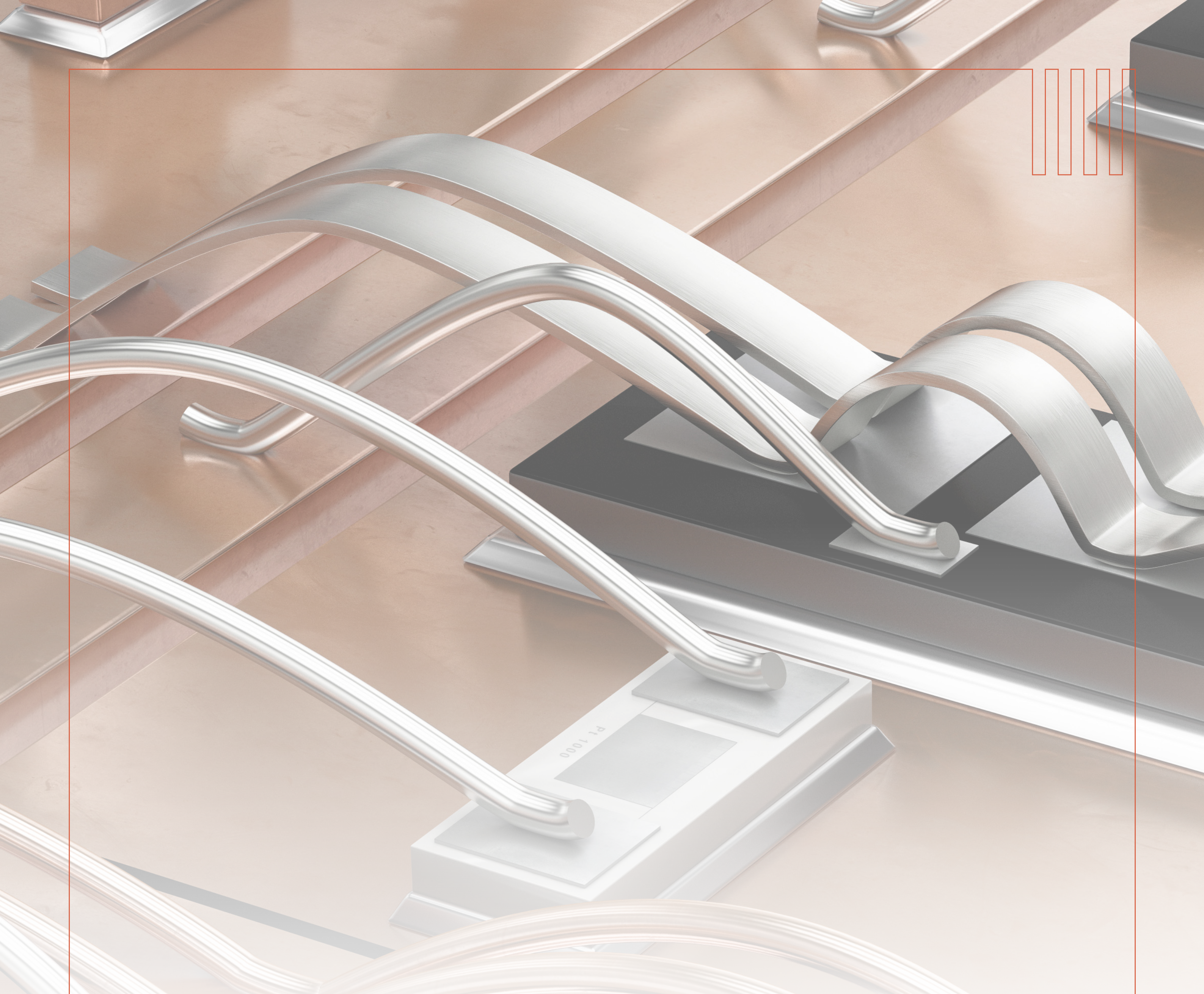


YAGEO GROUP
YAGEO Nexensos

Temperature Sensing in Next Generation Power Electronics

Sinterable temperature sensor in SMD technology

Precise Temperature Control Ensures High Performance of Power Electronics

Power electronics are considered the pacemaker of any electric vehicle: performance, pace and efficiency are determined by the layout and capabilities of the voltage converter and inverter units. Higher switching frequencies, higher power levels and the resulting operation at higher temperatures contribute to longer driving ranges and more dynamic driving modes. In addition to electric vehicles, other applications such as wind turbines and telecommunication infrastructure benefit from power components operating at higher frequencies. A higher operation temperature raises the need for new materials and new connection technologies: Silver-sinter processing is on the way to becoming the standard connection technology. Process simplification occurs when components can be mounted in one process step using a single mounting technology. In addition, well-designed components facilitate simplified power module geometry, with no need to isolate the temperature sensor. The end-result is a wider application and operating window.

