Lightning Talk: Latest Results and Upcoming Challenges in Simulation of 3D ICs

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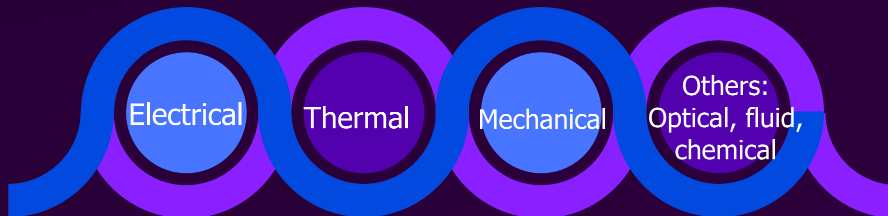
Why use Physical Simulation Analysis for IC Design & What are the Challenges?

- Simulations can be used to test "what-if" scenarios and explore design concepts prior to physical fabrication and testing
- Can help to reduce cost and design turnaround time

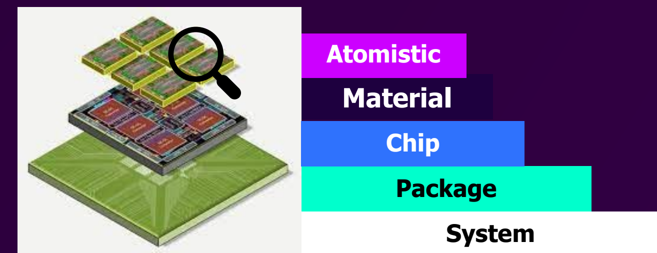
Multi-domain physics

- Multiple physics domain that are interconnected
- Each domain of physics might utilize different numerical methods, which could make integration and coupling a challenge



Multi-scale

- Might involve large number of transistors, which requires scalable algorithms and high performance computing
- Varying functional components (Chips, interconnects, heat sink, etc.)
- Heterogenous integration (2.5D, 3D)



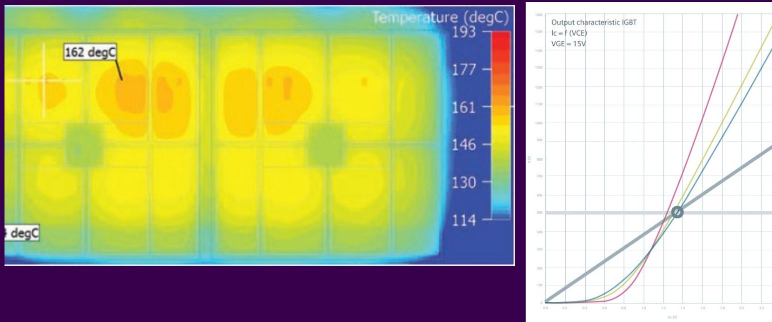
Trade-off among multi-disciplinary and multi-scale requirements make it even more challenging

Multi-Domain Physics Simulation Analysis

Electro-thermal coupling

- Joule heating from electronics
- Effect of temperature on electrical performance (e.g. resistivity)

Electro-thermal simulation of an IGBT power inverter using Siemens Simcenter Flotherm
(Siemens Digital Industries Software)



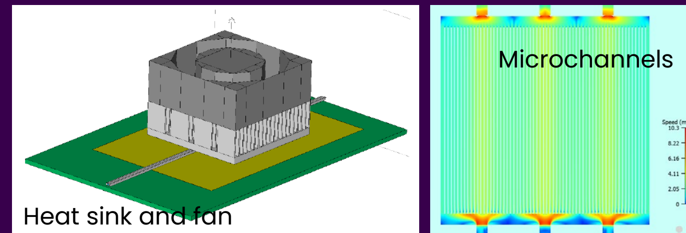
Temperature-dependent IV curve

Thermal-only simulation resulted in up to 34% difference in temperature

Thermal-Flow coupling

- CFD / conjugate heat transfer to evaluate cooling strategies,
- E.g. Air cooling, liquid cooling, Phase change material

Thermal-flow modeling using Flotherm
(Bognár et. al. THERMINIC, IEEE, 2022)



