App For The Thermal Simulation Of Power Electronics Test Devices

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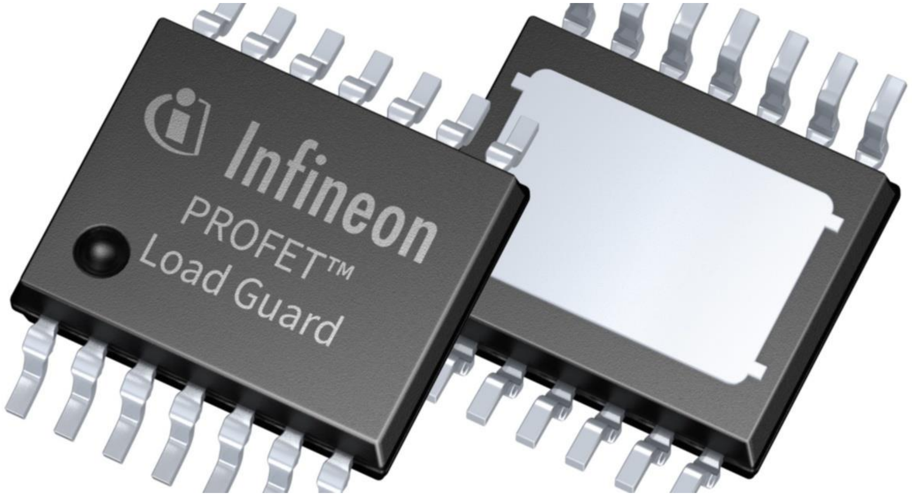
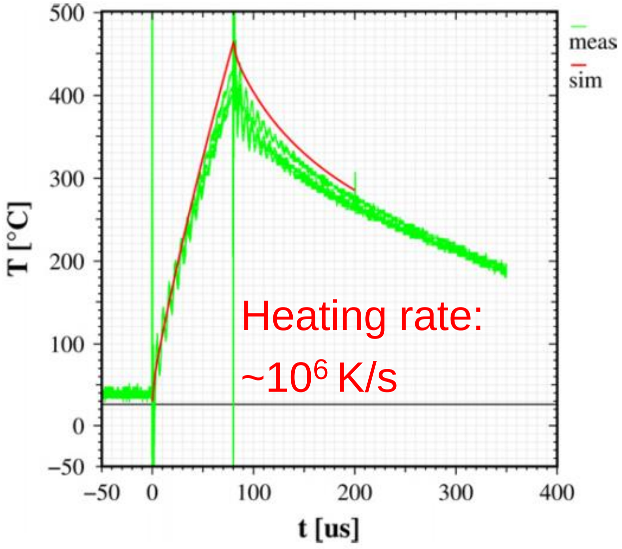
Introduction & Motivation

- Power microelectronic devices
  - Silicon substrate + active area + metallization
- Automotive high-side switches are used to turn electrical loads ON and OFF by switching the positive side of the load supply. Additionally, smart high-side switches are designed with the ability to protect themselves and diagnose possible unintended system behavior.
- Short circuit events, overload events, power cycling, ...
  - Rapid changes in temperature
    ⇒ mechanical stress
    - (CTE_{Cu} = 17 ppm/K, CTE_{Si} = 2.56 ppm/K)
  - Thermo-mechanical fatigue
  - Eventually, failure of the device





Temperature profile during a short circuit pulse in a trench power MOSFET.

[M. Nelhiebel et al., *Microelectron. Reliab.* (2011)]

Polyheater test devices

- Study thermo-mechanical fatigue of power metallizations
  - at application-relevant heating rates
  - under highly accelerated stress conditions

- Polyheaters consist of:
  - Structural layers:
    - Si substrate (120 µm)
    - Cu power metallization (20 µm)
  - Functional layers:
    - Polysilicon for Joule heating
    - Aluminium (M1)
    - Oxides/dielectrics

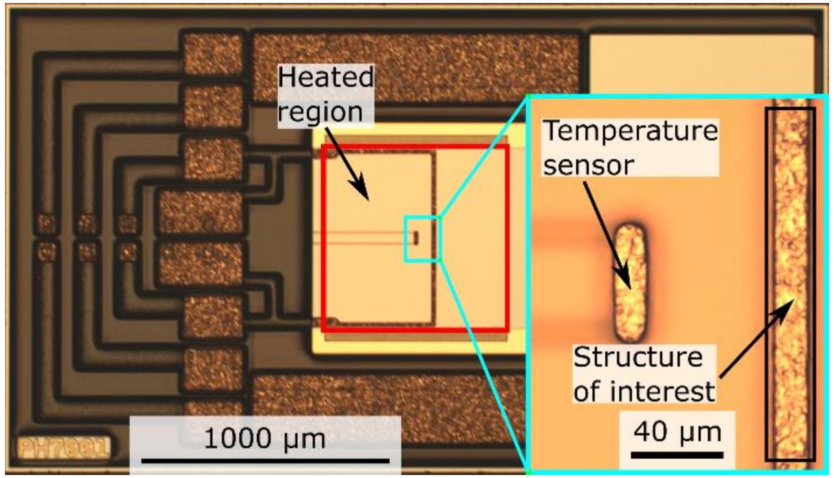


Fig. 3: Light microscope image of a polyheater device featuring a Cu line with width and thickness of 20 µm.