Product Innovation: Sinterable Pt1000 in SMD Form Factor

The sinterable Pt1000 temperature sensor in the SMD package from Nexensos offers the step to next-generation temperature sensing. The design was developed to contribute to power module optimization: the electrical isolation between the sensing layer on the top side and the backside metallization allows potential-free positioning of the temperature sensor adjacent to the heat source (see Fig. 1).

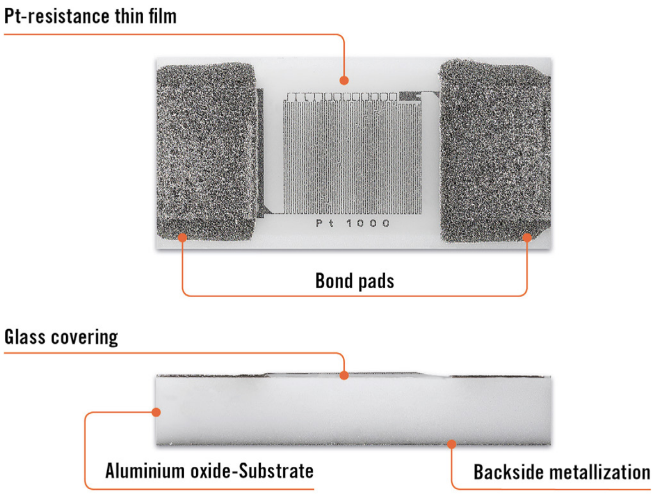


Fig. 1: Components of the sinterable Pt1000 SMD-SC temperature sensor. Bond pads (AgPt) for thin and thick wire bonding and backside metallization (AgPd) optimized for silver sinter processing.

This design freedom enables optimization of the power module layout. Temperature measurement is faster, and more accurate. In addition, the substrate design can be simplified; the sensor and other components can be installed at the same electrical level, on the same substrate. The need for mounting the sensor chip on a separate "island" is eliminated (see Fig. 2).

In order to understand in more detail the impact of sensor positioning on the board, a simplified model was employed to investigate heat distribution and response times in state-of-the-art silicon-based power modules as well as next generation silicon-carbide based setups; the chosen design geometry is independent of the material selection, the material properties as well as the operating temperature have been adjusted to resemble Si and SiC based designs.

Modelling studies have been accomplished using the Comsol CFD modelling suite, material properties and parameters have been chosen to describe the setup of the sensor; the focus of this study has been put on the temperature detection. Design optimization has not been targeted in this approach. Therefore, additional effects like heat dissipation by bonding wires are not included. The effects of different potting compounds have not been taken into account. The study focuses on the effects of the distance and the substrate layout, and the impact of the distance between the heat source and the temperature sensors, as well as an additional etched trench.
The junction operating temperature has been set to 150 °C for silicon-based power modules and to 200 °C for next generation wide band gap (WBG) materials. Heat production has been included by the set of the junction temperature. The power dies themselves, and the temperature sensor remained un-powered; self-heating effects of the temperature sensors have also been omitted.

