An Integrated Workflow for Semiconductor Package Design

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Increasing complexity in semiconductor design

Semiconductor companies are approaching their reckoning with Augustine's law as continued efforts to keep up with Moore's law, the increasing demand for computational power, and the widespread applications of edge computing are exponentially increasing design complexity. All the while semiconductor companies must not increase product time to market, give up on profit margins, or sacrifice on quality. This is leading to advanced packaging being more important than ever and we are seeing packaging complexity increase exponentially with 2.5D/3D designs. So, just like the aerospace companies before them the semiconductor industry must adopt a model-based system engineering approach that emphasizes an integrated product design workflow.

Thermal Simulation

One of the most critical challenges in advanced packaging is to keep the semiconductor temperatures at bay. 150 ºC is the maximum operating junction (semiconductor active region) temperature for most Si based technologies. Higher temperatures or large temperature swings have a destructive effect on the structure of the package, therefore thermal design has become an increasingly important aspect of the package design workflow. By keeping the junction temperatures low, the thermo-mechanical stresses originating from the CTE (coefficient of thermal expansion) mismatch between structural layers can also be kept lower. This helps avoiding issues such as cracks or delamination in the die attach layer or in the C4 bumps.

The thermal and mechanical behavior of complex package structures can be analysed using co-simulation of dedicated CFD and FEA solvers. We'd like to demonstrate this analysis process in a few simple steps:

The definition of the package can come from either an MCAD tool or can be created within a thermal simulator directly. We used Simcenter FloEFD as a CFD solution embedded in the NX environment. FloEFD has a 'Package Creator' tool which supports the quick modelling of common package types using a parameterized input. Beside the feature sizes the material properties should be defined in this stage. A model of a FCBGA (Flip Chip Ball Grid Array) Package can be created this way in minutes, see Figure 1.

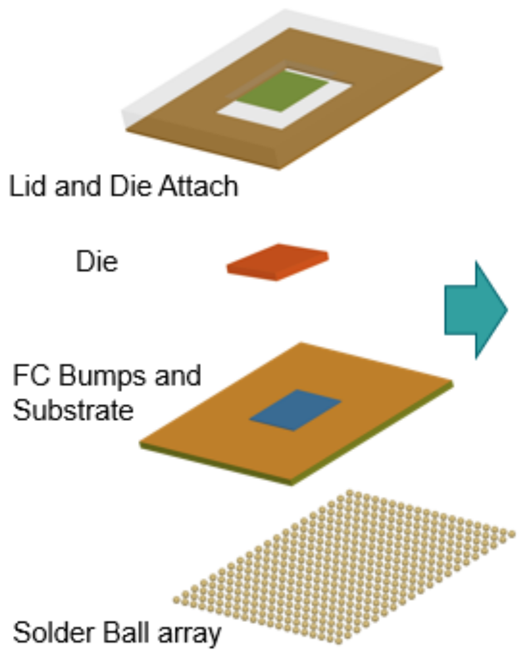

Figure 1: Example FCBGA Package Created in FloEFD for NX

The component can be simulated individually or mounted on a PCB resembling its intended application environment:

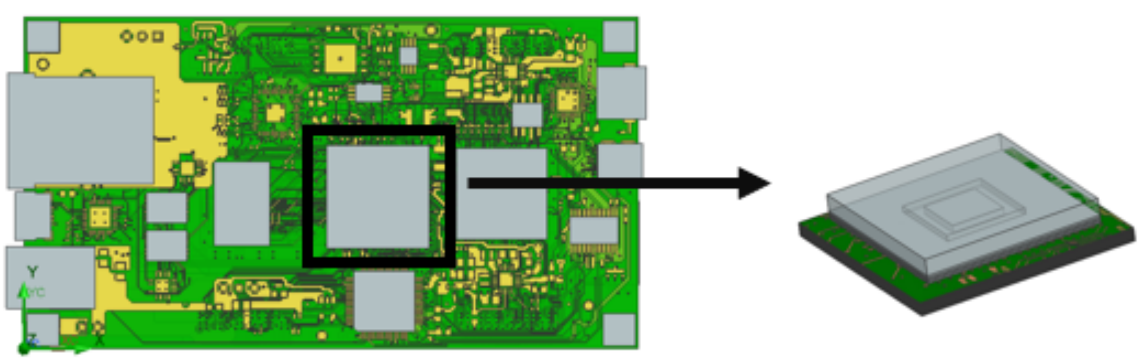

Figure 2: PCB model import and adding a refined package definition

You can choose to perform simulation using the entire PCB or just cut out a narrow section below the package depending on the goal of the study. Before the thermal simulation could begin, the material definitions should be adjusted. The simulation can be set to conduction only or convection and radiation can be enabled as well. A refined thermal mesh is created automatically before the simulation can begin. This current example had 1.2 Million cells generated under two minutes and took 25 minutes to reach a solution for a transient simulation. Results can be seen below, including material temperatures and airflow over the device.