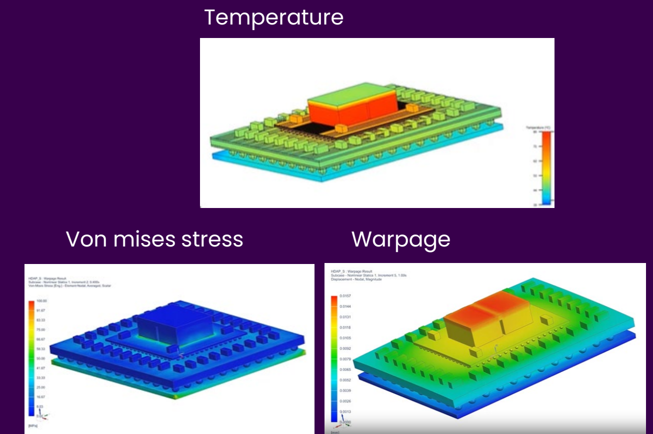
Vol. flow rate [ccm]	Microchannel CPU temp. [°C]	Microchannel GPU temp. [°C]	Microchannel Memory temp. [°C]	Microchannel + HSF CPU temp. [°C]	Microchannel + HSF GPU temp. [°C]	Microchannel + HSF Memory temp. [°C]
0	OTL	OTL	OTL	109	93	79.5
10	134	97	50.5	81	65.5	48
100	54	42	26	44	37	27

Simulate combined strategy of microchannel + heat sink and fan

Thermo-Mechanical coupling

- Effect of varying thermal expansion properties among materials

Thermo-mechanical analysis of FOWLP
(Siemens Digital Industries Software)



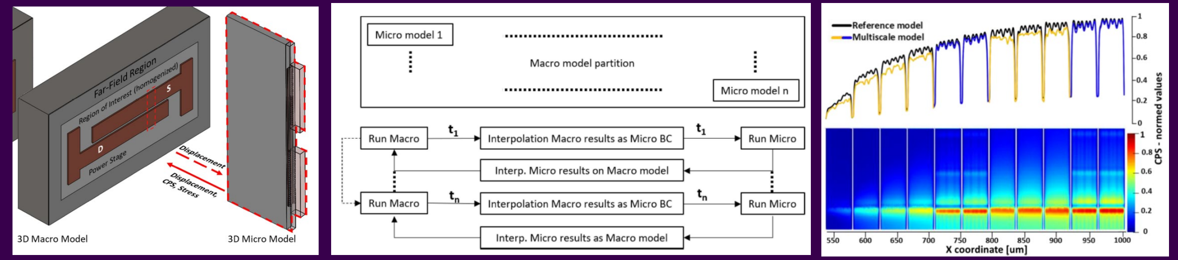
Predict thermal-induced stress and warpage, which may lead to reliability issues

Multi-Scale Simulation

Coupling across different length-scales

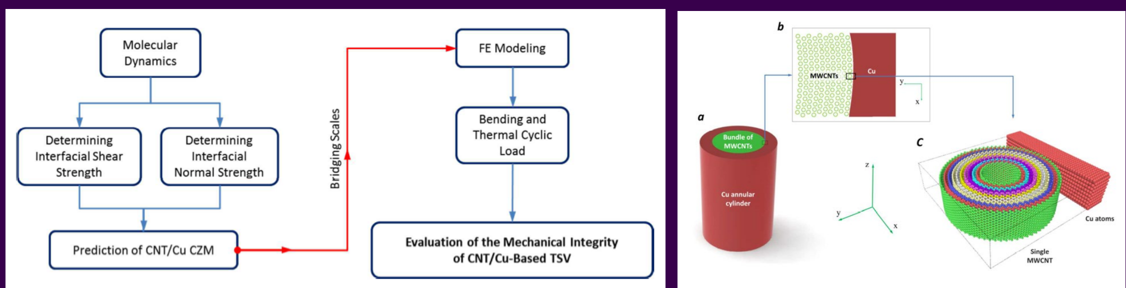
- Lumped parameter model / 3D model
- Macro-scale / Micro-scale

  Two-way coupling of Thermo-Mechanical Simulation of Power Integrated Circuits (Bojita et. al., 2022, IEEE J. Electron Devices Soc)



