SUMMARY

It is well known that power semiconductor devices are now going through a rapid evolution. Especially IGBT (Insulated Gate Bipolar Transistors) modules are getting more accepted and increasingly used in the power electrical industries as high power and high voltage switching components. This is due to an advantages such as high input impedance, low on voltage, and high frequency capability, which are achieved by combining the attributes of power bipolar transistor (BJT) and power VDMOS.

Under a quality aspect, the probability of failure in electronic equipment is strongly dependent on the operating temperature, especially regarding the junction temperature. Thermal overstressing is the most common failure cause in modern electronic systems. Therefore, it is really important to understand the static and dynamic thermal characteristics of modules on which IGBTs are mounted.

In this project the thermal behavior of the IGBT power module, named as E2 Module, provided by ABB semiconductors AG was investigated under static and dynamic conditions. Thermal interference and solder size effects were investigated for steady state analysis. In the dynamic response, the thermal impedance was characterized by two transition times. For a Pulse Width Modulation (PWM) scheme, conduction and switching losses were considered and a RC component model was proposed to predict the thermal characteristics in steady state periodic condition.

The 3D thermo-mechanical simulator SOLIDIS-ISE was used to analyse the static and dynamic thermal characteristics of the IGBT power module. The RC component model was extracted to predict the long time thermal characteristics of the module.

Thermal resistance Rjc, junction to case, was calculated to be 8.88 [K/kW] per module on IGBTs and the minimum temperature on molybdenum surface was 9K lower than peak temperature 322.2K. With thermocouple method, the thermal resistance Rjm from junction to the middle of baseplate was measured as 5.32 [K/kW] per module on IGBTs. This value is somewhat smaller than the simulated result of 6.3[K/kW], but size and position of the thermocouple in the baseplate contributed to a large uncertainty in the measured results. The infrared measurement was also used to measure the thermal resistance of one subassembly. The measured result was 98.1 [K/kW] per chip on IGBT, quite close to the simulated value of 92.5 [K/kW]. The difference between the measured and simulated values was less than 6% at various applied powers. This strong correlation between the simulated and the measured data serve to validate these models.

In a steady state condition, the material thickness influence, the thermal interference between the adjacent chips and the solder size influence were simulated and analyzed. It was found that soldering of the E2 Module played an important role in determining the thermal performance. Less than 20% reduction of solder area can be allowed to keep the variation of the thermal resistance within 10%. The minimal chip distance, for which thermal interference does not take place, was found to be 6mm.

In the dynamic response of the thermal impedance, two distinct transition times at $400u\sec$ and $80m\sec$ were observed due to the dynamic thermal behavior. The first transition time results from a change in the heat flux direction caused by heat capacitance difference between the upper and lower part of the E2 Module. 3D spreading effect of baseplate occurred after $74m\sec$ and made second transition time in thermal impedance curve of E2 Module.

To make the real conducting power of PWM scheme, switching energies were added to one time step of conduction loss and 1500 time steps were used to represent 3 cycles of the curve up to 0.06 second. During the first cycle, the maximum temperature difference was increased up to 16.03K and 3 cycles was 27.25K. For subsequent times, the temperature would be periodically increased in a similar way until to reach the steady state. Switching lossed power influence and diode conduction effect were also simulated and discussed.

The simplified RC Component Model (RC_CM) was developed using the results of a single SOLIDIS-ISE simulation run. The goal of RC_CM is to produce an accurate, computational efficient, and easy-to-use thermal model so that dynamic simulation in a long time range can be efficiently performed. The dynamic response of SOLIDIS-ISE and RC_CM agreed well at the concerned points (middle of silicon, top of substrate and top of baseplate). With the RC_CM model, the mean temperature of chips was calculated as 42.82K on IGBT and 3.73K on diode at steady state periodic time. The frequency effect was also simulated. The CPU time for steady state periodic condition in SUN UltraSpac-II, 250MHz workstation was around 2 minutes for the RC component model, while SOLIDIS-ISE estimated 10 days.

The work in this project showed the static temperature distribution and the transient heat spreading in semiconductor modules. These simulations were made possible after the existing simulation software was adapted to fulfill the needs of these problems. The benefits for development and production of semiconductor modules, with regard to energy and power dissipation, rise from the possibility to simulate and estimate the temperature

distributions inside and outside of the module structure more accurately. This reduces the safety margins necessary in the product specifications of such devices. Thus, the performance and therefore the safe operating area at given specifications can be increased. In conjunction with occasional soldering problems in the module production process, the project showed the kind of temperature inhomogeneities that can arise, if precipitations appear in the solder layer. This information is very important for the evaluation of admissible non-ideal soldering.