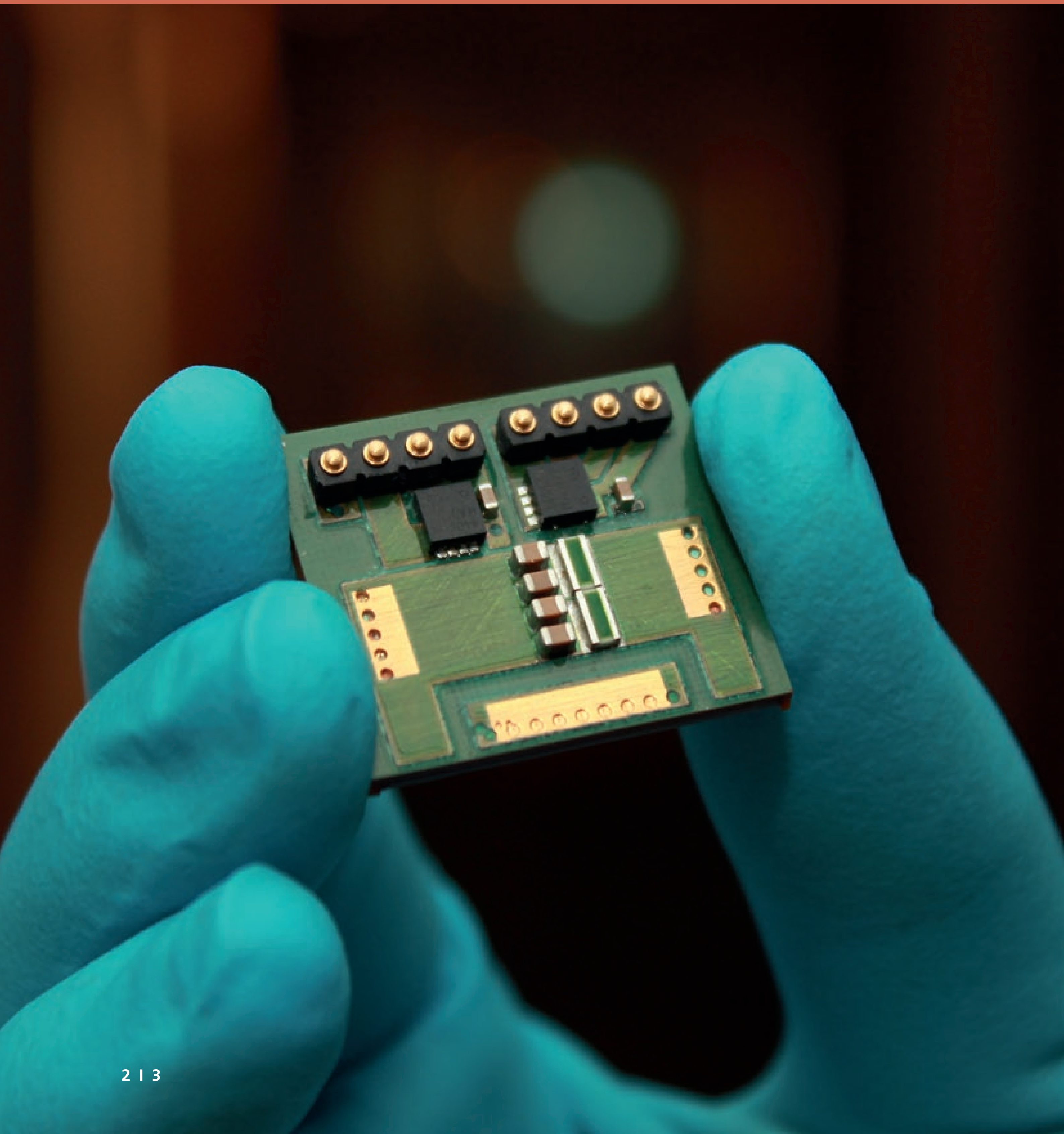
Fraunhofer

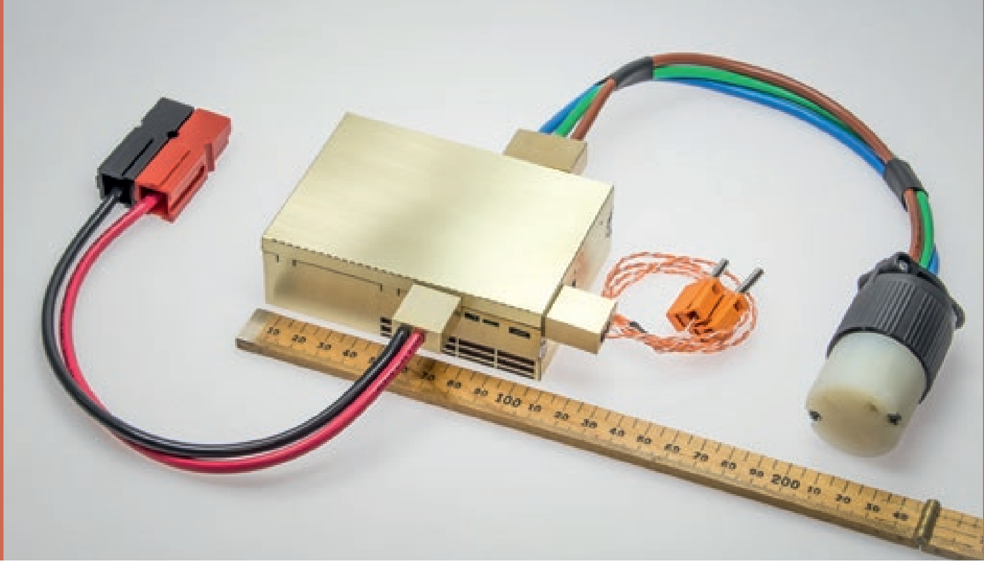
IZM

FRAUNHOFER INSTITUTE FOR RELIABILITY AND MICROINTEGRATION IZM

POWER ELECTRONICS

POWERFUL KNOW-HOW FOR POWER(FUL) ELECTRONICS





ELECTRICAL SYSTEM AND CIRCUIT DESIGN

Life without electricity is more or less unimaginable today. However, these days we also know that the natural resources fueling our electricity consumption are limited. On the one hand, this has sparked increasing commitment to finding intelligent and flexible means of feeding power from sustainable sources into existing power networks. On the other end of the scale, the (energy) efficiency of power-consuming products, from switched-mode power supplies, to electric and hybrid cars and railway traction drives, through to large industrial drives, has become crucial. All of the latter technologies areas and more rely on power electronics, and each makes individual demands on the system, which have to be taken into account during the circuit design and layout, the selection of packaging technology and the design of the system overall.

WE DEVELOP COMPLETE POWER ELECTRONIC SYSTEMS – FROM DESIGN TO PROTOTYPE

Moreover, good solutions for improving energy efficiency and miniaturization of inverters include wide-bandgap semiconductors like silicon carbide (SiC) and gallium nitride (GaN). However, taking advantage of their capability requires particularly tightly integrated electrical, thermal and mechanical design of the complete system, in order to facilitate the possibly high switching speeds and to take into account all relevant EMC aspects, while ensuring optimal thermal management of semiconductors and the package as a whole. This is seeing a trend towards complete system solutions, in which the switching cell itself is fitted with passive components like DC-link capacitors and output filters. Control and regulation, as well as safety, functions, are integrated into the package directly, rather than connected at a later stage.

Fraunhofer IZM's expertise covers the entire development chain, from system and circuit design (particularly in terms of EMC), drive development, thermal management, packaging, embedding and encapsulation, right through to reliability and damage analysis.

