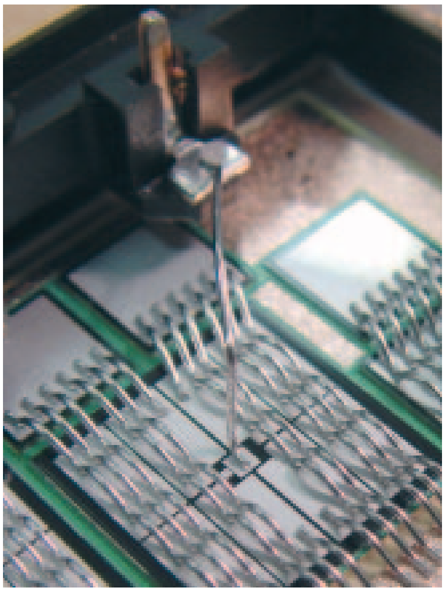


Power Electronics – from Chip to System

IZM

Fraunhofer Institut
Zuverlässigkeit und
Mikrointegration

Design and technologies for power electronics

Power electronics is the key technology for flexible and intelligent power supply for a large variety of applications. Typical power electronic applications encompass e.g. electrical drives, switch-mode power supplies, regenerative energy sources or automation technology. In order to meet the demands for reduced cost and optimum reliability, there is an increasing need to consider technological aspects at all design stages. The Fraunhofer Institute for Reliability and Microintegration IZM has all the expertise and experience required at every stage of the entire development chain:

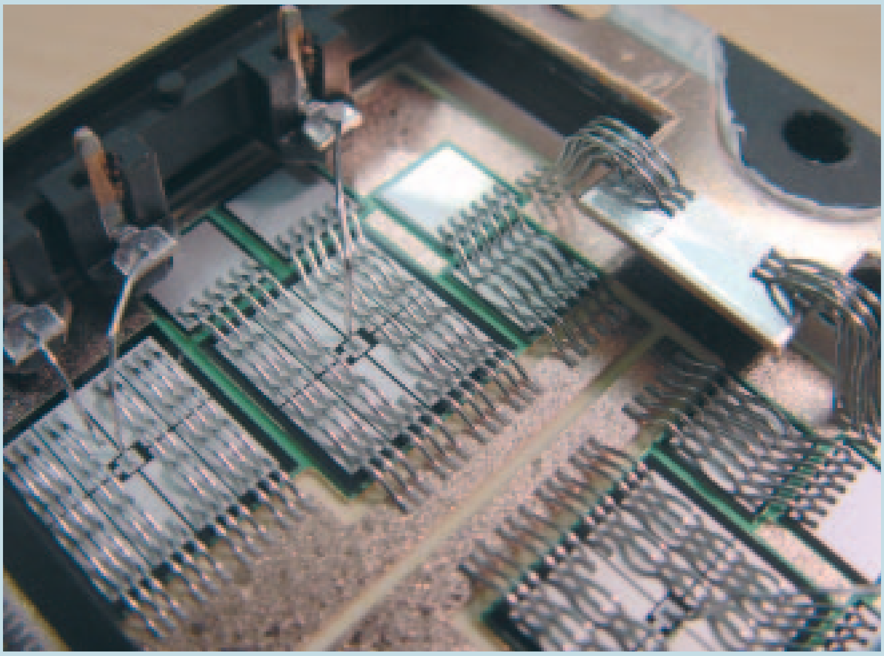
IZM IN

POWER

- Power electronic system design
- Assembly and interconnection technology
- Thermal management
- Electromagnetic compatibility
- Reliability and failure analysis

Fraunhofer IZM develops novel and reliable power electronic systems with high performance and high electromagnetic compatibility. Additionally, we undertake research in electromagnetic interference phenomena as well as in the thermal and thermo-mechanical domain by simulations and experiments. We offer our customers technological support during the design phase and also technical assistance through the testing stages of device development. We continuously develop new methods in assembly and interconnection technology for power semiconductors, leading to new packaging and module technologies for power electronic systems.