- Nano-scale

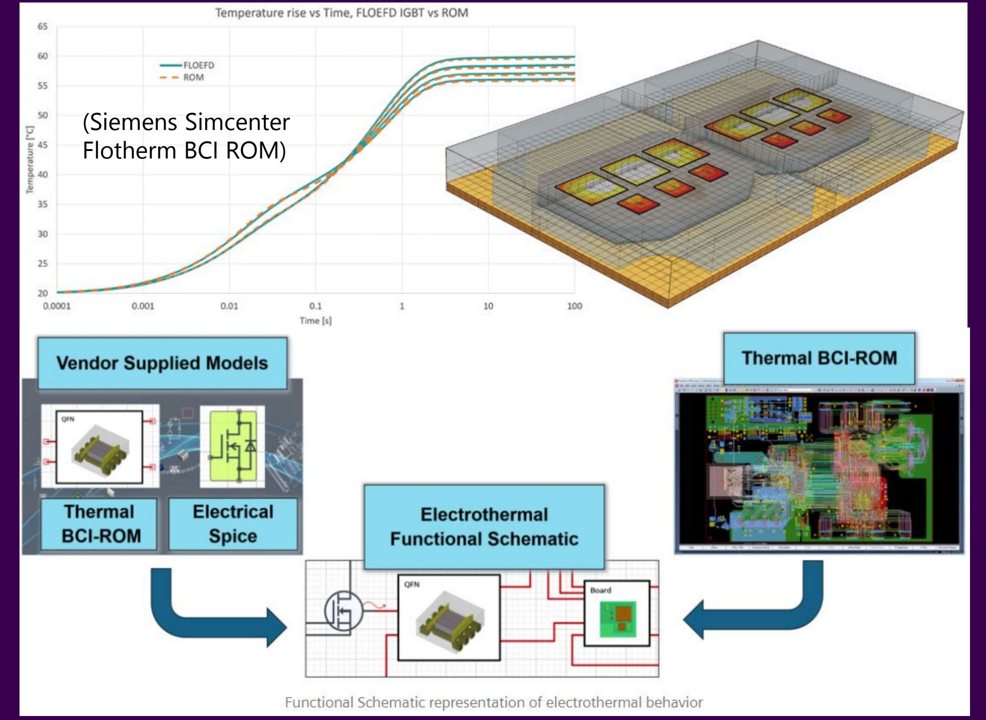
  Molecular Dynamics simulation to determine CNT/Cu interface adhesion properties for thermo-mechanical simulation (I. Awad, et. al. Nanotechnology, 2015)



Reducing Computational Complexity

- Reduced order model (ROM) to simulate physics behavior independent of boundary conditions
- Hours of simulation can be simulated in a matter of minutes

  Spatial temperature response of the BCI-ROM vs high fidelity simulation of an IGBT using ROM (Siemens Digital Industries Software)



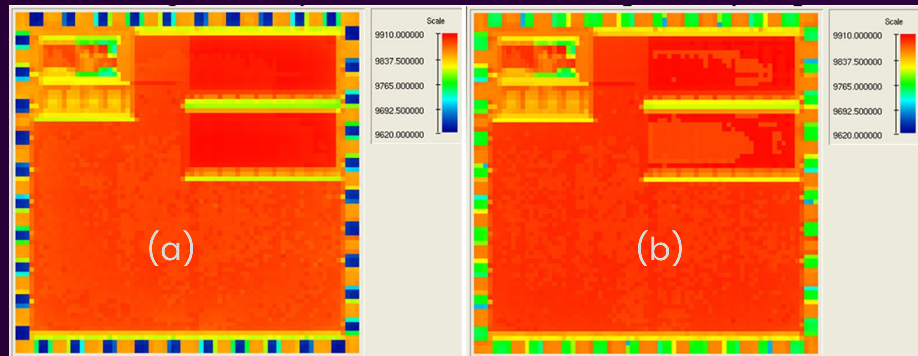
Upcoming challenges

With increasing complexity in design, How to reach optimal performance faster?

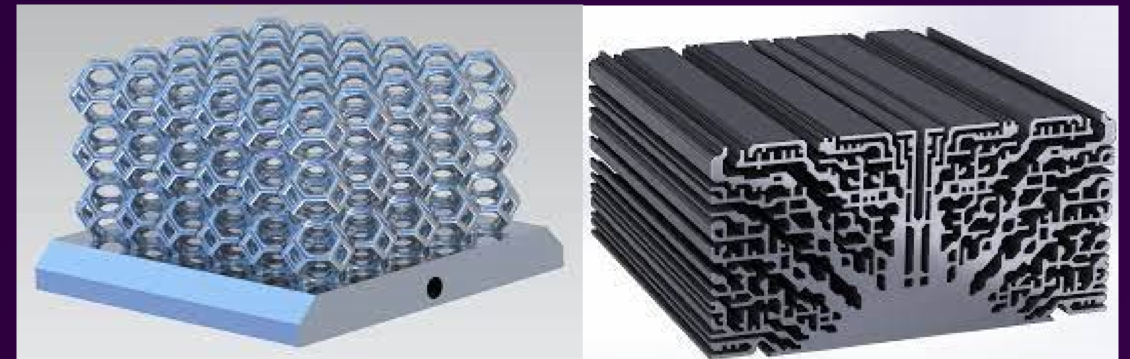
- Seamless and intelligent integration of different physics domain / scales and automatic model generation
- Novel simulation methods to speed up analysis
- Data management and visualization for collaboration
- Embedded sensors could permit run-time optimization of work-load

How to make sure the optimal design generated can be manufactured?

- Embedding manufacturing / fabrication considerations at early stage (e.g. hotspots detection, optimizing filling strategy)
- Consideration of advanced manufacturing methods at design stage: e.g. lattice design, topology optimization



Simulated surface topography colormap for Chemical-mechanical polishing using Calibre CMPAnalyzer
(a) before and (b) after fill optimization



Novel heat sink designs for 3D printing (Siemens)