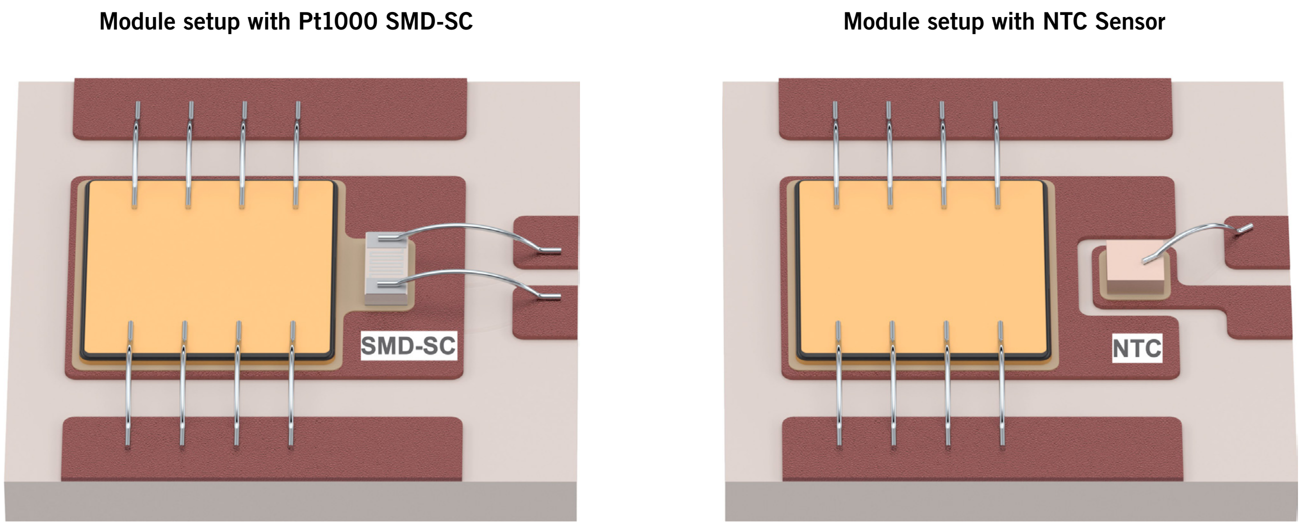


Fig. 2: Design options for electrically isolated (left) and top & bottom contacted temperature sensors (right).

As mentioned previously, special attention has been given to the substrate layout; the new sensor type allows for substrate simplification by removal of the (redundant) etched trench. In Fig. 3, different geometries resulting in varied distances between the temperature sensor and the heat source are compared: due to the sensor design, a flexible positioning of the sensor has been achieved where the sensor can be placed directly next to the power dies (left); hereby, the distance has been modified to resemble currently employed options to position the sensor on the substrate.

For comparison purposes the effect of the etched trench on the sensing accuracy as well as on the response time has been highlighted in the adapted model (Fig. 3, right). The etched trench is required as additional design element for through-contacted components such as NTC-based sensor elements; this design ensures electrical isolation between the sensor and the power electronic substrates. Using a Pt1000 sinterable SMD sensor with top-located electrical contacts eliminates the need for an isolating trench, greatly simplifying the board design and manufacturing process.

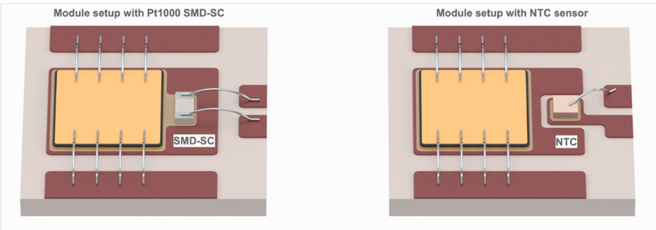


Fig. 3: Substrate geometry and position of the sensor: Distance variations of the sensor (left) and position of the sensor in substrate geometries providing an additional etched trench for insulated sensor positioning (right).

Modelling Results

Sensor Position

The sensor position has a substantial influence on the accuracy of the temperature measurement. In the considered configurations, both at 150 °C and 200 °C operating temperatures, the spread between junction temperature and detected temperatures is heavily impacted by the distance between the sensor and the power dies. As mentioned at the beginning, the chosen model does not consider any specific potting materials and heat dissipation can take place across the entire surface. In summary, the overall temperature distribution is lower compared to a condition where potted components are considered without affecting the general trend: The almost linear dependency of the temperature drop on the distance is clearly visible from Fig. 4.

With increasing distance, the drop of temperature becomes more pronounced and the deviation from the junction temperature decreases the accuracy of the measured temperature. For through-contacted temperature sensors that rely on the bulk resistance of the entire sensor cross section, an additional etched trench is required to mount the sensors in a potential-free manner. This additional design element further increases the distance between the heat source and the sensor position and impacts the accuracy. The temperature drop between the power die and the sensor chip is even more pronounced, leading to a non-linear drop at the chosen distance here. In Fig. 5, the temperature distribution (a) as well as the drop of measured temperatures in configurations with and without an additional etched trench are elaborated in more detail.

