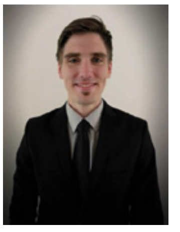
Electrothermal Simulation Study by ZFW

Successfully carried out with MicReD® Power Tester and FloEFD™



By Christian Rommelfanger, ZFW

ZFW, Zentrum für Wärmemangement (Center for heat management) based in Stuttgart, specializes in comprehensive services in heat management and lifetime testing of components and systems. No matter the industry, our clients all basically want the same thing: a fast and simple solution for a specific thermal problem. We rely on a fast and easy to use CFD system that is capable of handling different applications as our consulting projects are spread through almost every industry sector, from automotive to production systems, and usually our clients give us a call when a project is time critical. That's why we use congruent CFD software to give our customers a fast and reliable answer to their questions. Besides simulation we offer our clients a wide range of measurement techniques and test benches. We think, in a modern engineering department, simulation and measurement needs to fit closely together to work effectively.

In power electronics, it is critical to have a tight fit between simulation and measurement. Even small differences in the simulation can have a big difference in predicting the lifetime of a component. Within an industrial project, ZFW conducted a detailed electrothermal simulation study of a bridge rectifier as an example for the use of coupled simulations to get more

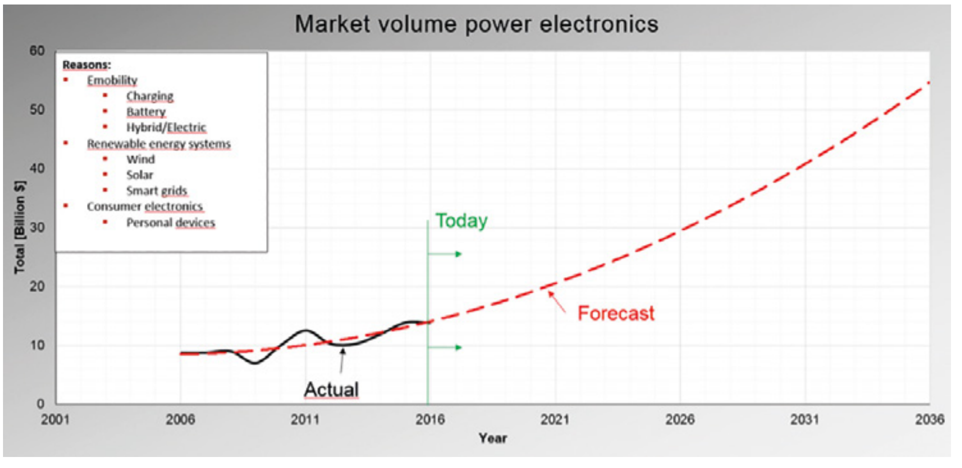


Figure 1. Forecast of the power electronics market

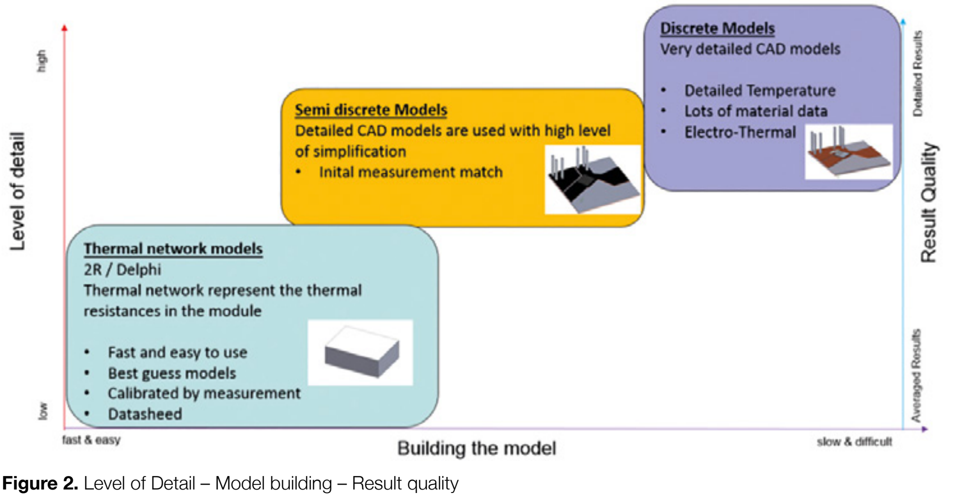


Figure 2. Level of Detail – Model building – Result quality

Types of power electronics			
Input	**Output**	**Name**	**Application Example**
AC	DC	Rectifier	E-mobility, renewable energy systems or industrial applications. Exchange between AC and DC electricity (socket <-> battery)
DC	AC	Inverter	
DC	DC	Converter	In mobile phones to maintain the voltage at a fixed value independent from the state of charge
AC	AC	Converter	Change of frequency or voltage, for example in power distribution network for change utility frequency 50 Hz to 60 Hz power grids

Table 1.

accurate results for reliability prediction of power electronics.

The forecast of the power electronics market predicts a rise of 200% in the next ten years. (Figure 1) There are several reasons for the increased demand in power electronics, such as the rapidly increasing market for e-mobility, the strong demand for renewable energy, and the uprising market for personal devices – just to mention a few. In most of these applications clients have high requirements on the sustainability of the device.