The technologies available at Fraunhofer IZM include the complete assembly of power modules in solder and heavy-wire bonding technology, flip-chip or COB technology and encapsulation. Alternative assembly technologies for power semiconductors are also investigated. Additionally, we offer services in the areas of quality, reliability and failure analysis.



Die and heavy-wire bonded power module

Electrical system and circuit design

High switching currents, voltages and frequencies, increasing operation temperatures and reliability demands as well as strict guidelines for electromagnetic compatibility – the requirements for modern power electronic systems are becoming more and more stringent. The integration of sensors as well as protection- and control-related functions into power modules and applications constitutes another crucial challenge.

Fraunhofer IZM develops cost-optimized solutions for these prevailing problems. We have broad expertise and experience in developing power electronic systems according to customer specifications:

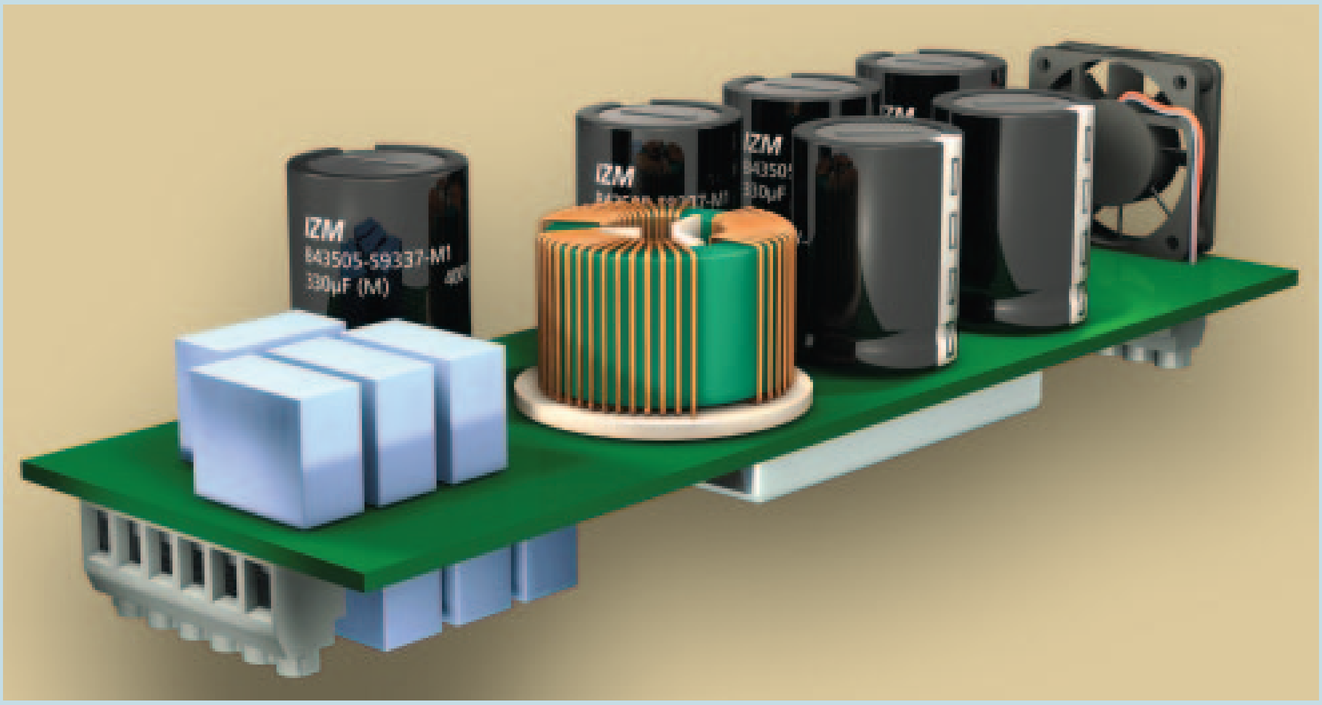
- Converter design and prototyping, e. g. for applications as traction, industrial and vehicle drives, piezo actuator technology and switch-mode power supplies.
- Control of power electronic devices and systems.
- The use of a broad range of simulation tools during all design phases, e.g. Matlab, Simplorer, FEM and PEEC tools.
- Design to EMC requirements by predicting and modeling electromagnetic interference phenomena.