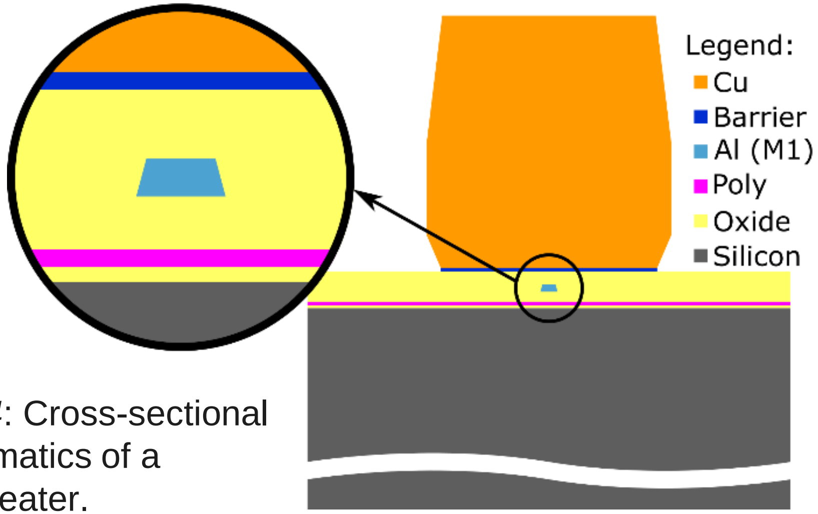
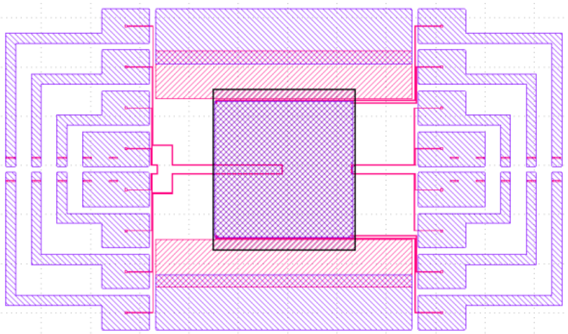


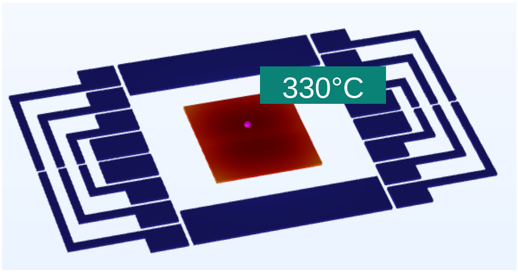
Fig. 4: Cross-sectional schematics of a polyheater.

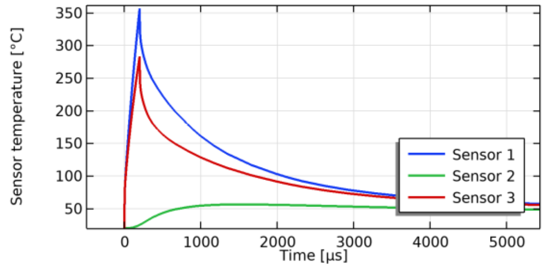
Why do we need thermal simulations?

- The temperature field has to be known to calculate thermal stresses
- We can only measure locally by including temperature sensors
  - Temperature sensors measure their own temperature

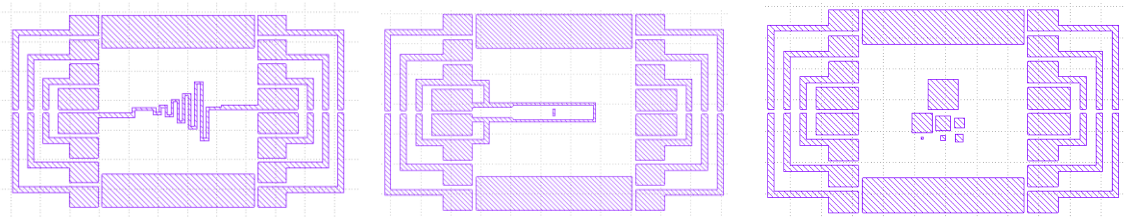


- For the plate-type polyheaters, there is a relation between the sensor and copper temperature

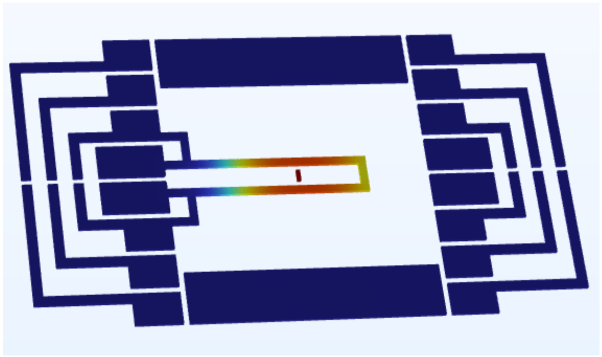




- There are polyheaters containing various other geometric patterns, where the relation between sensor and copper temperatur is very different from plate-type polyheaters