Keeping in mind that the rule of thumb of a 10 K change in temperature leads to almost 50% change in lifetime, it becomes clear that even with typical errors from thermal simulations, the error in the lifetime prediction can be worse. A 5% error in power losses within the device can have a serious impact in lifetime prediction. Usually our customers have +/- 10% error in their power loss prediction.

That's why it is very important for engineers to have accurate models for reliability prediction in early stages of development. Furthermore, it is crucial to have good and accurate boundary conditions that match the application.

In a nutshell, power electronics means the application of solid-state electronics to control electric power. In modern industry, there are plenty of applications where power electronics helps to control power. AC/DC rectifiers are used to change the alternating current of the electricity grid network to direct current for loading the battery of an e-car. In personal devices like mobile phones, DC/DC converters are used to maintain the voltage at a fixed value independent from the state of charge of the battery.

Figure 3. MicReD Power Tester

Most companies use the basic empirical based Coffin-Manson model (Equation 1) and add specific influences in the equation that they observed in experiments.

$$N_f=a* \Delta T^n$$

N_f: Cycles to Failure
a,n: Empirical Parameter
T: Temperature
Equation 1

A typical addition to the Coffin-Manson law is an Arrhenius approach (Equation 2) to implement the influence of the average junction temperature to the lifetime prediction.

$$N_f = a* \Delta T_j\text{-}n*e \frac{E_a}{K*T_m}$$

E_a: Activation Energy
K: Empirical Parameter
T_m: Average Temperature
T_j: Junction Temperature
Equation 2

The MicReD® Power Tester was used to determine the empirical coefficients in the Coffin-Manson equation. As well as for many additional parameters for various types of customer based lifetime laws. There are many different strategies to determine the constants in the lifetime laws for components, such as constant temperature change or constant current and so on. Which tactic is the right one always depends on the specific application. Assuming the following constants for a given application, that fit the basic Coffin-Manson law, we arrive at the results that a change of the Junction Temperature of around 10 K leads to about 44% change in lifetime (Equation 3).