We offer the following services to help clients in research and industry develop customized power electronic systems:

- Circuit design and prototype construction, including use of wide-bandgap (WBG) semiconductors
- Control of power electronic components, particularly of WBG semiconductors
- Broad range of simulation tools for all design phases, including Matlab, Simplorer, Solid Works, FEM and PEEC
- EMC-compatible design using modeling and simulation of electromagnetic interference phenomena on system level
- Development of EMC concepts, filters and shielding
- In-house laboratory for prototype testing and characterization

COVER

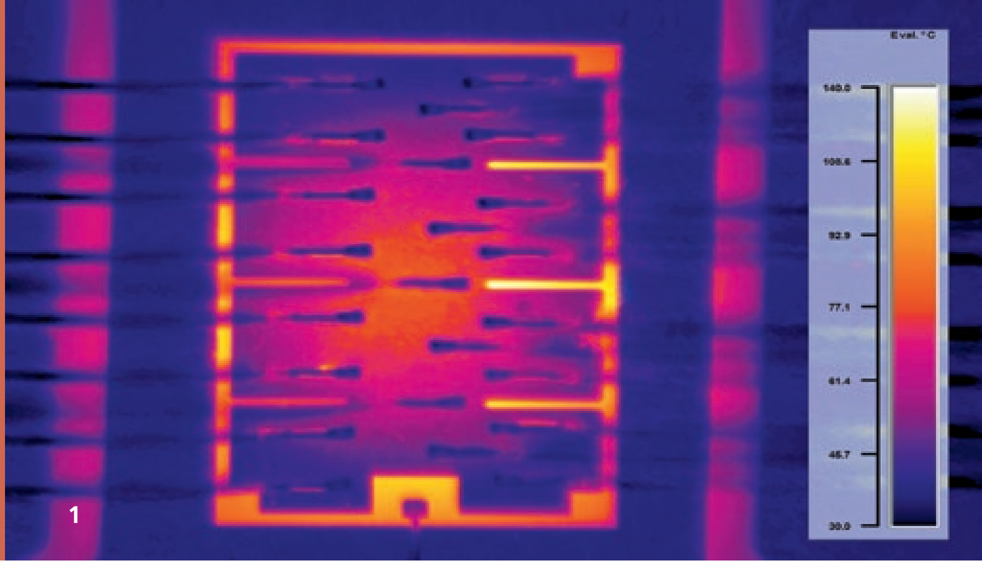
Power electronics for alternative energy sources

LEFT

Power electronic module with WBG semiconductors embedded into a PCB

TOP

2 kW GaN photovoltaic inverter sized 250 cm



THERMAL MANAGEMENT

Reliable heat dissipation is a key factor in designing power electronic systems. To ensure reliability, the thermal path of the entire system must be considered: Heat dissipates from the chip through a number of interfaces, thermal interface materials, heats spreaders and substrates, before being emitted by a heat sink into the surrounding environment. Each station in the thermal path affects temperature resistance and has to be optimized to meet the requirements of the system, including its intended operating environment.

HEAT DISSIPATION FROM CHIP TO SYSTEM

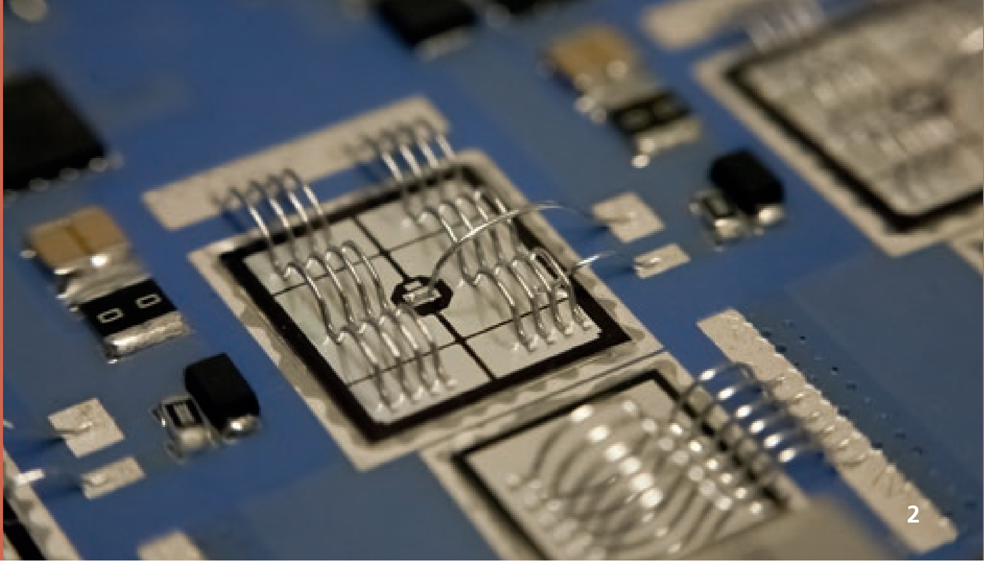
Fraunhofer IZM offers comprehensive expertise and technologies for reliable and cost-efficient thermal management, including:

