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Investigations on thermal contact conductance between filled polymer composites and solids using micro thermography

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Background

When optimising cooling paths in electronic devices, thermal interface materials (TIMs) are used to improve the thermal transfer between two solid surfaces. TIMs are thermally conductive filled polymer composites. For a good thermal transfer between the solid surfaces not only a high thermal conductivity of the TIM but also a high thermal contact conductance between TIM and surface is required.

Heat has to pass three thermal resistances connected in serial, see Figure 1. While the bulk resistances can be measured easily, and have been investigated in several studies, thermal contacts between filled polymers and solid surfaces have not yet been investigated in detail and just a few experimental results are available.

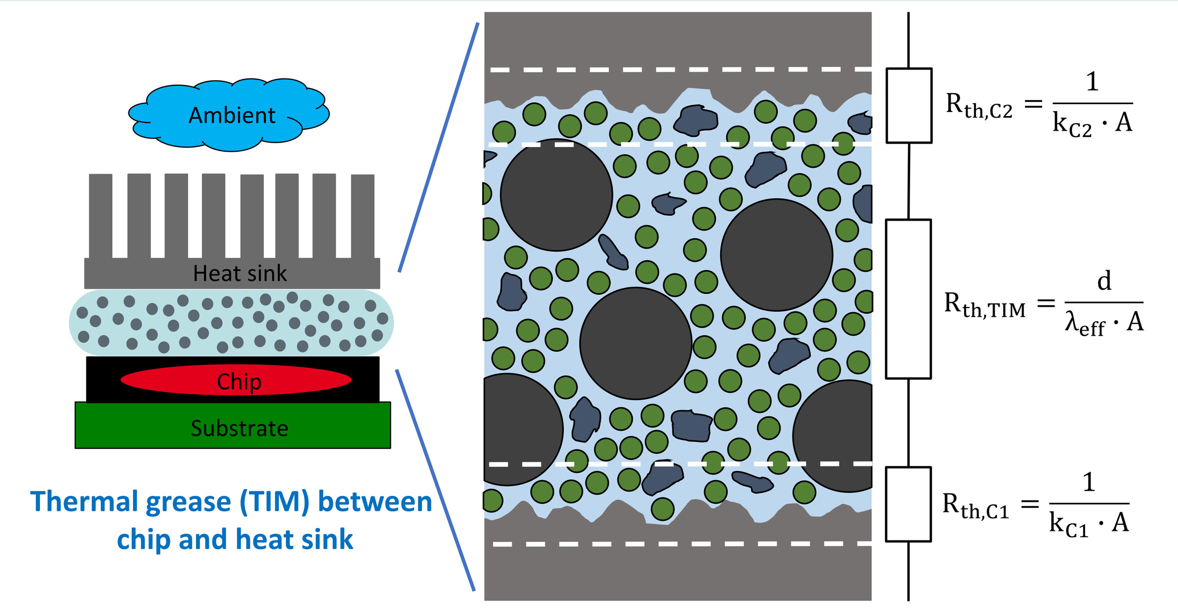

Figure 1: Microstructure of TIM between chip and heat sink
R_{th}: Thermal resistance in $\frac{K}{W}$; λ_{eff}: Effective thermal conductivity of filled polymer in $\frac{W}{mK}$;
d: Thickness of TIM layer in m ; k_C: Thermal contact conductance in $\frac{W}{m^2K}$; A: Area in m^2

Approach

Xian et al. [1] published an extensive summary of transient and steady state measurement methods for thermal contact conductance. However, all these studies are used for solid-solid contacts and not resolved spatially. In the presented study we use micro thermography to measure and study thermal contact conductance between filled polymers and solid surfaces on a microscale.

Warzoha and Donovan [2] already used micro thermography for measurements of TIM junctions with great success. Ishizaki et al. [3] and Burghold et al. [4] used lock-in and micro thermography for investigations on solid-solid contacts. We extended the method to gain spatially resolved information and analysed the effects of surface structure, filler distribution, particle size and shape on thermal contact conductance.

