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PhD Thesis proposal (3 years) M/F

Reference [HMTFT057]

Humidity diffusion characterization tool for power electronics materials and components

PhD Thesis supervisors:

Mitsubishi Electric R&D Centre Europe [MERCE]**:** Pierre-Yves PICHON, Senior Research Staff
IMS laboratory in Bordeaux: Loïc THEOLIER, Maître de Conférences HDR/ Associate Professor, and Alexandrine Guédon-Gracia, Maître de Conférences HDR/ Associate Professor

Overall context

Mitsubishi Electric R&D Centre Europe is the European R&D centre from the Corporate R&D organisation of Mitsubishi Electric. Situated at the heart of Europe's leading R&D community, Mitsubishi Electric R&D Centre Europe is in Rennes, France and conducts research into next generation digital information and power electronics systems.

A power converter is an electrical device for converting electrical energy. Power electronic modules are elementary electronic components to realize the power conversion functions in the converters [1]. In these components silicon IGBT or SiC MOSFET power semiconductor chips are connected to a heat dissipating substrate and encapsulated in a dielectric material which functions are: 1/ to provide electrical isolation against high voltage in the blocking mode; 2/ to protect the semiconductor chips against humidity, vibrations, dusts etc…

Problem description

The dielectric encapsulation materials can be classified under two types: soft silicone gels and hard epoxy resin-based materials with ceramic fillers. Temperature-humidity failure modes associated with silicone gel-based designs include the electrochemical dissolution-precipitation of the electrode metals at the high electric field region near the semiconductor chip edge, resulting in isolation failure. For voltage ratings under 3.3kV the utilization of hard epoxy materials has enabled to significantly improve the power module designs in terms of heat dissipation, reliability against thermomechanical cyclic stresses and manufacturing simplicity. However, compared to silicone gels, the humidity diffusion coefficient is about 5 orders of magnitudes smaller, and the moisture saturation level about 2 orders of magnitude higher [2].

Thus, due to the slower diffusion kinetics it becomes lengthy to test, model and predict the moisture distribution in the components, and characterize its effects on their reliability. This thesis aims at overcoming the challenge of increased R&D development cycles with respect to power module components, materials design, and reliability characterization.

Objectives, methods and outputs

The objective of this PhD thesis is to develop an innovative tool to quickly characterize humidity diffusion in epoxy encapsulated components. This tool will be based on methods to characterise the hygrothermal behaviour of a power semiconductor package as a compact electrical equivalent diffusion model.
In this research, it is assumed that the most relevant humidity-related failure modes and mechanisms are related to the humidity concentration at the semiconductor chip, or in the direct neighbourhood, where electric fields are strongest (chip surface, guard ring, brazing material and substrate near the guard ring). Thus, the compact model is a simplified version of a more complete model where the humidity concentration in the whole package is known as a function of the use profile (P_{loss}, RH_a, T_a).
Since the diffusion coefficient and the saturation conditions of the materials and interfaces in the power module may be temperature and humidity-dependent, it is expected that a coupling between the temperature and humidity diffusion models is needed.

The strategy to reach this goal contains both experimental and modelling approaches.
- Identify measurement variables at the power module package level: sensor position, warpage, stress, mass, etc…
- Developing a humidity concentration model of the package that includes the mission profile parameters. Such a model may require to experimentally characterize humidity diffusion parameters for the materials and interfaces of the package.
- Validate the model experimentally on a power module package.
- Reduce the model complexity and deliver an R&D tool for time-efficient characterization of its parameters.

Detailed objectives / organization

This PhD work will be a collaboration between IMS laboratory in Bordeaux (Pessac, FR) and Mitsubishi Electric R&D centre Europe (Rennes, FR). The PhD student will be a MERCE employee, and the working time will be shared between IMS laboratory and MERCE. The main location will be Bordeaux and stays at Rennes will be business trips paid by the company.

In addition to the different research steps described in the “Objectives, methods and outputs” section, the candidate will entail the following tasks:

- Redaction of quarterly reports
- Redaction and publication of scientific papers
- Redaction of the thesis manuscript
- PhD defence

Prerequisites

For this PhD, MERCE is looking for a highly motivated student with master’s degree or higher education levels **in the field of (power) electronics with an interest in material science and modelling.** The student shall demonstrate experience and/or strong interest in developing skills in the following fields:

- **Experimental and physical analysis methods:** Planning and executing the measurements; and critically analysing the results tests considering the existing literature.
- **Modelling methods:** review the relevant literature models and basic physical phenomena (diffusion, thermodynamics, interfacial kinetics). Select the models based on a trade-off between predictive accuracy, simplicity/calculation time and availability (e.g. analytical equations, R-C diffusion equivalent, Finite Element Modelling …).

- **Organizational skills:** project planning (including sourcing materials and test vehicles at suppliers and project partners), concise reporting, organizing the data and communicating the results in scientific communications (peer-reviewed publications and conference presentations).
- **Language skills:** English spoken / written

Duration: 3 Years - Period: from September/October 2026

Contacts:

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Application:

Thanks for providing us an application letter and your CV mentioning the reference [HMTFT057].

References:

[1]https://www.mitsubishielectric.com/semiconductors/powerdevices/products/power-module/igbt-module-nx/

[2] Characterization of the bulk moisture diffusion in epoxy-based potting compounds for IGBT semiconductor power modules, Tomas et al., ESREF 2025, Bordeaux France, available in https://hal.science/hal-05323088/document