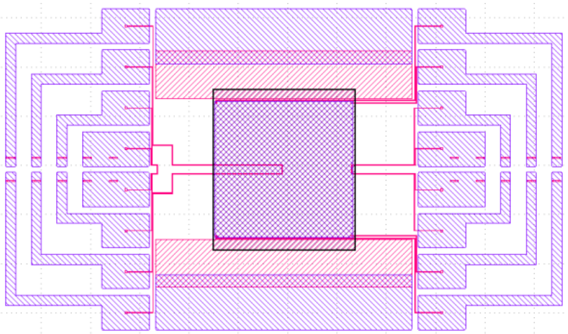


- ... and temperature is not always homogeneous

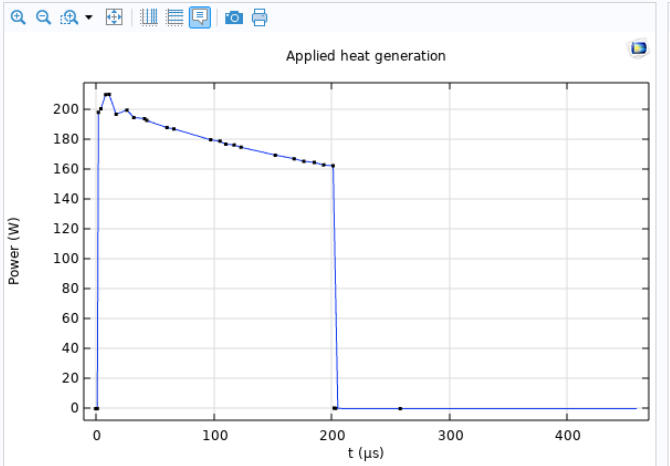


Objective and requirements for the simulation app

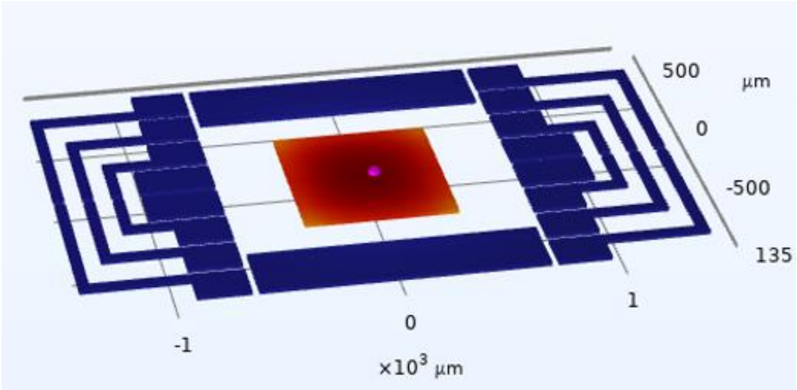
- Build model from GDS layout file
  - More than 50 different device types are available



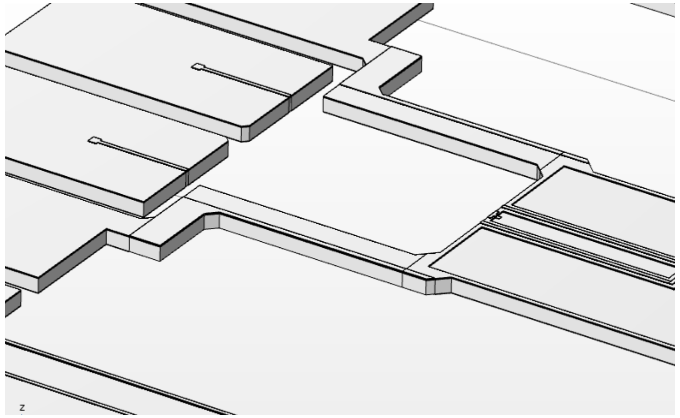
- Load and pre-process experimental data
  - Smoothing and down-sampling of oscilloscope data



- Provide predefined and user defined evaluations
  - Min/max, statistics and local transients



- Extruded geometry
  - Millimeter scale devices with hundreds of nm thick layers need a swept mesh