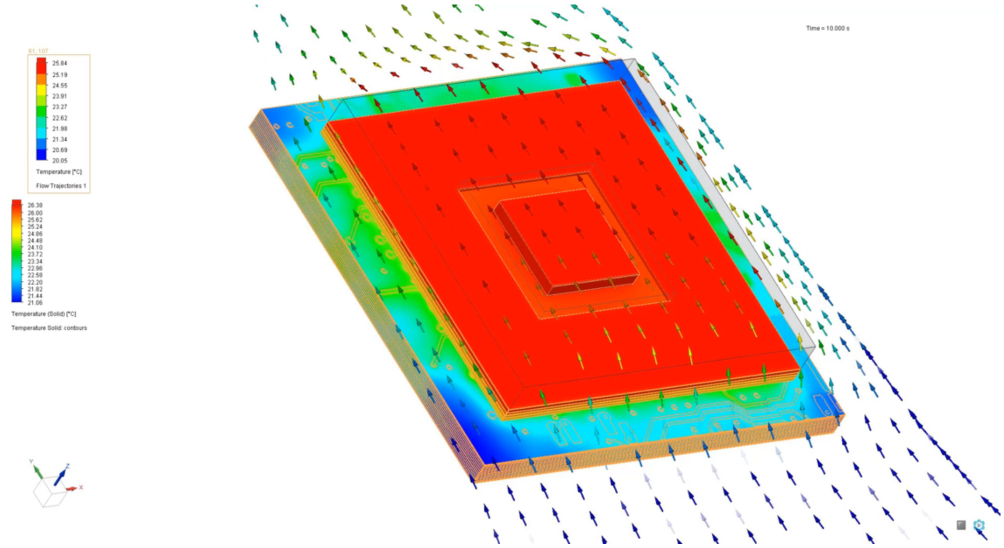

Figure 3: Thermal and airflow simulation results

Structural Simulation

Based on the same model we can create an efficient hex-dominant mesh and conduct linear stress analysis directly using the existing model and calculate fields such as the Von Mises stress or equivalent tensile stress:

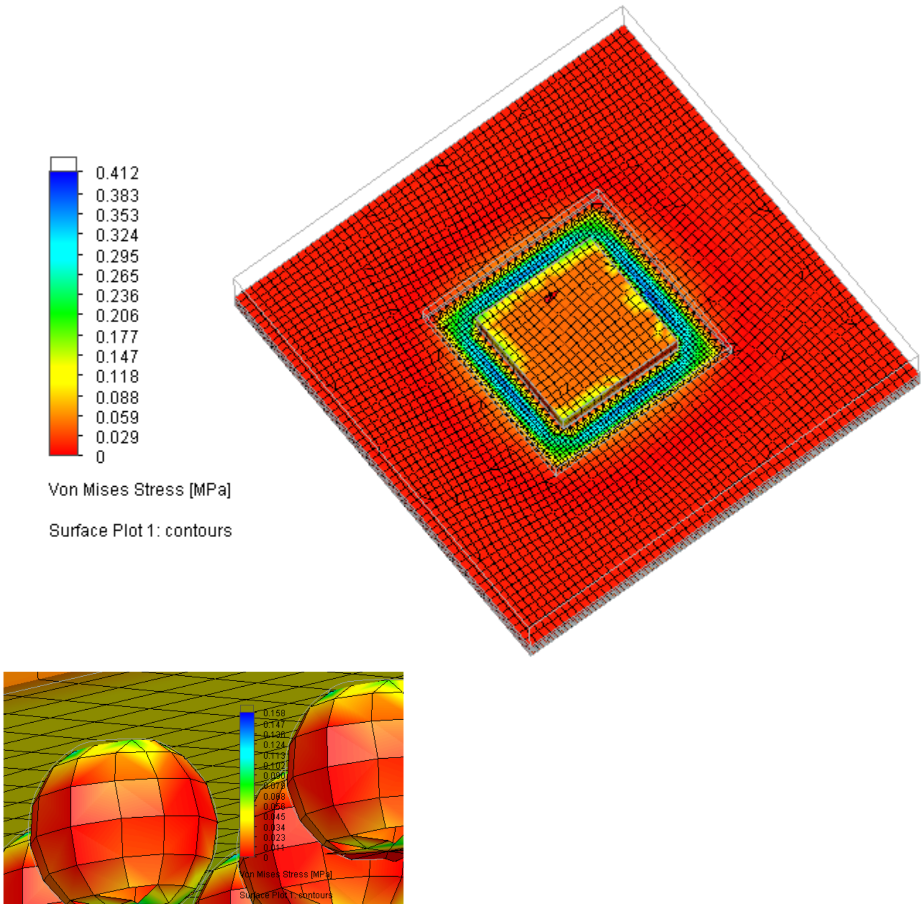

Figure 4 Von Mises Stress results generated in Simcenter FloEFD

To perform non-linear analysis, mesh, materials, glue contacts, constraints, and loads are to be defined and one can choose from a variety of useful solvers, such as creep, displacement, and fatigue simulations for thermal cycles. Figure 5 shows creep simulation results of our example case for thermal load.

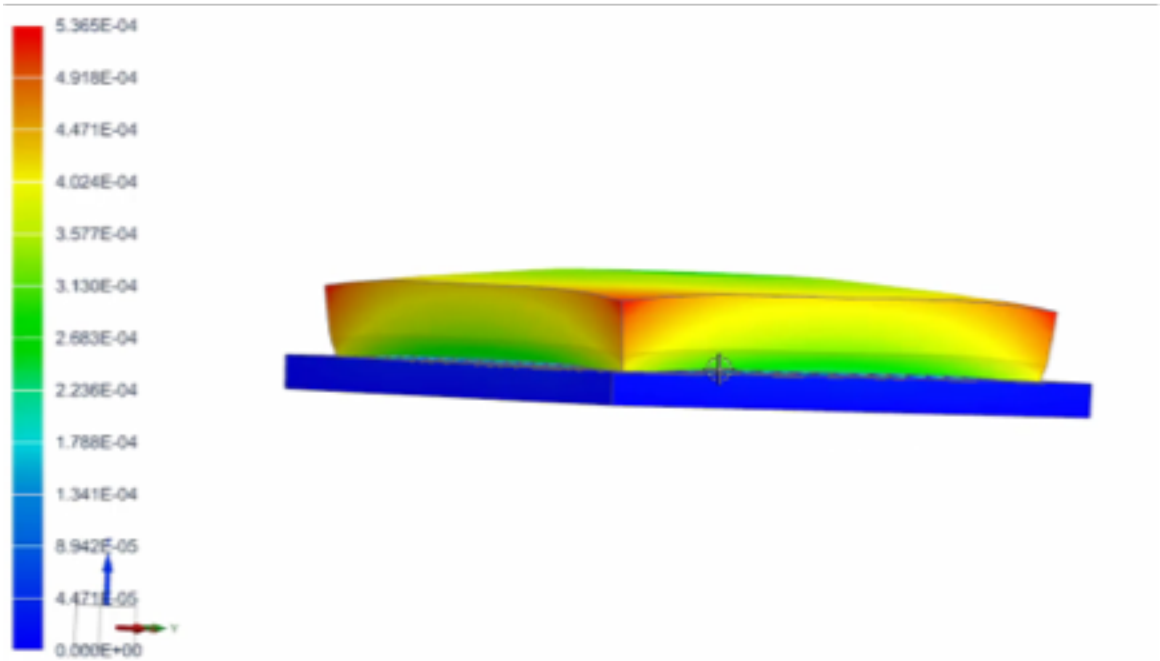

Figure 5: Displacement simulation results under thermal load

Thermal Model Calibration

GIGO, Garbage in – Garbage out is a commonly used term among simulation engineers. Less dramatically put, your simulation results will only be as good as its import parameters. Very often material parameters such as thermal conductivity coefficients, interfacial thermal resistances between layers are defined with high levels of uncertainties only or not known at all. The reason is that bulk materials may show different properties than after being processed and the interfacial thermal resistances often depend heavily on material surface qualities. For this reason, even in case of the most carefully prepared models it is recommended to test the resulting thermal properties of a component and in case of mismatch between the simulation and the test results, the thermal model parameters should be re-calibrated. The Thermal Transient Testing process can apply a power step on the semiconductor die and measure its corresponding thermal response. The 'unit power step response' will be characteristic to the thermal system, hence the transfer function of the package can be calculated.