Current research projects of Fraunhofer IZM focus on the technology-oriented design of power electronic systems and the integration of active as well as passive components. One goal of the research activities is the development of an integrated design technique, which incorporates interdisciplinary design parameters from the areas of electromagnetic, thermal and mechanical reliability.

FROM THE IDEA

TO THE SYSTEM

5 kW propulsion converter
in IGBT technology



Assembly and interconnection technology

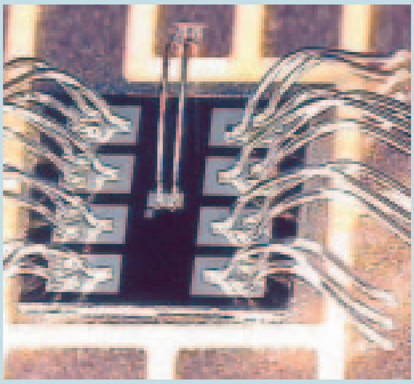
Assembly and interconnection technologies play a significant part in power electronics, particularly in terms of optimizing reliability and improving thermal management. Here, the following processes are successfully employed:

- Die bond soldering using solder preforms or pastes
- Al-US heavy-wire bonding (100 – 500 µm) for connecting power semiconductors, such as IGBTs and diodes
- Polymer encapsulation
- Interconnection of power electronics to logic and casing
- X-ray and Scanning Acoustic Microscopy, visual inspection and mechanical tests

SMALLER.

CHEAPER.

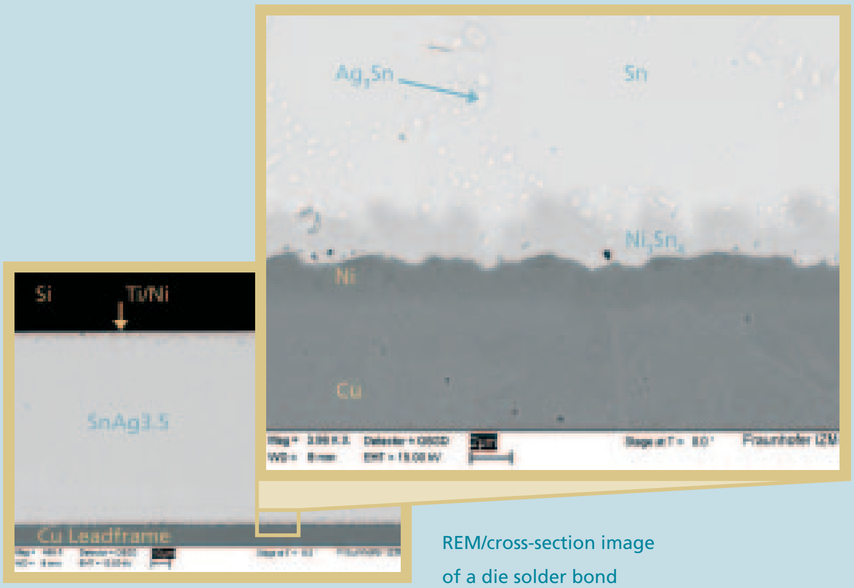
BETTER.



Heavy-wire bonded IGBT

The individual process steps are systematically analyzed and continuously improved at Fraunhofer IZM in order to prepare these technologies for industrial use. The activities include:

- Co-operations with material manufacturers (e.g. DCB, heat spreaders) to improve processing capability, cooling and reliability
- Development of innovative soldering technologies to prevent voids in large area solder joints
- Die-bond soldering with thin layers (e.g. Au/Sn) to improve thermal performance
- Optimization of adhesive die-bond technologies that are used for lower power densities
- Optimization of heavy wire and ribbon bonding, esp. for increased current density
- Development of alternative bonding technologies (flip-chip, ultrasonic bonding, Cu heavy wire or ribbon bonding, sandwich assemblies)
- 3D multi-layer integration for extended functionality and modularization (chip-in-polymer, stacking solutions)
- Testing of materials, such as GaAs, InP, SiC and GaN, as well as thinned semiconductors
- Optimization of encapsulation and packaging technologies for thermally optimized assemblies at high dielectric strength and temperature stability