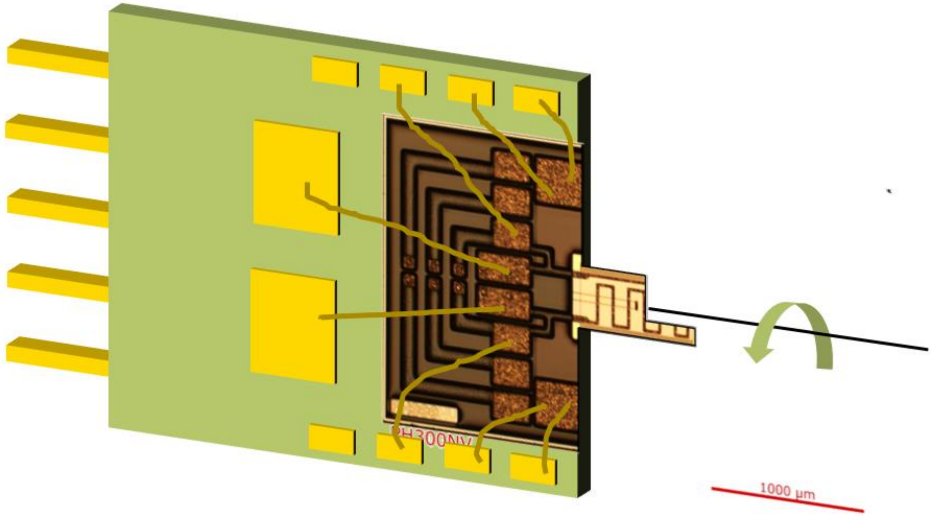


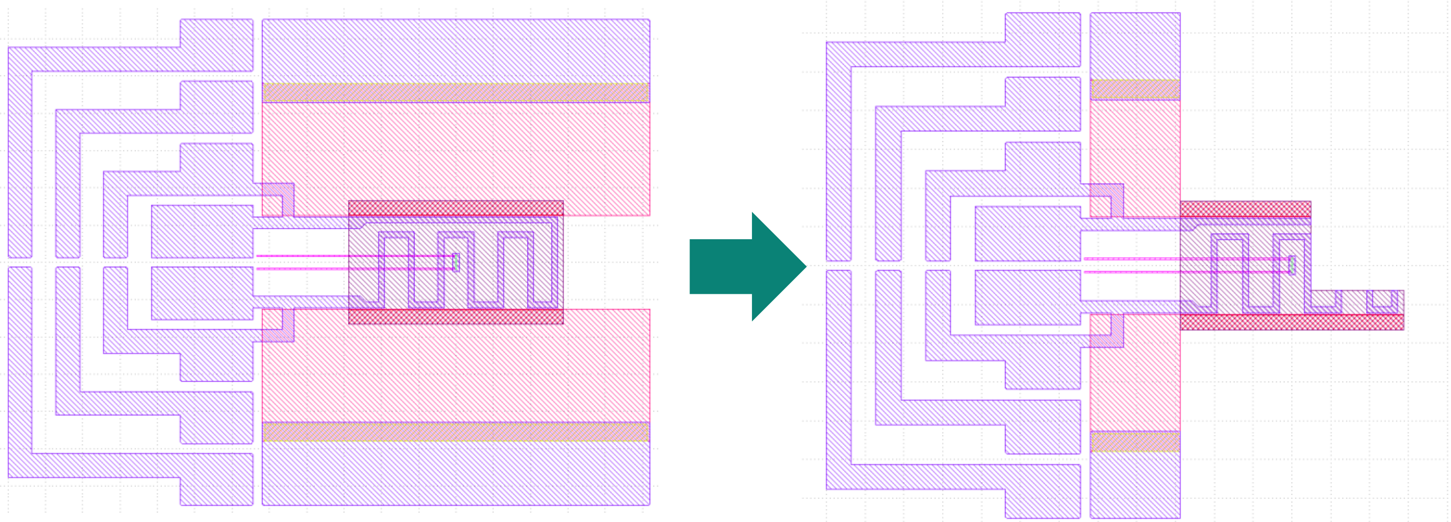
Modules and modelling technique

ECAD module

- The ECAD module is used to load the device layout from a GDS file, which contains the 2D footprint of every layer
- A layer represents either a deposition or removal of a material and extrusion and boolean operations are used to build a 3D geometry
- This appears trivial, but it is a key feature!
  - It not only enables the easy setup of models for a variety of devices, experimentalists can even draw and simulate their design ideas for new polyheater types without needing a simulation expert to build models

Example: Will it work to FIB cut a PH300NV polyheater to enable x-ray microscopy measurements?