Method and Materials

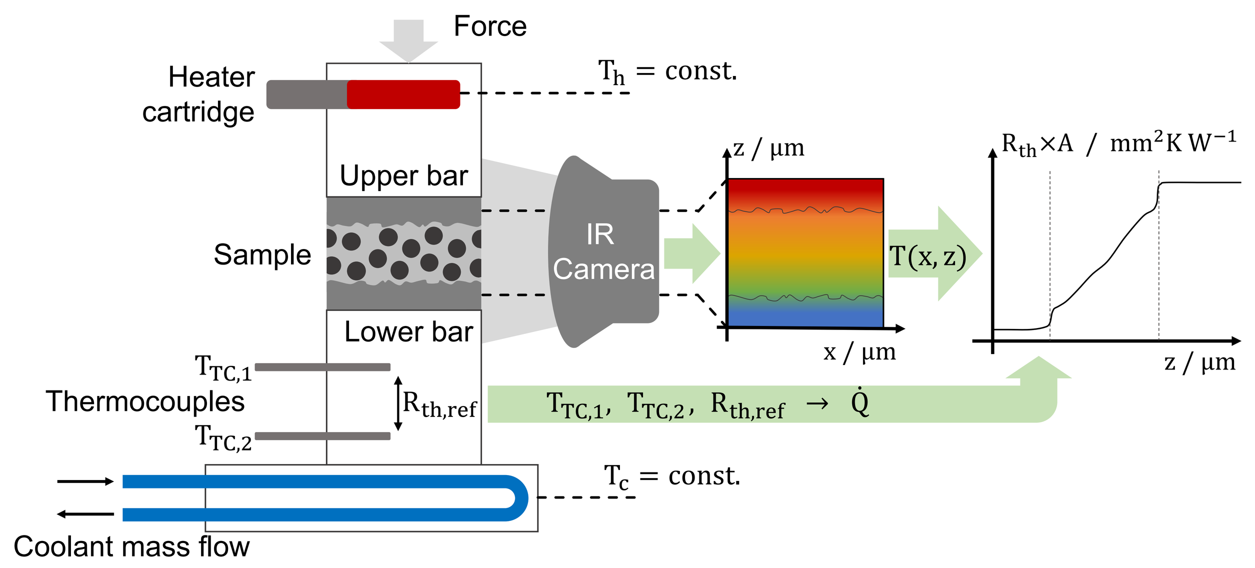

Figure 2: General micro thermography setup
$R_{th}×A$: Thermal insulance in $\frac{mm^2K}{W}$; T: Temperature in K or °C ; $\dot{Q}$: Heat flow in W

- Multi-layer samples
  - Aluminium substrate and filled epoxy composite
  - Variation of surface structure, filler size, shape and content
- Steady state thermal measurement
- Sample placed between heated and cooled aluminium bars, see Figure 2
- Measurement of temperature field on sample surface using IR camera*
- Heat flow determination with reference temperature measurements in lower aluminium bar
- Calibration of heat flow determination with well known reference sample, see Figure 3

* Used system: Infratec VarioCam HD 860 with close-up lens 0.5x
14 microns per pixel

