
Figure 1: top view of experimental teststructure for temperature 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.
Figure 2: experimental results of SOI NMOS, $w=320\mu m$
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 ($\alpha \sim 1.5$) :

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

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

$$R_{TH}(T) = R_{TH,ref} \left( \frac{T}{T_{ref}} \right)^{\alpha}$$  \hspace{1cm} (2)
Total temperature change caused by ambient and power dissipation [4]:

$$\Delta T = R_{TH}(I_C \Delta V_C + \Delta I_C V_C) + \Delta T_A$$  \hspace{1cm} (3)$$

$$\Delta I_C = TC_F(I_C)I_C \Delta T + \frac{\Delta V_C}{V_A} I_C$$  \hspace{1cm} (4)$$

Keeping $V_C$ constant:

$$\Delta T|_{\Delta V_C=0} = R_{TH} V_C \Delta I_C + \Delta T_A$$  \hspace{1cm} (5)$$

$$= \frac{\Delta T_A}{1 - TC_F(I_C)R_{TH} I_C V_C}$$  \hspace{1cm} (6)$$

Keeping $T_A$ constant:

$$\Delta T|_{\Delta T_A=0} = R_{TH}(I_C \Delta V_C + \Delta I_C V_C)$$  \hspace{1cm} (7)$$

$$= \frac{I_C R_{TH}(1 + \frac{V_C}{V_A}) \Delta V_C}{1 - TC_F(I_C)R_{TH} I_C V_C}$$  \hspace{1cm} (8)$$
**RTH-Extraction Method**

Variation of $I_C$:

\[
\Delta I_C = \frac{\partial I_C}{\partial T} \Delta T
\]
\[= TC_F(I_C) I_C \Delta T \quad \text{(9)} \]
\[= TC_F(I_C) I_C (\Delta T|\Delta V_C=0 + \Delta T|\Delta T_A=0) \quad \text{(10)} \]
\[= \frac{TC_F(I_C) I_C}{1 - TC_F(I_C) R_{TH} I_C V_C} (\Delta T_A + I_C R_{TH} (1 + \frac{V_C}{V_A}) \Delta V_C) \quad \text{(11)} \]

Extraction of $R_{TH}$:

\[
\frac{\Delta I_C}{\Delta V_C} |_{\Delta T_A=0} = I_C R_{TH} (1 + \frac{V_C}{V_A}) \quad \text{(13)}
\]
\[
R_{TH} = \frac{I_C(V_C + \Delta V_C, T_A) - I_C(V_C - \Delta V_C, T_A)}{I_C(V_C, T_A + \Delta T_A) - I_C(V_C, T_A - \Delta T_A)} \frac{\Delta T_A}{\Delta V_C} \frac{1}{I_C(1 + \frac{V_C}{V_A})} \quad \text{(14)}
\]

This is eq. 3 of [5] using $I_C$ instead of $I_B$ as sensed signal.
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
- $\Delta T_A = 10^\circ C$
- change base drive with temperature to keep power dissipation constant
Figure 3: extracted dependence of RTH on ambient temperature
Figure 4: output characteristics of HBT w/o. selfheating
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
References