

Flagship Project

Power Electronics

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Power electronics is an essential technology in all future sustainable energy scenarios since it is the only technology that can deliver efficient and flexible control of electrical energy. It will therefore underpin the emerging low carbon economy. As a result the share of electrical energy which will be controlled by power electronics is expected to increase from 40% in 2000 to 80% in 2015. Latest market analysis "Power Electronics: Technologies and Global Markets" shows that the global market for power electronics devices in 2007 was \$9.8bn and this is expected to reach \$17.7bn by 2013 with a compound annual growth rate of 11.6%. In 2007 power electronics also contributed to another \$1 trillion of sales in related hardware electronics.

Key facts about power electronics applications:

Connection of **renewable energy sources** to power grids is not possible without power electronics.

Future electricity networks must incorporate power electronics to maintain stability with increased levels of intermittent (renewable) generation.

Transport: electric and hybrid drive trains are only possible with efficient and intelligent power electronics. Weight savings through power electronics will reduce fuel demand.

Power supplies: new concepts can improve overall efficiency by 2-4% yielding huge overall energy savings. Motor drives: use 50-60% of all electrical energy consumed in the developed world: a potential reduction in energy consumption of 20-30% is achievable.

Home appliances: electronic thermostats for refrigerators and freezers can yield 23% energy saving: an additional 20% can be saved by using power electronics to control compressor motors (with 3-phase PMDC motors).

Lighting: power electronics can improve the efficiency of fluorescent and HID ballasts by a minimum of 20%.

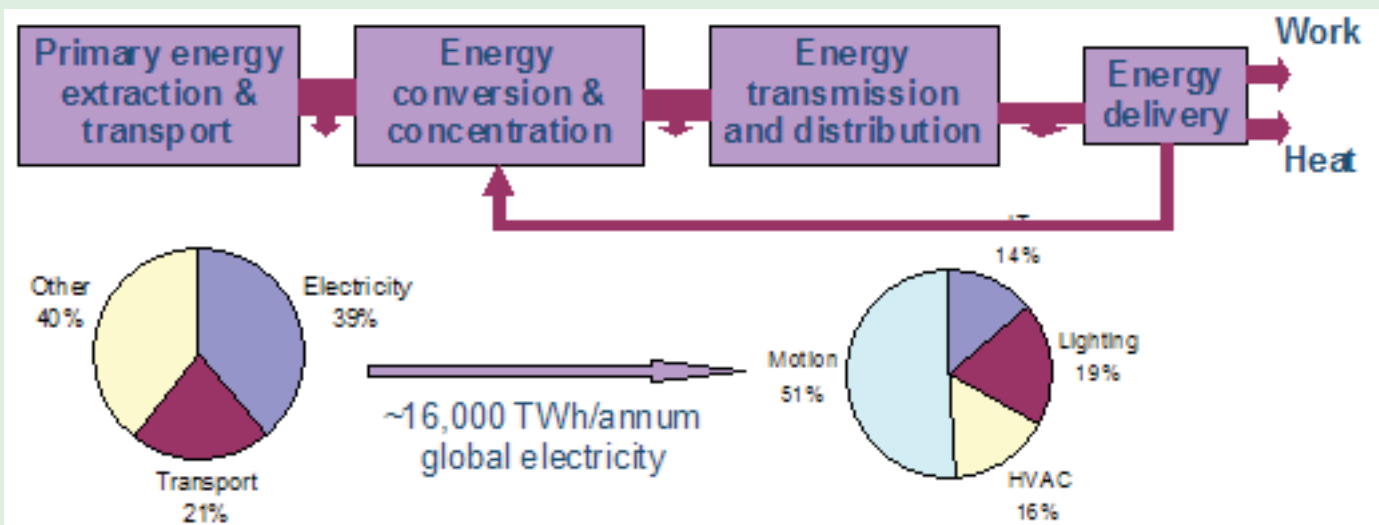


Figure 1: Power electronics underpins all parts of the energy supply chain and will play an increasing role in the delivery of energy.