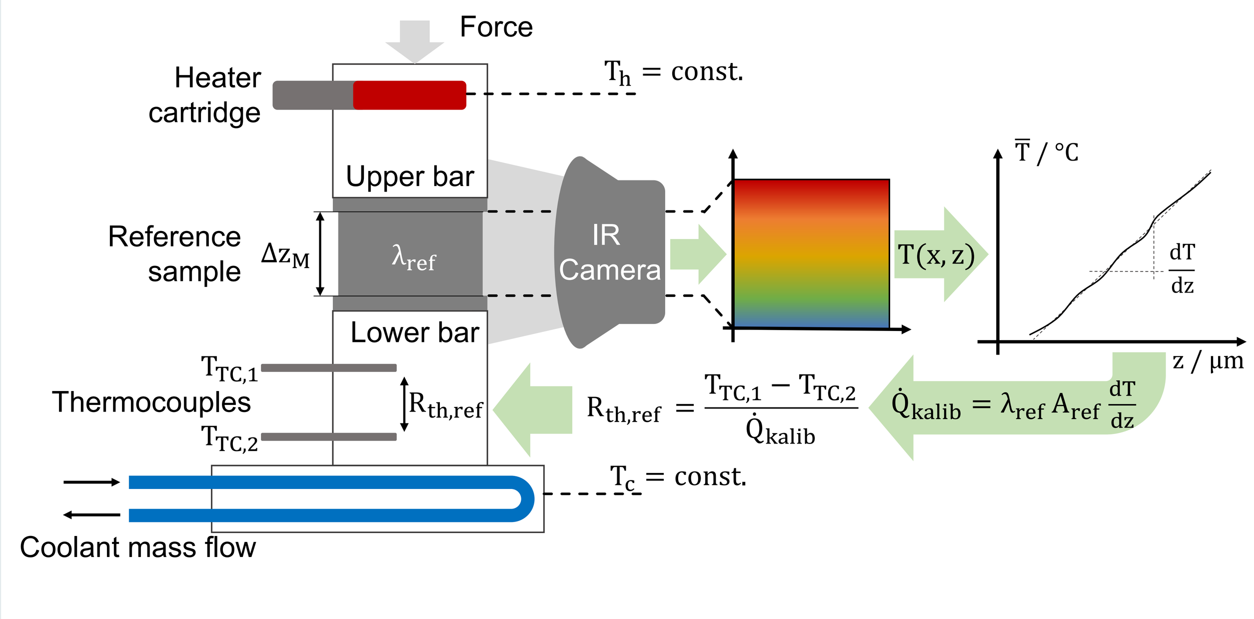

Figure 3: Calibration procedure

Evaluation and Results

- Averaging of temperature field along $x-$axis
- Calculation of continuous thermal insulance using temperature data and heat flow, see Figure 4
- Localisation of contacting zones using microscopy images
- Separation of bulk and contact zones
- Linear regression in bulk zone
- Extrapolation to virtual contact $z-$ levels $z_{C,1}$ and $z_{C,2}$
- Evaluation of contact insulance and contact conductance with

