PEMREL

Power Electronic Module construction for RELiability testing, characterisation and manufacturability assessment

State of the Art - Background

Power electronic modules (PEMs) are self-contained power electronics components that are widely used in aerospace, automotive and alternative energy generation & distribution applications. They play an important role in the conversion, control and delivery of electrical power. At present the vast majority of power electronics modules are packaged using solders and wirebonds. PEMs have highly inhomogeneous structures. They consist of semiconductors, ceramic, copper, aluminium, polymers and sometimes composite materials. These materials are assembled together in the packaging manufacturing process using soldering, direct bond copper (DBC), wirebonds, and pressure contact interconnection techniques. This is the traditional approach to packaging of IGBT inverter modules.

Present state-of-the-art manufacturing for plastic packaged IGBT modules involves the solder attachment of the dies to a substrate followed by ultrasonic bonding of IGBT emitter and gate and diode anode connections, there being up to 600 individual bonds in a large module. Creation of such a large number of individual bonds is expensive, time consuming and a source of yield loss. During operation, the wires are a known reliability weak point and in the event of device destruction the bond wires typically fail open-circuit by a high energy fusing process. This failure process is inherently unpredictable and the high energies dissipated within the module can lead to rupture of the module housing. In addition, the typical bond wire and bus-bar assembly leads to relatively high levels of parasitic inductance which compromises device switching performance leading to increased switching loss and/or over-rating of device blocking voltage. Finally, the thermal management arrangements in conventional modules remove heat from just one die surface, restricting the maximum heat flux that can be sustained for a given maximum junction temperature.

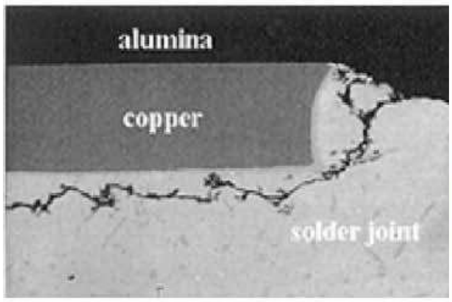
Early failures in a power electronic module are usually due to manufacturing failures that show up quickly. These failures can quickly be screened out with stress burn-in techniques. The second period of the product reliability has a constant failure rate until it reaches the time when wear-out mechanisms result in an increase in the failure rate. The constant failure rate is due to random events. Up until the 1990’s the exponential, or constant failure rate (CFR), model, had been the only model used for describing the useful life of electronic components and was the foundation of the military handbook for reliability prediction of electronic equipments known as the Military-Handbook-217. This became the de facto industry standard for reliability prediction.

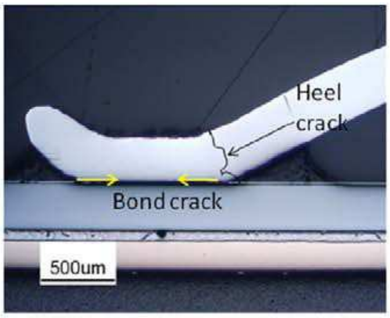
With the introduction of integrated circuits (ICs), more and more evidence was gathered suggesting that the CFR model was no longer applicable. Phenomena such as infant mortality and device wear-out were shown to be the dominated failures not suitable to be predicted by the constant failure rate model which is applicable only to the second region of the bathtub curve. In 1994 the publication of the “Perry Memo.”, by US Secretary of Defence William Perry, effectively eliminated the use of most defence standards, including the MIL-HDBK-217 series, due to the mounting criticism of only using the constant failure rate model for reliability predictions of electronic components and systems.

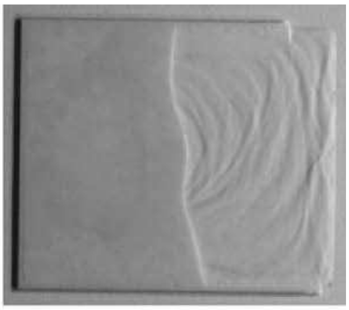
With the advances in packaging and the use of ever changing materials for custom designed power module packages it is becoming increasingly important to predict reliability with accuracy without the need for extensive qualification periods post design.

Objectives

Key developments that will be undertaken in this project are to develop reliability models of this new packaging technology and embed these into a virtual prototyping software environment







(PowerLife). This will enable engineers to assess manufacturing variability on subsequent package reliability both for current packaging technology and the new SiC packaging technology. In addition to this the virtual prototyping tool will allow designers to investigate the interaction of the thermal path and the electrical performance when addressing the reliability and robustness of a new power module design.

Description of Work

WP1: FMMEA Analysis

Work package 1 will undertake an FMMEA analysis based on data in the public domain which will drive experiments for module type 1; experimental studies to develop acceleration curves and mechanical data will then be carried on novel bonding processes for input to module type 2. For the type 2 module the designs will be obtained from another project within the consortium

WP2: Physical wear-out model development

Physics of failure models will be developed for both module type 1 & 2 structures. The methodology used will combine the accelerated test results on test coupons from WP1 with finite element simulations. The accelerated test results will provide failure times for different temperature excursions and failure locations. Finite Element simulations will identify the stresses and strains in the materials when subjected to the temperature changes. This together with the failure data will be used to generate physics of failure models which relate life consumption to the mechanical behaviour of the materials.

WP3: Optimisation framework and model integration

This work package will extend the PowerLife software to enable design for manufacture and reliability of power modules Type 1 & 2. Working closely with Dynex and Semelab, a captures all the relevant design variables, their variations, and constraints for module types 1 & 2. The tool will provide the ability consider design variable variations and uncertainties and their impact on reliability distributions for type 1 & 2 modules.

WP4: Module samples for evaluation

Type 1 & 2 modules to be generated. These should be typical of the constructions required to be evaluated.

WP5: Electrical, Thermal and Reliability Evaluation

Modules arising from WP4 will be evaluated either as complete modules or representative test coupons to facilitate faster collation of results. This data will then be used to validate the developed physics of failure models and the integrated virtual software environment.

WP6: Virtual Tool Validation

Modules type 1 & 2 will be assessed using the developed PowerLife software for electro-thermal, electromagnetic, and reliability performance. In terms of thermo-mechanical behaviour, reliability and robustness margins will be predicted for both passive and power cycling. The results will be compared with data gathered from WP5 to aid validation of the models and software.

Expected Results

The research results are expected to have application in a number of related areas such as future electricity networks, renewable energy technologies and land and marine transport. Synergy already exists with ongoing work on planar packaging technology for high voltage IGBT modules and there is potential to develop further links with future research projects in the aerospace sector. The partner has a strong record of developing and exploiting links with other programmes to maximise the impact and efficiency of the combined research, for example through further EU. It will be our aim to maintain these and develop new links arising from the technology resulting from this project.

Acronym:	PEMREL
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