- Technology and processing know-how
- Thermal design (using thermal and fluidic simulation)
- Material characterization
- Measurement technology

The following techniques and technologies are established in our thermography laboratory:

- High-resolution transient infrared thermography
- Active power cycling with optical temperature monitoring
- Water cooler measurement station
- Thermal characterization of materials (glues, pads, metallic bonds, …):
  … Interface resistance
  … Thermal conductivity
  … Thermal impedance
- Thermofluidic simulation on system level
- Wind tunnel

Fraunhofer IZM's particular strengths are the combination of simulation with experiment and a strong focus on technological aspects. This means we have the equipment and know-how to help optimize thermal management for application-specific parameters early on in the design phase. Measurement data is used to validate and/or improve simulation models. Simulation allows rapid assessment of different thermal management designs and the ability to optimize individual factors, for example, heat sink design, fan arrangement, positioning of components or the substrate build-up. With Fraunhofer IZM's technological know-how, thermal behavior and dissipation can be tackled comprehensively, from analyzing component, to each level of the system, through to the package as a whole.



CHIP INTERCONNECTION / DIE ATTACH

The following techniques are used to optimize the thermal behavior of highly reliable power electronics:

- Large-surface bonding with solder preforms or pastes, by means of Ag sintering or diffusion soldering
- Heavy wire and ribbon bonding of power semiconductors
- Interconnection with control electronics and housing/encapsulation
- X-ray and ultrasonic microscopy, visual inspection and mechanical testing

To ensure transfer to industry is as straightforward and smooth as possible, Fraunhofer IZM systematically analyzes and optimizes each aspect of the technology and processing chain. Our work includes:

- Developing materials and soldering processes that increase the post-processing melting point (transient liquid phase soldering)
- Cooperation with material manufacturers (e.g. of DCB/DAB/AMB, heat spreaders, sinter and solder pastes) to improve processability, cooling and reliability
- Development of alternative technologies like flip-chip, ultrasonic bonding, Cu heavy wire and ribbon bonding, sandwich assemblies (double-sided cooling of chips)
- Development of Ag sintering techniques for chip and heat sink assembly
- Development of innovative pore-free, large-surface soldering techniques
- Die soldering with thin layers (e.g. Au/Sn) to improve thermal performance
- Optimization of adhesion techniques using ICA [isotropic conductive adhesive] and HCA [electrically non-conductive, thermal conductive adhesive], which are applied for lower power densities
- Alternative heavy wire and ribbon bonding techniques (Cu, Cu/AlX)
- 3D multilayer integration for increased functionality and modularity (chip-in-polymer, stack assemblies, power chip embedding)
- Packaging of GaAs, InP, SiC and GaN, as well as thinned semiconductors
- Optimization of encapsulation and housing technologies for thermally optimized assemblies with high dielectric strength and temperature stability

All our work in this area aims to minimize a system's weight and volume, simplify the technologies used, and reduce cost without compromising thermal behavior. Operating temperatures of over 200 °C will pose particular challenges for packaging development in the future.