$$\textit{Coffin–Manson: } N_f = a * \Delta T^n$$

$$a = 10000000000$$

$$n = 2{,}7$$

$$N_f\,(80\ °c) = 72720$$

$$N_f\,(70\ °c) = 104288$$

Equation 3

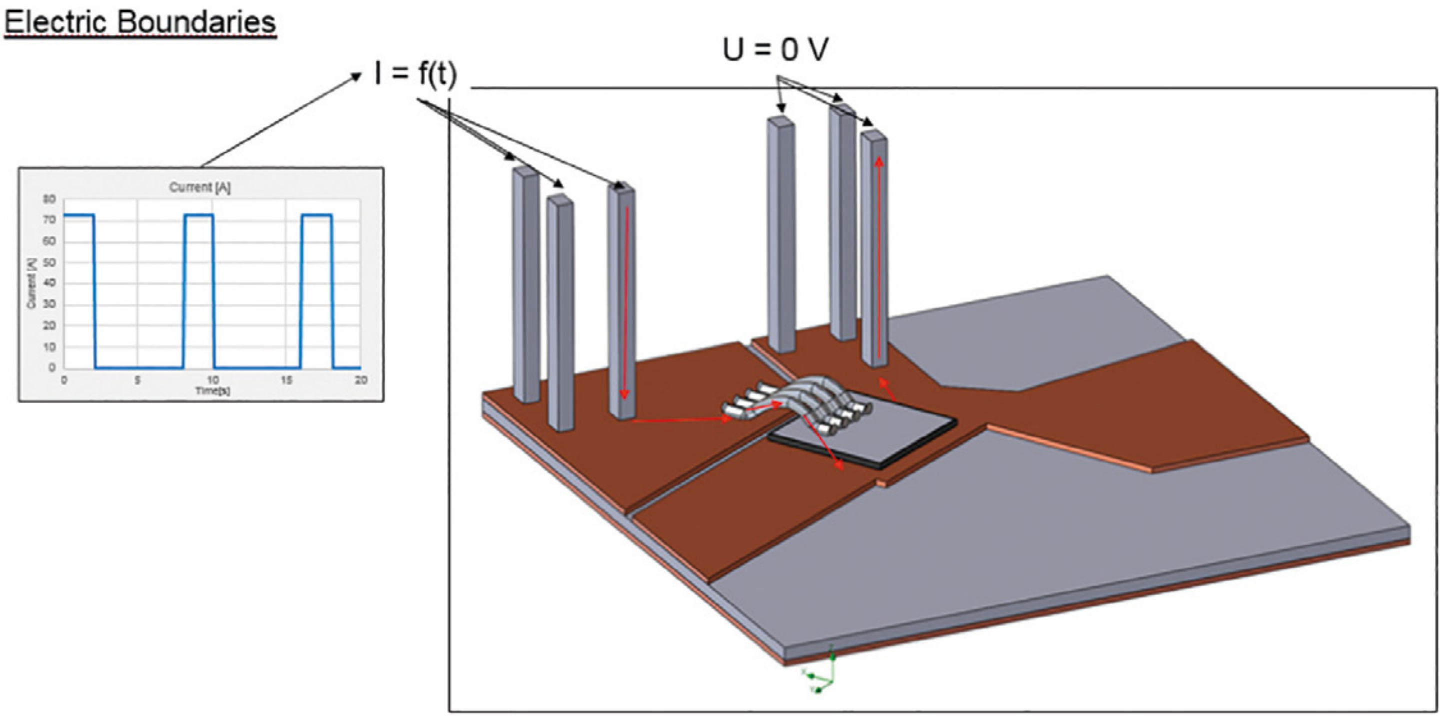


Figure 4. Electro-thermal simulations in FloEFD

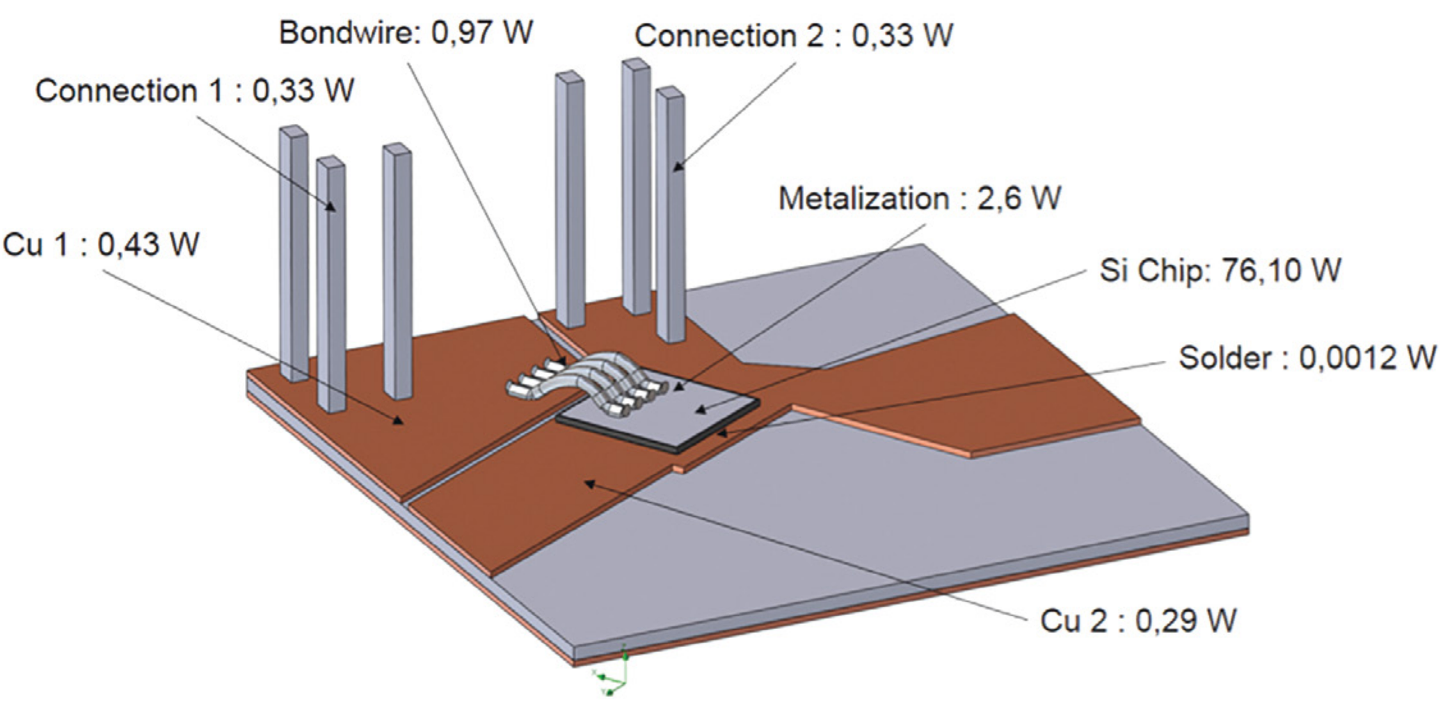


Figure 5. Detailed Power loss distribution increases design accuracy

"With these findings from the study, using the combination of the MicReD Power Tester and FloEFD, reliable simulation models can be created and used in the future."
Christian Rommelfanger, ZFW

As mentioned before, a 10 K change in temperature leads to almost 50% change in lifetime. Because of this relationship between temperature and lifetime, it is critical to have accurate models for electronics. The results of thermal models can be improved by coupling the thermal simulation with an electric one.

Figure 4 shows an overview of how electro-thermal simulations works with FloEFD™. The geometry is based on a single diode of a bridge rectifier. The electric boundaries are three power steps in 20 seconds with a length for each power step of two seconds. The thermal boundary is a fixed temperature at the bottom of the device.

The 3D electric simulation can predict the actual Joule heating in every part of the system. Two-way coupling between electric and thermal simulation works in two directions. It enables the direct transfer from the power losses due to Joule heating into the thermal simulation (figure 5) and the temperature for predicting the temperature dependent electric resistance into the electric simulation.