$$k_C = \frac{1}{(R_{th}×A)_C}$$

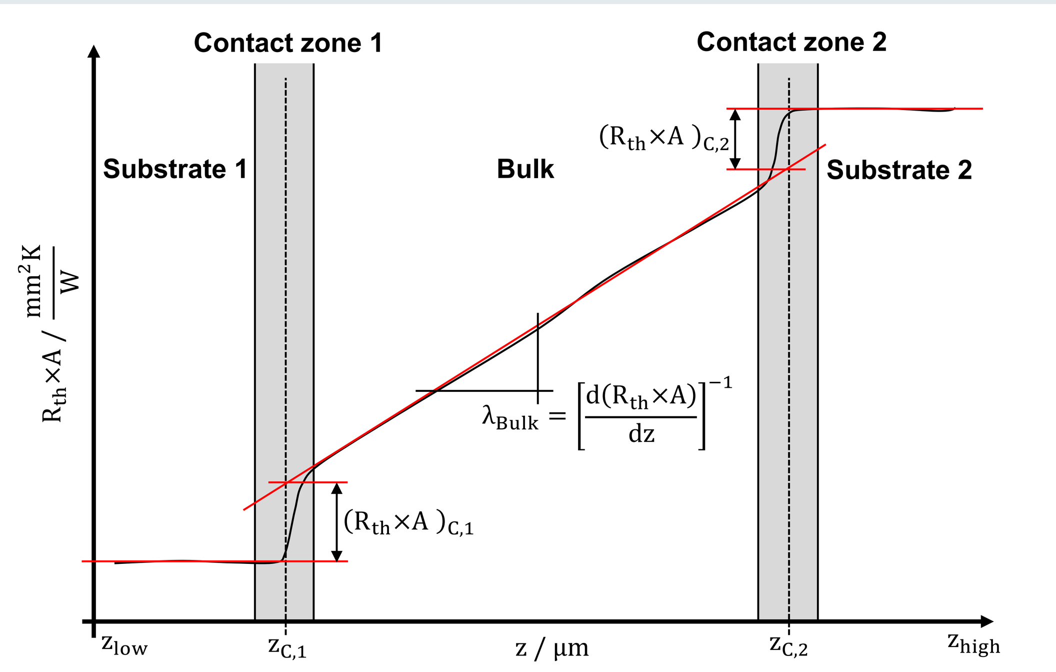

Figure 4: Evaluation of micro thermography data

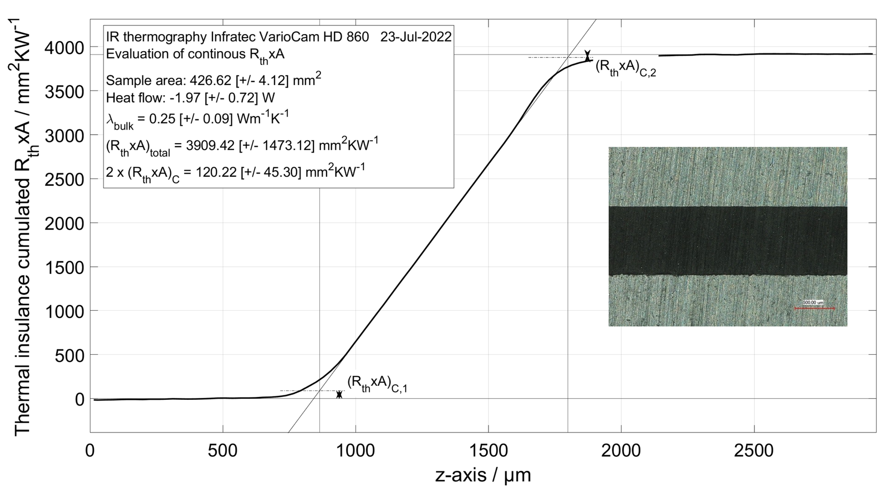

Figure 5: Results sample 1
Aluminium substrate R0: $Ra = 1{,}4\ \mu m$, $Rz = 14\ \mu m$
Epoxy unfilled

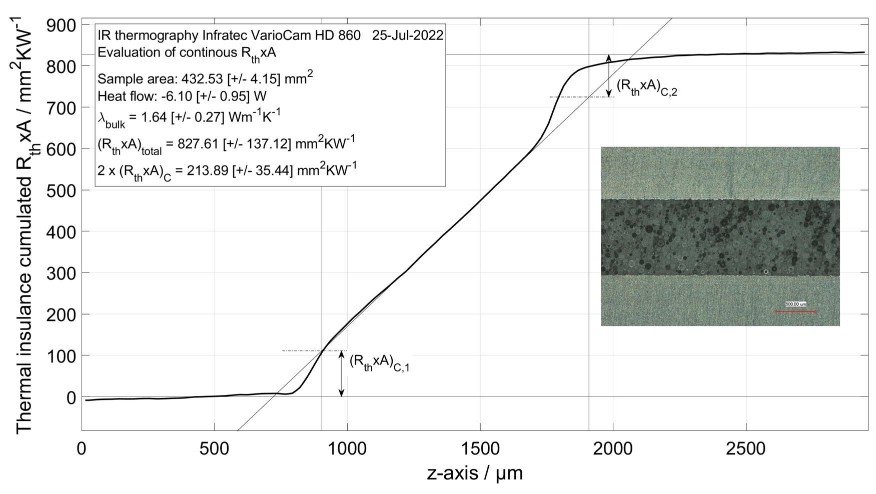

Figure 6: Results sample 2
Aluminium substrate R2: $Ra = 3\ \mu m$, $Rz = 45\ \mu m$
Epoxy with spherical alumina filler: $\varphi = 0{,}5$, $D_{50} = 65\ \mu m$