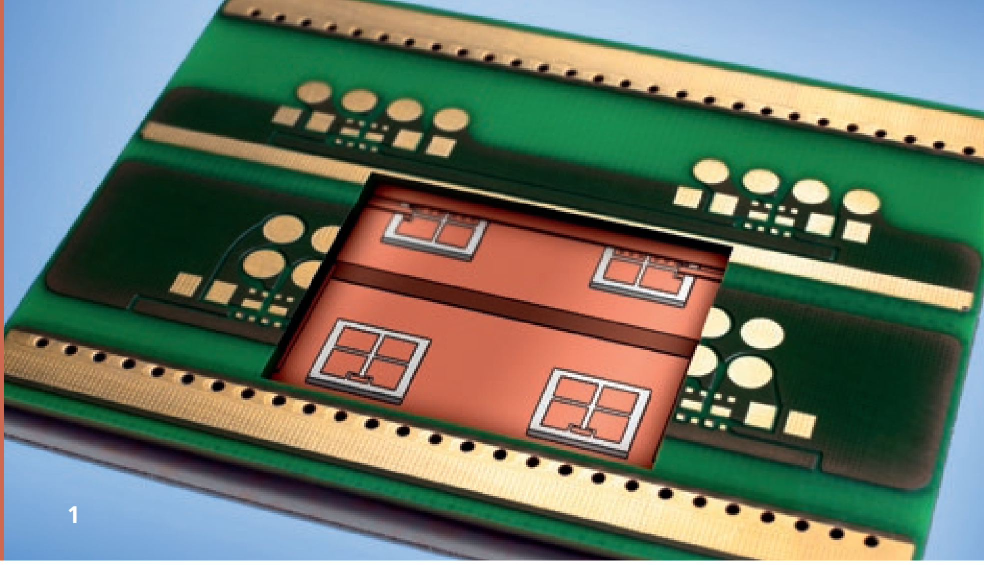
INTEGRATING BIG SYSTEMS INTO SMALL SPACES

1

Infrared image of a MOSFET with Al bonds during load cycling

2

18 kV high-speed switch on a thick-layer ceramic substrate



1

ENCAPSULATION AND EMBEDDING

At Fraunhofer IZM, Si (IGBTs), SiC (JFETs) and GaN semiconductors are integrated into power electronic modules. To improve module reliability, standard gel potting is used for the encapsulation of conventional power electronic assemblies (DCB and wire bonds). For encapsulation of compact, lead-frame modules, high-temperature resistant molding compounds are used that allow ongoing operating temperatures of > 200 °C. Encapsulation processes for customized modules are developed using process simulation techniques, encapsulation materials are characterized in terms of their high temperature stability and the reliability of the modules is verified. A main focus of research here is the correlation between polymer aging behavior and package reliability.