In the Si-chip itself power loss is 76,1 W. A stand-alone thermal model that would use the overall power loss of 81,6 W, as a volume source in the silicon would lead to an error of 7%. This leads to a temperature error of 8,4 K, assuming a junction temperature of 120°C. Calculating the lifetime with the error of 8,4 K would result in a 50% error in lifetime prediction.

The temperature dependent electric resistance of the silicon chip is calibrated through a parameter study of the measured $R_{SD_{on}}$ in the MicReD Power Tester for a given current. In the post process of the electric simulation the voltage drop in the Si-chip can clearly be seen.

In the thermal simulation, the distribution of the temperature through the diode is shown. Notice that the bond wire works in this transient load chase, due their thermal capacity as a heatsink. Comparing this simulation with measurement results in the MicReD Power Tester the error in temperature at the junction is less than 1K.

Conclusion

In reliability investigations of power electronics, it is important to have accurate temperature field prediction in the Si-Chip. Ordinary thermal models give a good insight in the temperature distribution in an electronic system, but when it comes to component reliability detailed electric/thermal studies need to be done due to their sensitivity to temperature. To simulate the thermal chip behavior, it is very important to have reliable material data. A parameter study that compares a measured voltage drop to a simulated voltage drop can help to characterize the material value. The error with a calibrated electro/thermal model can be less than 1K if the baseplate temperature is fixed (coolplate) and the heat losses occurs due Joule heating. The methodology used in this example isn't just for diodes it can transferred to MOSFETs and similar devices as well.