REM/cross-section image of a die solder bond

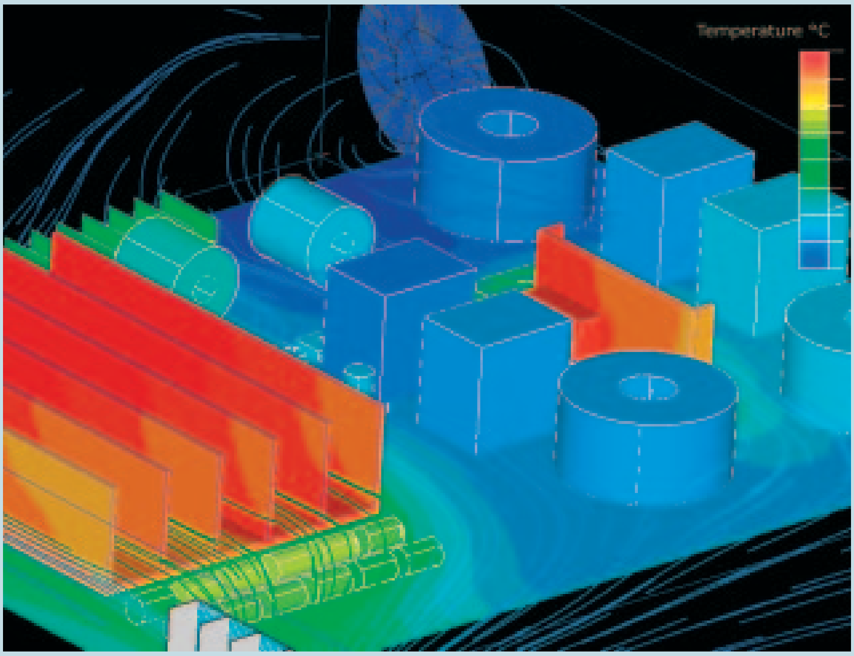
Significant factors are the module's weight, its size and the perfect matching of technologies, as well as the reduction of cost. Future challenges will arise from the transition to high-temperature electronics and the therewith necessary high-temperature interconnection technology.

Thermal management

The heat produced in power electronic components must be reliably dissipated. Here it is necessary to consider the entire heat path in a system: from the chip, the heat is dissipated through various boundary layers, thermal interface materials, spreaders and the substrate, before it is eliminated into the environment by a heat exchanger (cooler). All these stages influence the thermal resistance and must be optimized according to need.

Fraunhofer IZM provides an all-encompassing concept for implementing reliable and inexpensive heat-dissipation solutions. Listed as individual steps, the concept includes:

- Technology and process expertise
- Material characterization
- Thermal design (simulation)
- Measurement technology



Thermo-fluidic system simulation

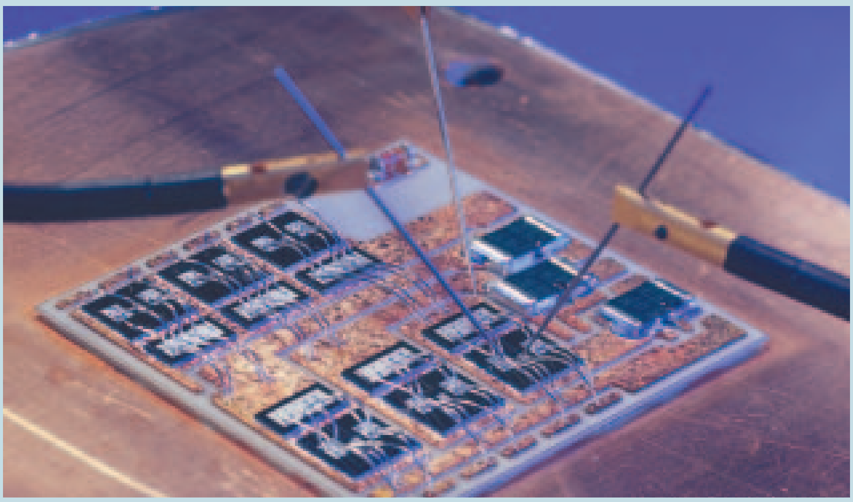
The following measurement methods are available in the thermal laboratory:

- High-resolution IR thermography
- Wind channel
- Water cooler measuring station
- Thermal characterization:
  … Thermal boundary resistance
  … Thermal conductivity
  … Thermal impedance
- Thermo-fluidic simulation at system level

One of Fraunhofer IZM's particular strengths is combining simulations with experiments. In this way the thermal path can already be optimally laid out under application-specific boundary conditions during the design phase.

Further current research activities include fluidic cooling in substrates, heat pipes and thermal compact models.

Electrical testing of IGBT



HEAT DISSIPATION FROM CHIP TO SYSTEM

Electromagnetic compatibility

The integration of power electronic systems leads to new challenges in the area of electromagnetic compatibility (EMC). Close placement of components and devices generates additional electromagnetic interactions, which are mostly undesired.

Fraunhofer IZM develops concepts to ensure the EMC at the early design stage. Modeling and simulation tools are employed and customized to analyze generation und propagation of electromagnetic interference. These tools are based on experience gained in research projects and consulting of industry partners:

- An in-house library for high frequency circuit modeling of interference sources, spreading paths, filter components and measurement set-ups conforming to EMC standards
- Tools for coupling field and circuit simulation
- Simulation environment for virtual EMC tests

For practical analyses, an EMC laboratory with comprehensive measurement equipment is available:

- Measurement equipment for conducted interference measurement
- Absorption chamber for radiation tests
- Comprehensive equipment for characterizing components, such as impedance and network analyzers

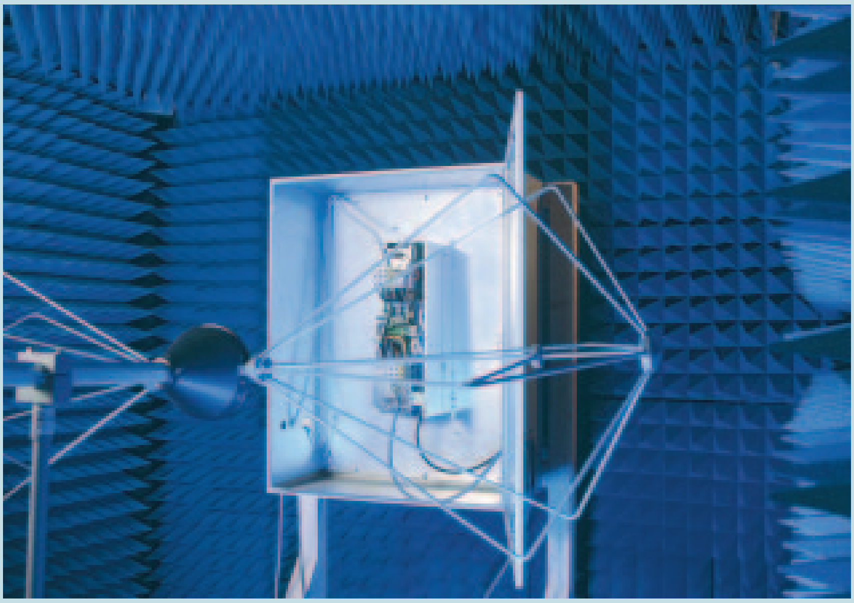
Key research areas are implementing simulation tools for methodical design of passive and active filters, as well as 3D simulation of the electromagnetic interference in power electronic systems. We support customers in EMC development for products and do trouble-shooting under laboratory and field-conditions.