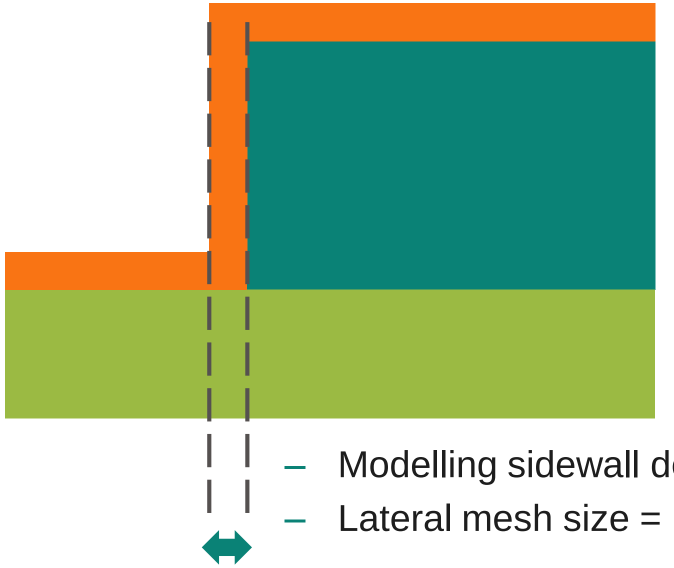




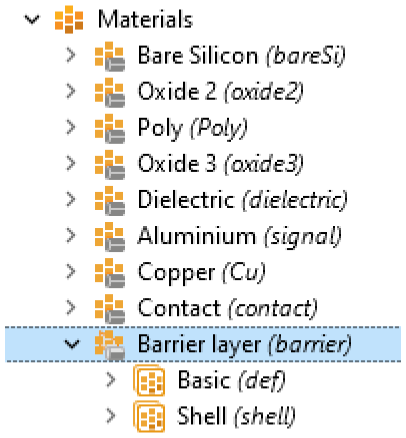
Heat transfer module

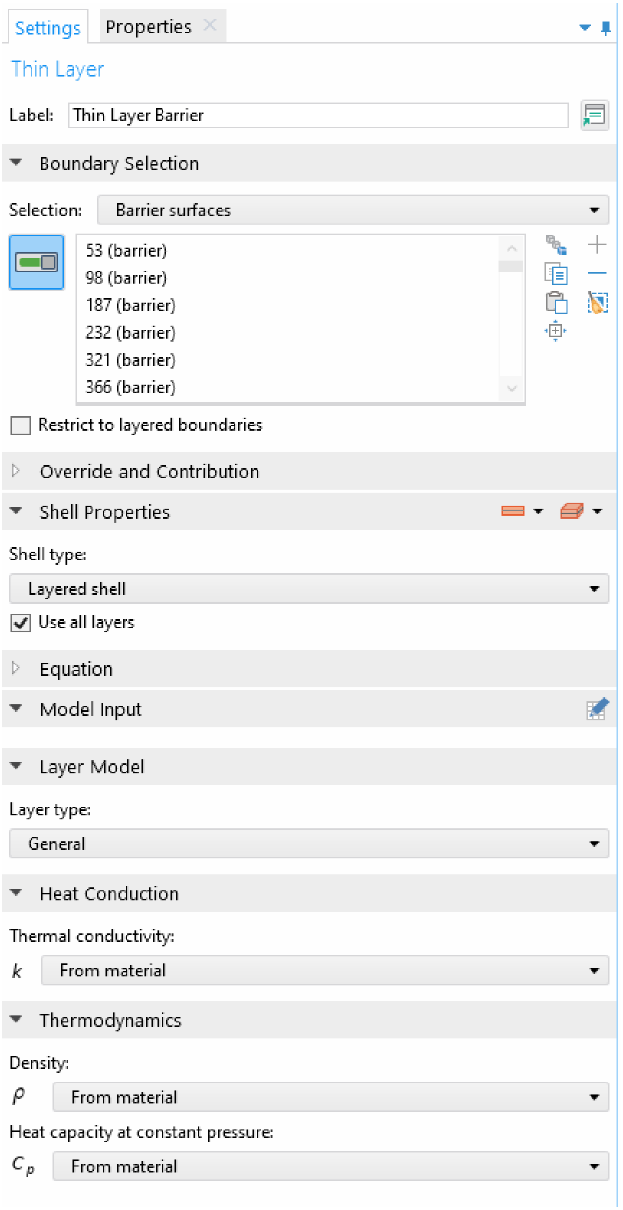
- The Thin Layer node of the Heat Transfer module is used to avoid meshing functional layers that do not require detailed resolution
- Improved accuracy on edges without needing to explicitly model sidewall deposition

- Conformal deposited thin layer



- Modelling sidewall deposition:
- Lateral mesh size = layer thickness!