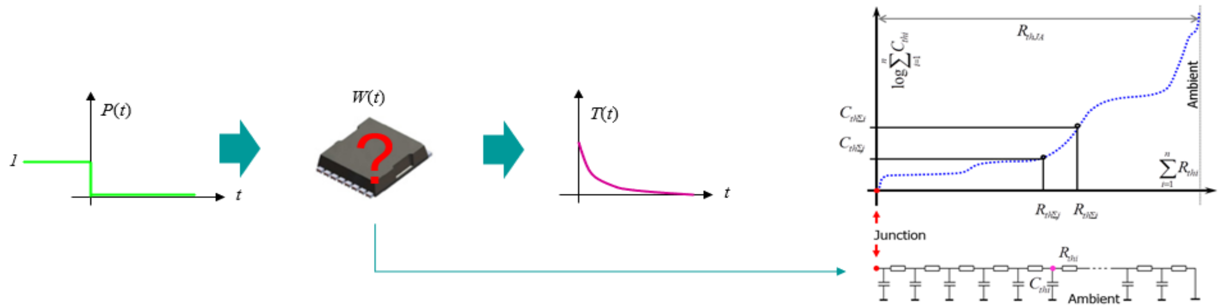

Figure 6: Thermal Transient Test Approach

As a result, the package can be modelled with an equivalent thermal R-C network consisting of hundreds of elements. For essentially 1-D heat spreading cases these R-C elements have strong correlation with the real thermal properties of the individual structural layers of the package.

For model calibration purposes, if we replicate the test in a CFD environment, in other words using the same boundary conditions, input power and transient time steps as in the test, the R-C network model describing the digital twin of the package must be the same as the R-C network model obtained from the test. In case of mismatch, one must find the missing contact thermal resistance values, adjust the ill-defined thermal conductivities, or even adjust the geometries if needed.

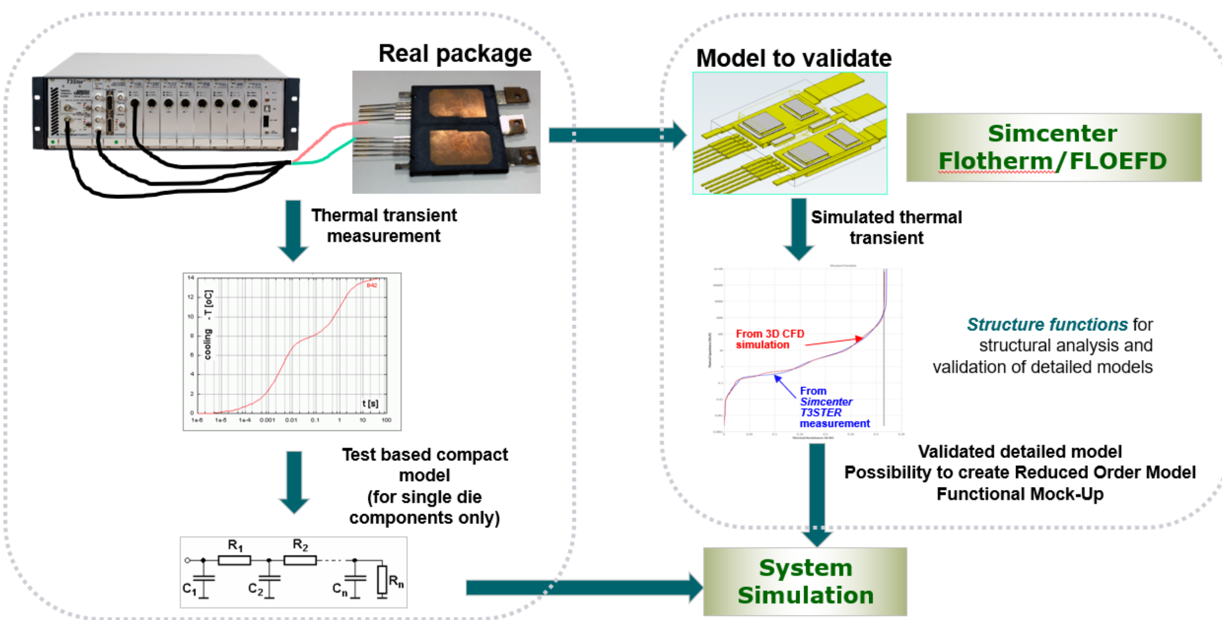

Figure 7: Thermal Model Calibration Workflow

The calibrated digital twin will have several benefits:

- It will behave thermally exactly as the real physical device, even for transient simulation cases
- The corresponding structural simulations will be more accurate, too as they need accurate thermal fields as an input
- The behaviour of selected materials will be understood and can be saved in libraries and used to create better models