OPERATIONAL

INTERFERENCE

RESISTANCE

EMC measurement station
(absorption chamber)

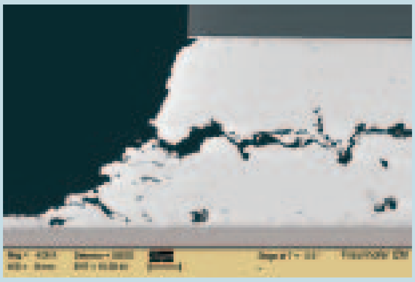


Reliability

Apart from optimizing the thermal design, ensuring thermal-mechanical reliability is of paramount importance: Thermally induced mechanical stress and strains lead to failures (e. g. wedge lift-off, solder fatigue, delamination, chip breakage) in power electronic systems and reduce the life-cycle.

Decisive parameters can already be optimized in the design phase to guarantee the highest possible reliability. System expertise in the areas of technology, material, simulation and experiment, plays a significant role in this.

The damage behavior of the materials and components is experimentally analyzed and characterized, and modeled on the computer, whereby, in the run-up, material or geometric parameters are selectively varied. In this way, e.g. a solder bond or a wire bond's life-cycle can be quantified and, if necessary, measures to improve the reliability can be implemented.



Crack in a solder joint

All aspects of power electronics relevant to reliability can be treated in this way:

- Solder or adhesive connections
- Wire bond connections
- Thermal vias
- Encapsulations
- Substrates and composite materials

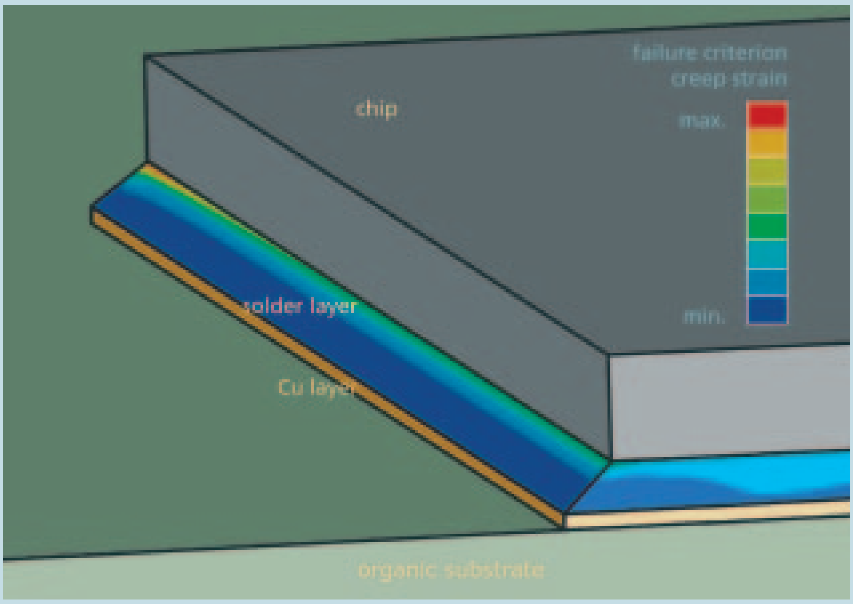
The relevant state-of-the-art measurement technology is available for these processes:

- Active or passive thermal-load changes for evaluating life-cycles
- Metallography, REM, EDX, FIB
- Ultrasound and x-ray microscopy
- High-resolution deformation measurement (contactless and with temperature variation)

Current research activities concentrate on transient material behavior and aging, as well as failure mechanisms in novel material combinations and bond measurements.

Our system expertise in the area of reliability make it possible for us to offer material and process technology solutions affordably and thereby make a contribution to optimizing life-cycles.

Thermo-mechanical FE simulation for lifetime prediction



DESIGN FOR RELIABILITY

Fraunhofer IZM services and support

- Consulting and feasibility studies
- System design, development and testing
- Material characterization
- Simulation (electrical, thermal, fluidic and mechanical)
- Process development/optimization
- Prototyping and small-series assembly
- Quality and reliability analyses
- Failure analysis
- Know-how and technology transfer

WE SPARK

YOUR INNOVATIONS

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