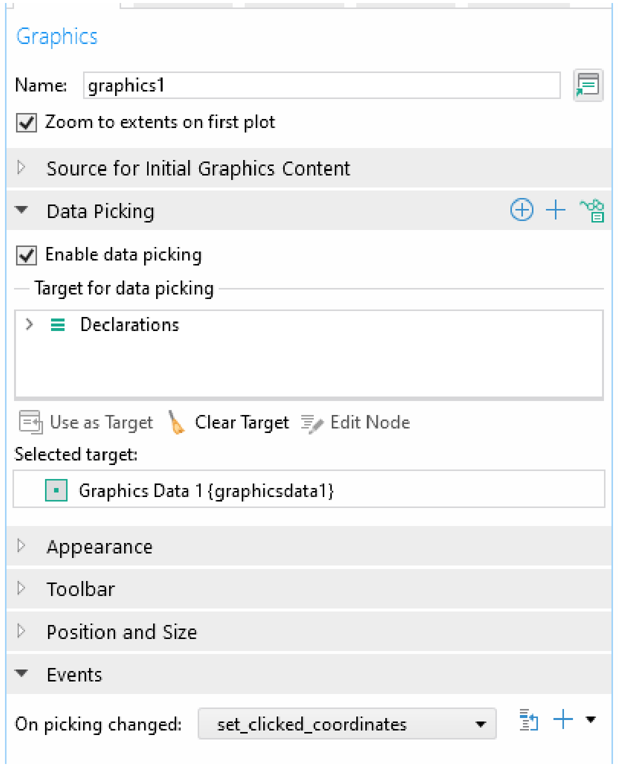


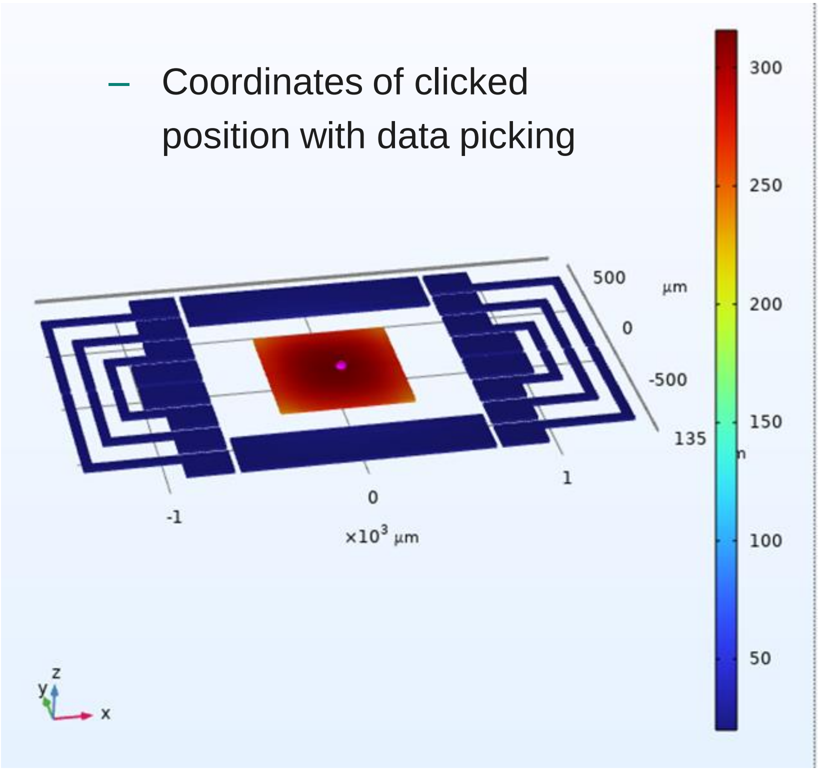


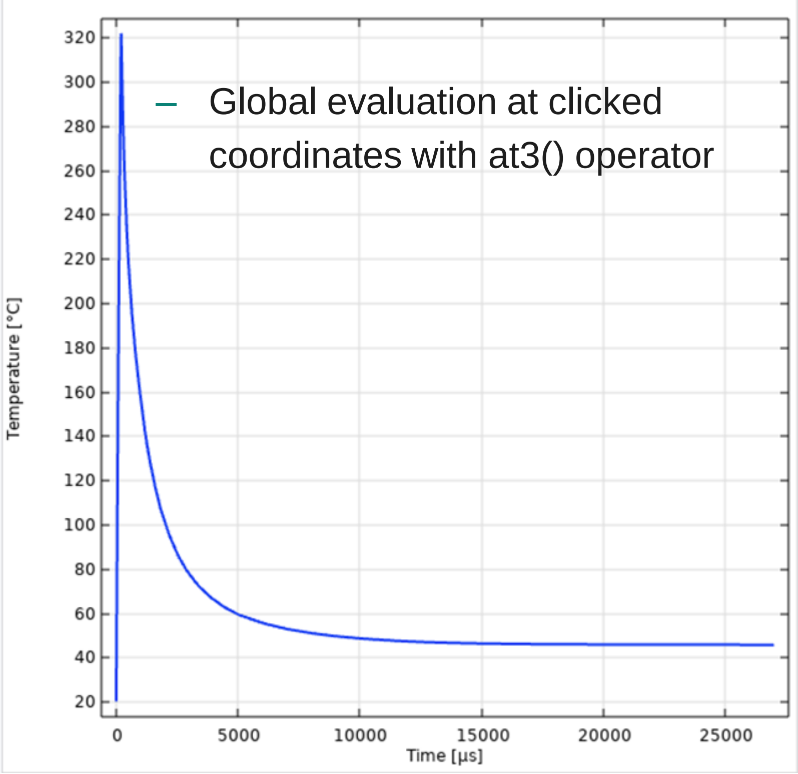
App building and validation

App builder

- An app was built on the model using a template from the default library
  - Inputs were created automatically from the model parameters
  - Non-COMSOL functions like reading csv-data and downsampling of a signal were implemented as Java methods
- The major advantage of an app over other solutions such as parameterized command line execution is in the visualization of results and interactive post-processing in addition to standardized outputs