With these findings from the study, using the combination of the MicReD Power Tester and FloEFD, reliable simulation models can be created and used in the future.

References

https://www.zfw-stuttgart.de/

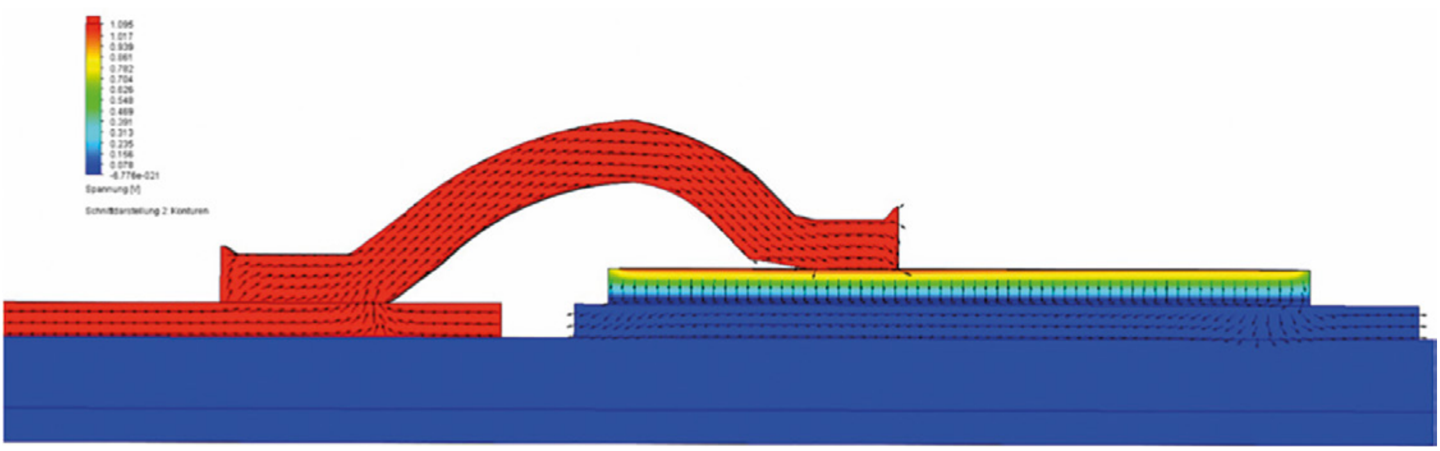


Figure 6. Voltage drop

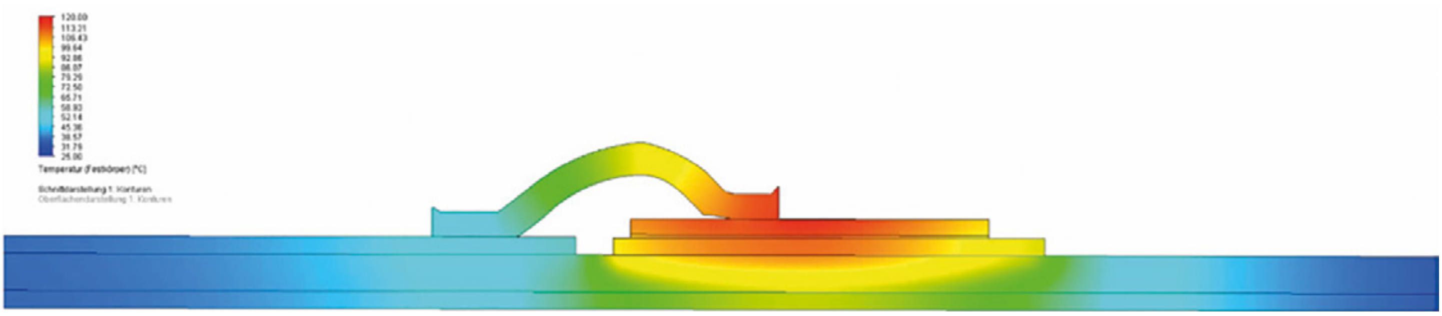


Figure 7. Temperature distribution