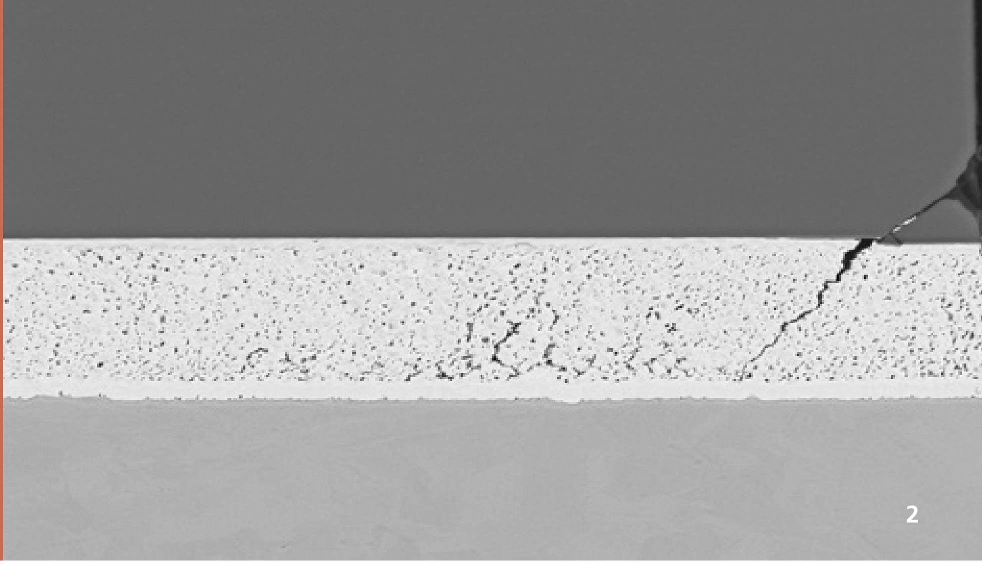
OUR PATH TO THE POWER SYSTEM IN PACKAGE

Chip embedding by lamination is applied for highly integrated, planar power electronic modules. The embedded chips are electrically connected to the PCB's copper traces by sintering (under pressure in a vacuum lamination system) the "bottom terminals" (drain, collector) and microvia connecting the "top terminals" (gate, source / emitter). This ensures low contact resistance and good thermal dissipation, both of which are needed in power electronics. Compared to conventional power electronic modules (DCB and wire bonds), embedding allows for shorter electrical connections, positioning components in the immediate vicinity of semiconductors and, due to lower inductances, higher switching frequencies. Moreover, integrating heavy copper vias and sintered heat sinks can improve dissipation of heat from the peripheries of the power semiconductors.

Using embedding, modules with electrical and thermal interconnection on both sides of a PCB is possible, paving the way for modular assembly of power electronic systems.

New, high-performance laminates and casting compounds (high Tg, high thermal conductivity) are used and characterized in the assembly of the modules. Fraunhofer IZM investigates and tests various assembly approaches and processes:

- Embedding of power semiconductors – Si, SiC, GaN – in PCB build-ups and molding compounds using compression molding
- Use of leading edge PCBs and molding materials
- Highly compact modules with short traces for high switching frequencies
- Modules for optimized integration or attaching of heat sinks
- Modular assembly of complex power electronic systems



RELIABILITY

Apart from ensuring the best possible thermal system design, understanding thermomechanical behavior on package, component and module levels is critical for ensuring overall system reliability. Thermally and thermomechanically induced failure mechanisms can lead to premature failure and limit lifetime. Using modeling, crucial parameters such as (extreme) operating conditions with system-level impact (e.g. operating temperatures and humidity) can already be optimized in the early stages of the design process. The aim is maximizing reliability while keeping cost and effort low.

The damage behavior of the materials and components is analyzed and characterized under application-specific conditions in experiments. By means of computer-assisted modeling, the impact on system reliability of material properties, processing and geometry parameters can be evaluated and optimization strategies facilitated. All aspects of system reliability can be investigated:

- Soldered, sintered or glued bonds
- Wire and ribbon bonds
- Embedding technology
- Processing parameters
- Thermal and electrical through-vias
- Chip, substrate and compound materials

We offer the following measurement techniques:

- Active and passive thermal cycling for lifetime assessment
- Condition monitoring, field data acquisition and processing, and the creation of mission profiles
- Test benches for combined and accelerated lifetime testing (vibration, temperature, temperature cycling, moisture)
- Modeling of failure mechanisms presenting in innovative material combinations
- Metallography, EBSD, FIB, SEM, EDX
- Ultrasonic and X-ray microscopy, as well as X-ray CT
- High-resolution deformation measurement (contactless and with temperature variation)
- Assessment of (transient) material behavior and aging

From packaging-level to final product, Fraunhofer IZM has comprehensive, systematic grasp of (micro)electronic assemblies. We help you find the best material, design and processing solutions for your technology and, thus, make a contribution to lifetime optimization.

DESIGN FOR RELIABILITY

1

PCB for 90 A with CAD impression of the embedded power semiconductors

2

Fatigue crack in silver interlayer following temperature cycling (1000 cycles / -55 °C – 125 °C)

3

Experimental built-up for assessment of the reliability of thermally conductive packaging materials (TIM)

YOUR PARTNER: FRAUNHOFER IZM

FRAUNHOFER IZM SERVICES

Our services cover all aspects of power module assembly using soldering, sintering and wire/ ribbon bonding, flip-chip, COB and embedding technologies, including insulation and environmental shielding. We also intensively research alternative assembly technologies for power semiconductors. Fraunhofer IZM is the right address for:

YOU HAVE A PROBLEM?

WE HAVE THE SOLUTION !

- Consultation and feasibility studies
- System design, development and testing
- Material characterization
- Simulation (electrical, thermal, fluidic and mechanical)
- Process development/optimization
- Prototype and small series manufacturing
- Quality and reliability analyses
- Failure and damage analyses
- Know-how and technology transfer

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