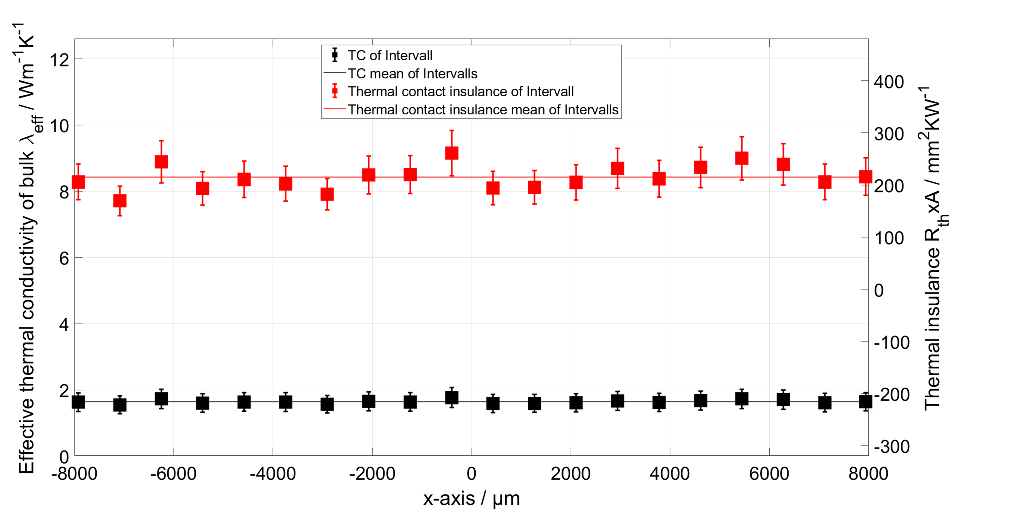

Figure 7: Analysis of local variation sample 2

- Smooth transition from substrate to TIM with unfilled epoxy, see Figure 5
- Significant contact resistance with filled epoxy, see Figure 6
- Linear course in bulk section in both cases

- Great variations in contact insulance along $x-$axis with filled epoxy, see Figure 7
- Variations caused by random filler and surface structures

Validation and Numerical Simulation

- Comparison of measured thermal conductivity
  - ASTM D5470: Steady state cylinder method
  - ASTM E1461-13: Laser flash analysis (Thermal diffusivity and heat capacity, TC calculated)
- Various samples with different filler materials, sizes and contents
- Overall good agreement, see Figure 8

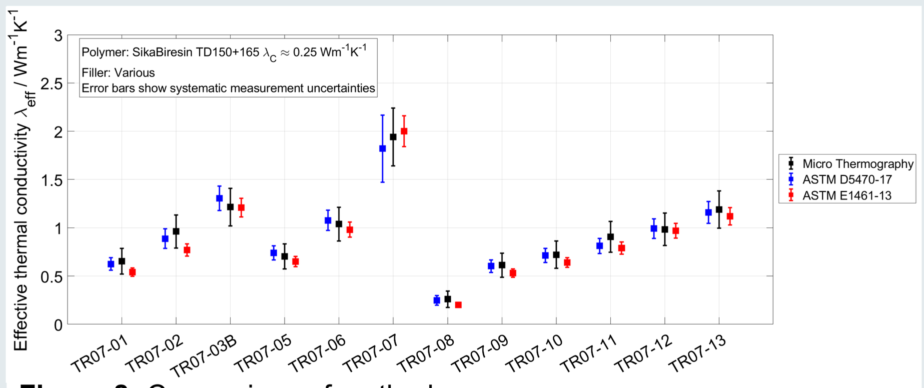

Figure 8: Comparison of methods

- Additional micro scale simulation approach for further studies
- Particle shapes and surface structure digitised
- Calculation of steady state heat flow through cube-shaped representative volume with $T =$ const. boundary conditions in $z-$direction
- Evaluation of continuous thermal insulance along $z-$axis