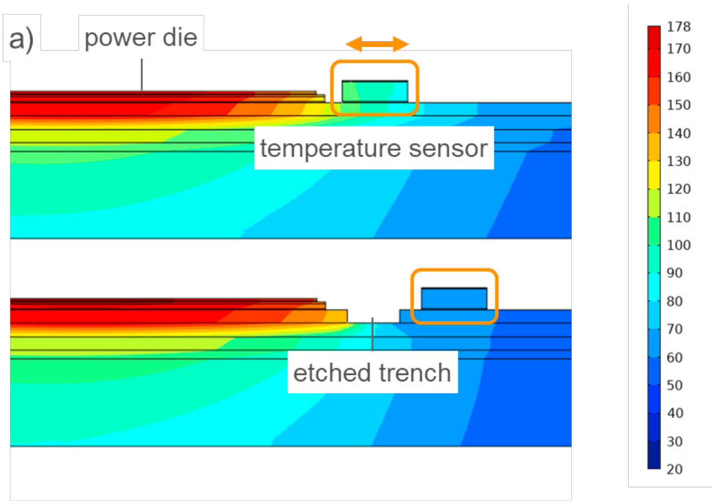


Fig. 4a: Temperature distribution in power modules operated at 150 °C junction temperature. Top: Substrate geometry without etched trench; Bottom: Additional etched trench for electrically insulated position of the temperature sensor.

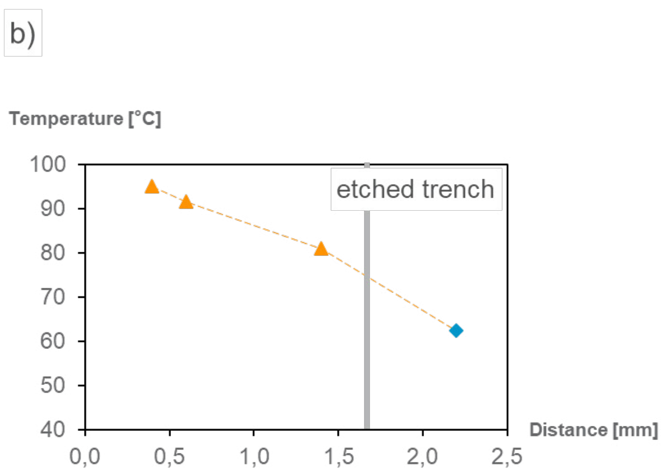
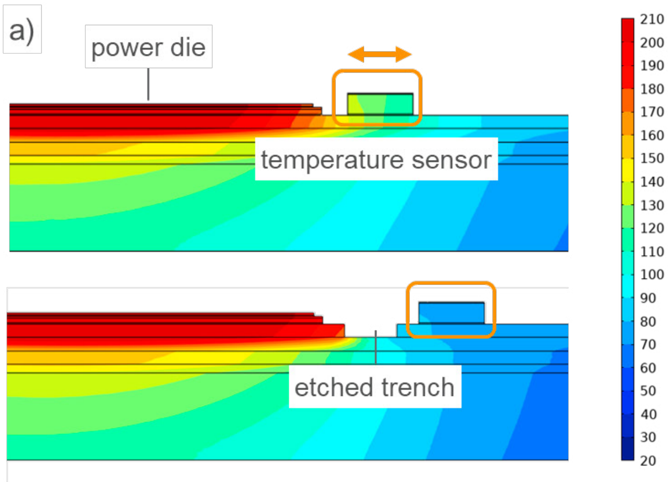


Fig. 4b: Detected temperature as function of the distance between power die and temperature sensor; the position of the additional etched trench is marked as grey double line.



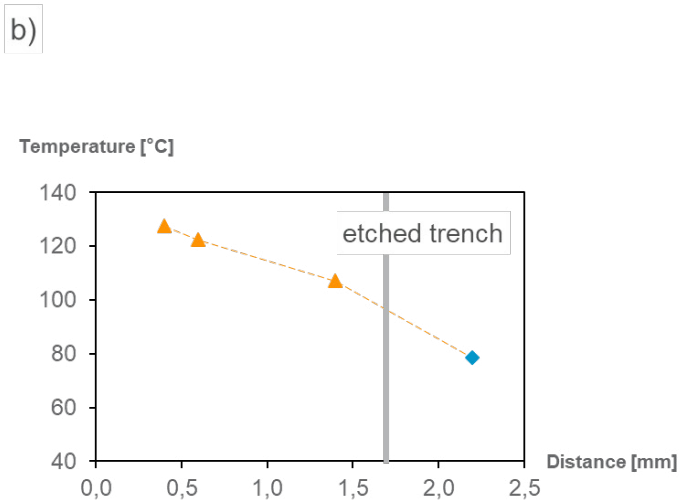


Fig. 5a: Temperature distribution in power modules operated at 200 °C junction temperature. The chosen parameters resemble a SiC-based configuration. Top: substrate geometry without etched trench; Bottom: Additional etched trench for electrically insulated position of the temperature sensor.