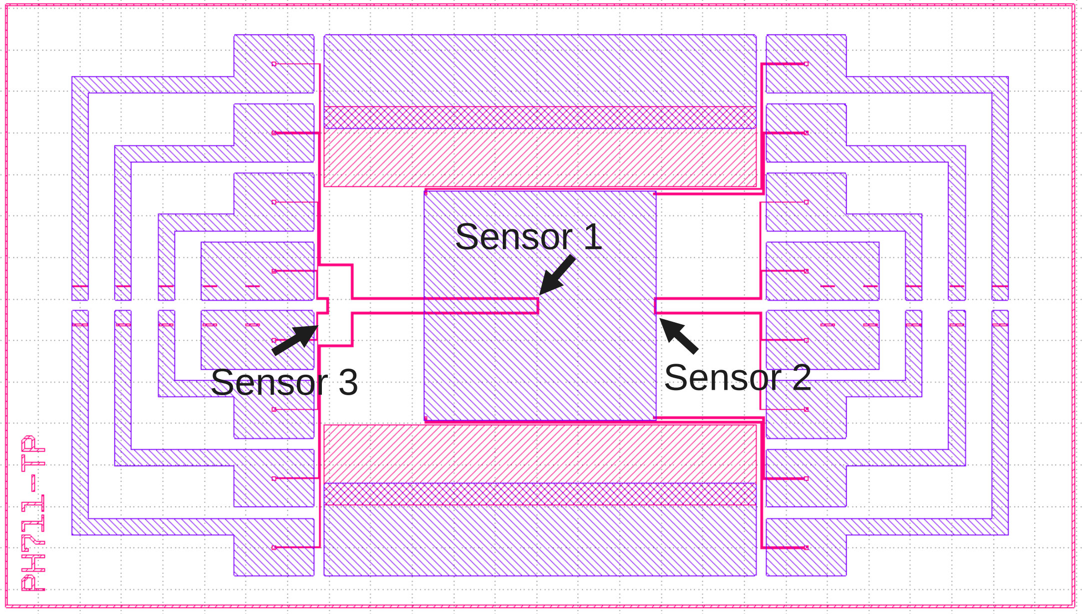


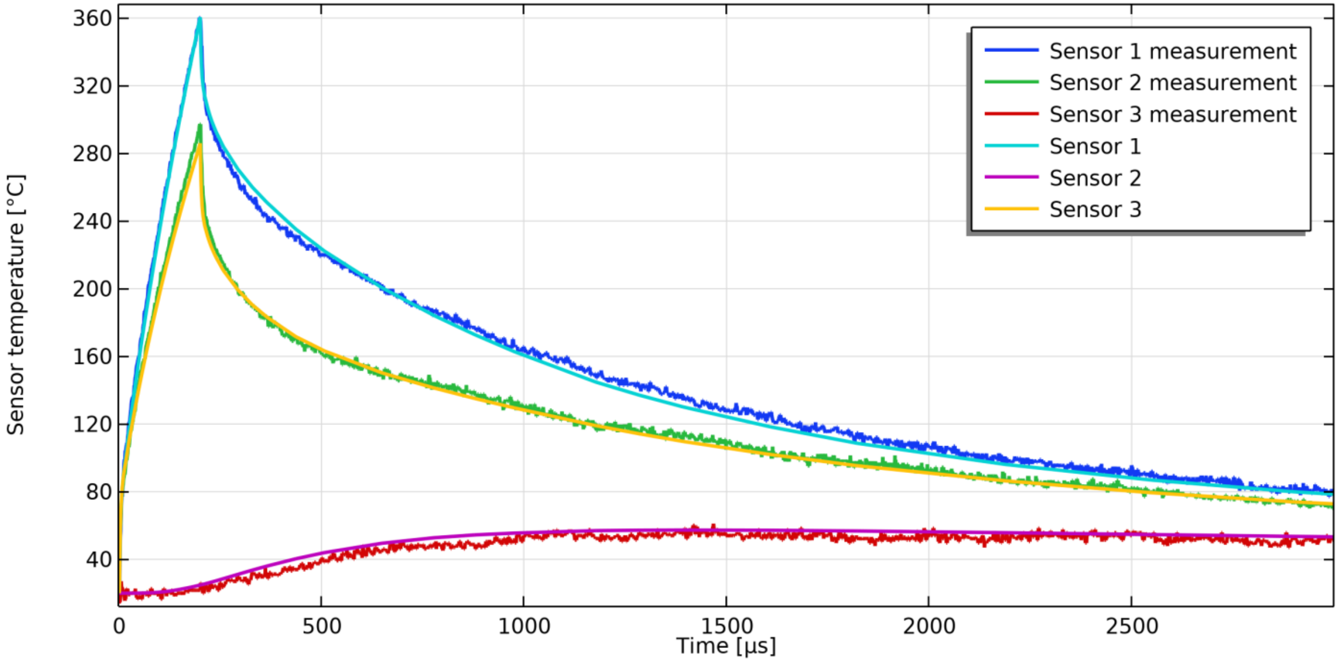


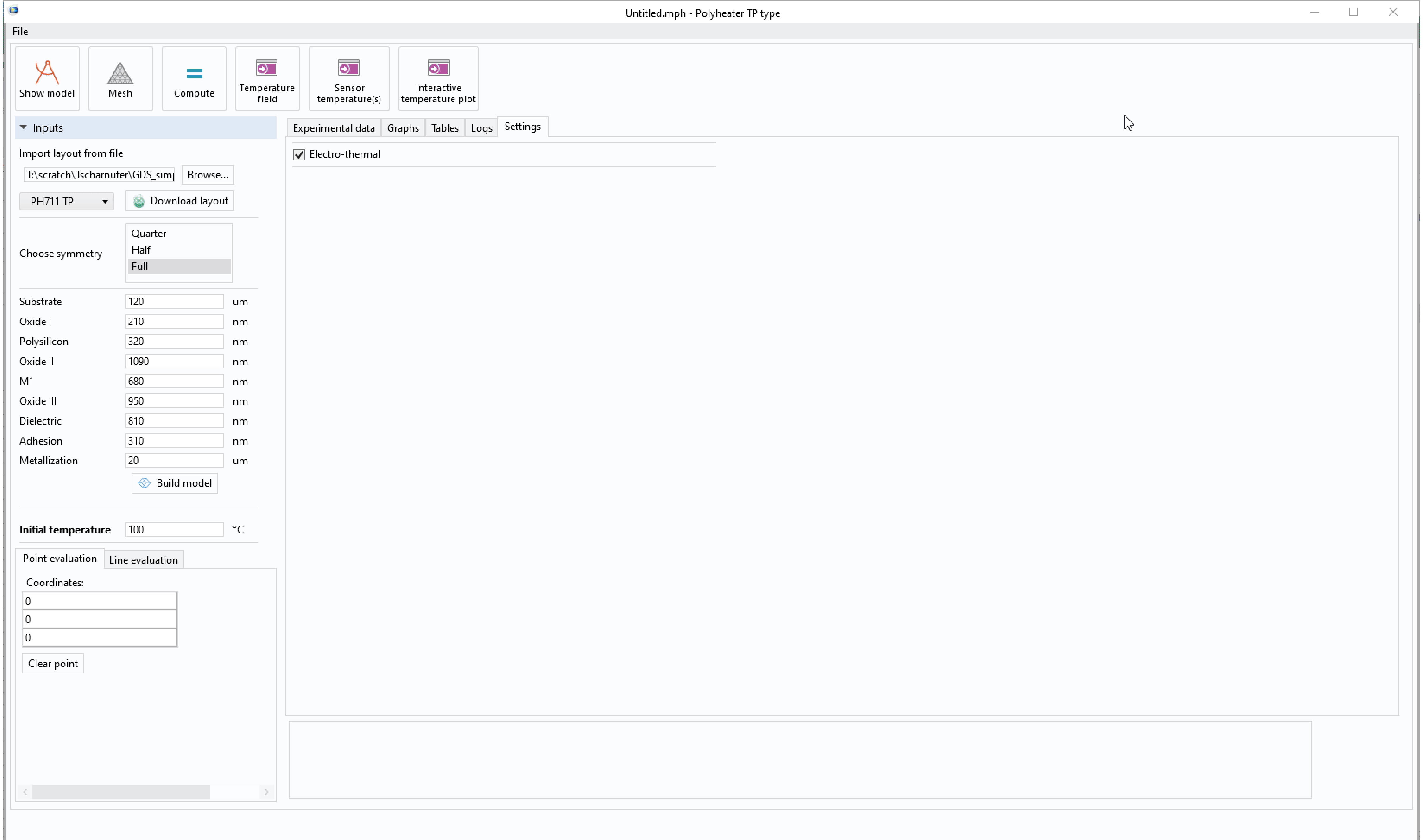


Validation

– A polyheater type with three temperature sensors has been specifically designed for validating the thermal simulations
– The sensors near the center and edge of the heated metallization and away from it enables us to verify that the heating and heat flow inside the device are predicted correctly






Untitled.mph - Polyheater TP type
File
Show model
Mesh
Compute
Temperature field
Sensor temperature(s)
Interactive temperature plot
Inputs
Import layout from file
T:\scratch\Tscharnuter\GDS_sim
Browse...
PH711 TP
Download layout
Choose symmetry
Quarter
Half
Full
Substrate 120 um
Oxide I 210 nm
Polysilicon 320 nm
Oxide II 1090 nm
M1 680 nm
Oxide III 950 nm
Dielectric 810 nm
Adhesion 310 nm
Metallization 20 um
Build model
Initial temperature 100 °C
Point evaluation
Line evaluation
Coordinates:
0
0
0
Clear point
Experimental data
Graphs
Tables
Logs
Settings
Electro-thermal

Infineon