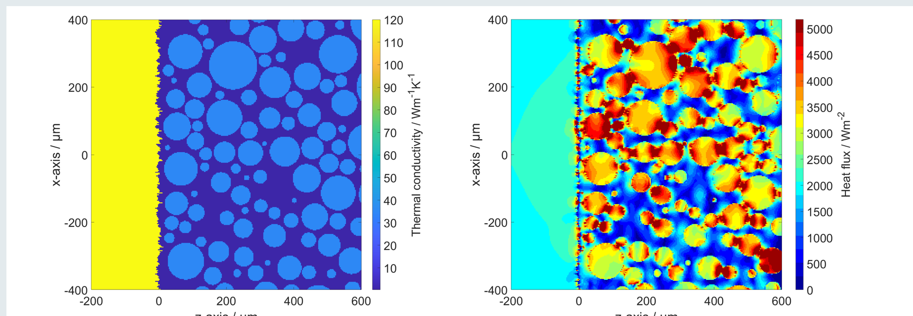

Figure 9: Section view simulation model

- Good opportunity for investigations on micro scale heat paths, see Figure 9
- Further insights due to even finer local resolution
- Boundary effects in particle arrangement become visible, see Figure 10

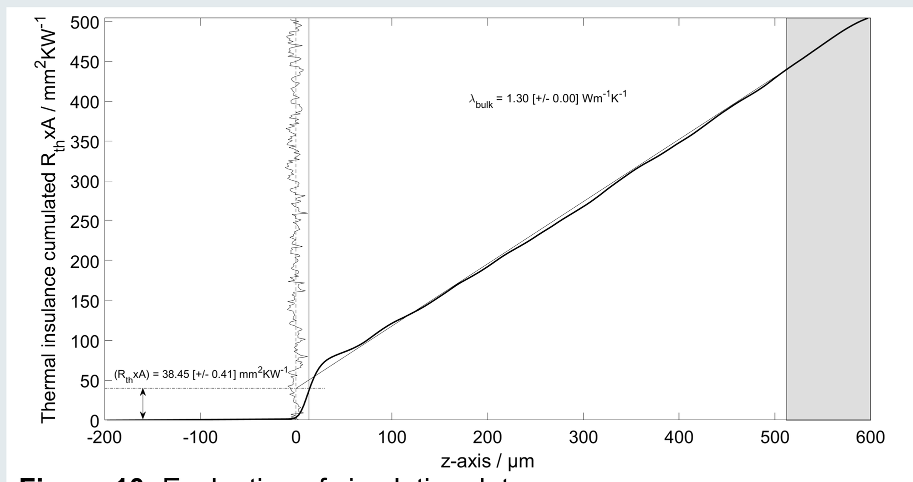

Figure 10: Evaluation of simulation data

Conclusion and Outlook

- Successful measurement of thermal contact conductance between filled polymer and solid surfaces using micro thermography
- Comparison of results with other methods (thermal conductivity) shows a good agreement
- Random surface and filler structures cause great variations along the investigated surfaces
- Effecting parameters for thermal contact conductance

Primary parameters
- Particle arrangement close to surface
- Particle-surface contacts
- Polymer layers between surface and particles
- Ratio of particle size to surface structure

Secondary parameters
- Filler material and thermal conductivity
- Particle shape
- Filler content

- Findings and effects can be reproduced with a microscale simulation model
- For further investigations, particle-surface contacts will be forced, detected and investigated

Contact

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