Fig. 5b: Measured temperature as function of the distance between power die and temperature sensor; the position of the additional etched trench is marked as grey double line.

The non-linearity of the decay indicates the impact on the accuracy of the measured temperature and underlines the performance benefit that can be achieved by minimizing the distance from the temperature sensor to the heat source. From a design perspective, the additional island on the substrate reduces the number of options to place the sensor; the dedicated spot is necessary for bulk resistance sensors (NTC) and adds additional complexity to the layout.

Dynamics

In addition to accuracy also the response time can be optimized by positioning the sensor closer to the power die. In Fig. 6, the thermal response for two different sensor positions upon powering the power die is monitored.

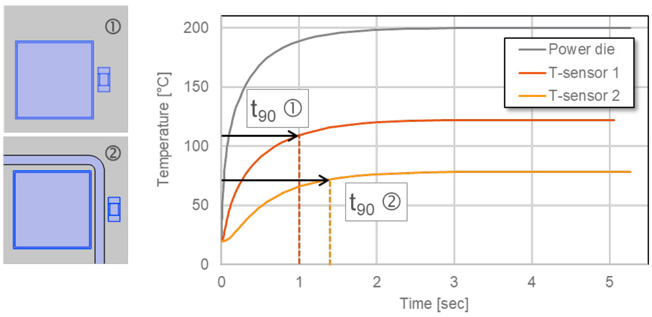


Fig. 6: Dynamics of temperature sensing: temperature response on switch-on process of power dies. Temperature sensor ① is located in proximity to power die, temperature sensor ② is separated from power die by etched trench.

The temperature ramp-up curve of the power die and the sensor next to the die feature almost identical slopes. The temperature measurement and response time is optimized by positioning the sensor close to the heat source ①. By adding the additional etched trench as described above, the position of the sensor moves further away from the power die ② resulting in a substantially slower response and a pronounced delay after the switch-on step.

The time to reach equilibrated conditions is best described by the delay to reach 90 % of the equilibrium temperature t_{90}. Comparing the t_{90} times for sensor position ① and ② with 1.0 and 1.3 sec reveals a substantially more dynamic detection with a 30 % faster detection for the position close to the power die.

In conclusion, not only is the accuracy improved by the proximity of the Pt1000 SMD-type temperature sensor to the heat source, the time to reach thermal equilibrium is significantly reduced, resulting in a much shorter temperature measurement response time. Overheating effects and temperature spikes can be avoided, and the overall life expectancy is significantly increased.

Sinterable Pt1000 SMD for Next Generation Power Electronics

The sinterable Pt1000 SMD package temperature sensor offers a variety of benefits for solving temperature sensing challenges in state-of-the-art and next generation power modules. The layout of the sensor, with an intrinsic isolation between sensing and contact layer allows for new designs and opens up new approaches, as highlighted in Fig. 1. As a result of the electrical isolation between the sensing area and the backside metallization optimized for sinter connections, the sensor can be placed on any available position on the power module board. The reduced distance between the heat source and the sensor element results in higher accuracy and significantly increased response time of up to 30 % of the temperature signal. Connection of the sensor compartment can be achieved by standard thin- and thick-wire bonding; the connection to the board is feasible with standard silver sinter processing which in sum allows for a seamless integration in standard production processes. The sinter connection is key to high temperature operation, opening the operation window far beyond 200 °C. While the Pt1000 sensor element is currently specified with an upper operating limit of 200 °C, on-going development activities target higher temperatures where the limits of sinter connections can be further utilized.

Additional advantages resulting from the ability to modify the substrate layout are quickly highlighted at this point: Omitting the additional etched trench that is required for potential-free mounting of through-contact components (NTC type) reduces design effort on substrate level. This substrate simplification not only reduces material and component costs; the enhanced mechanical stability compared to island-containing designs results in a reduced scrap rate during pressurized sinter processing. Reducing the size of the substrate contributes to smaller components and serves the overall trend towards miniaturization.

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