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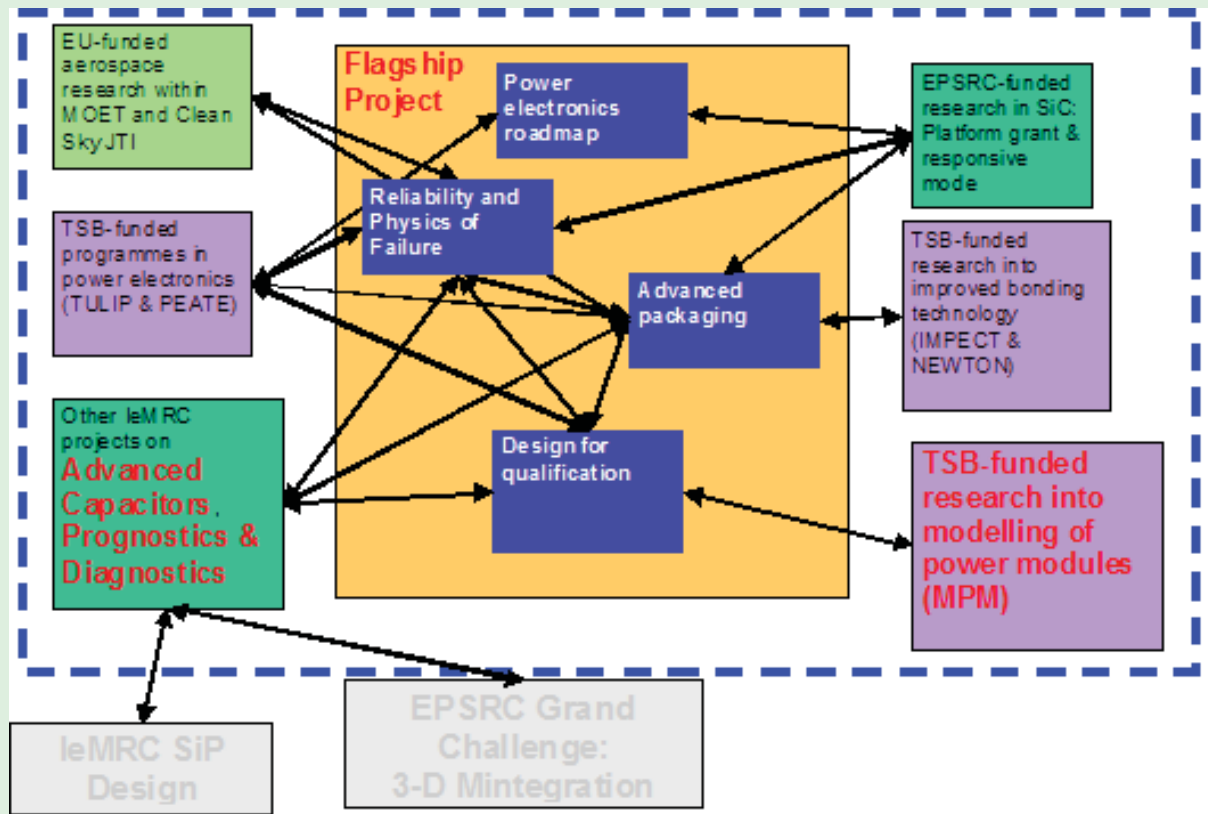
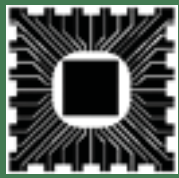


Figure 2: IeMRC Flagship project work themes and linkages to other funded work.

The key targets for the Flagship are technologies and techniques to improve power module performance. Funding of £811 k from the IeMRC together with contributions from 11 industrial partners has supported researchers at 5 academic institutions over a period of 42 months. The emphasis of the Flagship has been to undertake fundamental research that underpins power electronics across a range of applications. Further, strategic and application specific projects have been built on the foundations of the Flagship generating a project cluster with a total of “geared” funding exceeding £8 M. The academic partners are:

- University of Nottingham (power electronics, module design and failure analysis)
- University of Greenwich (point analysis tools, physics-of-failure reliability predictions, multi-physics modelling and numerical optimisation)
- Manchester (partial discharge effects)
- Newcastle (high-permittivity dielectrics and Silicon Carbide device fabrication)
- Oxford (heat transfer and thermal management)

Industrial support includes: Dynex Semiconductor, Goodrich, International Rectifier, Morgan Technical Ceramics, Raytheon Systems, Rolls-Royce, Semelab, SR-Drives, TRW Automotive.



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Work packages and key results:

Road mapping and technology watch

The project has supported a number of road mapping events in conjunction with the Integrated Products KTN. This work culminated in a UK centred power electronics road map highlighting the research priorities for IeMRC/EPSC and TSB support which was published in 2008. In addition the project maintains a watch on emerging technologies for power electronic modules and associated thermal management systems.

Reliability and physics of failure:

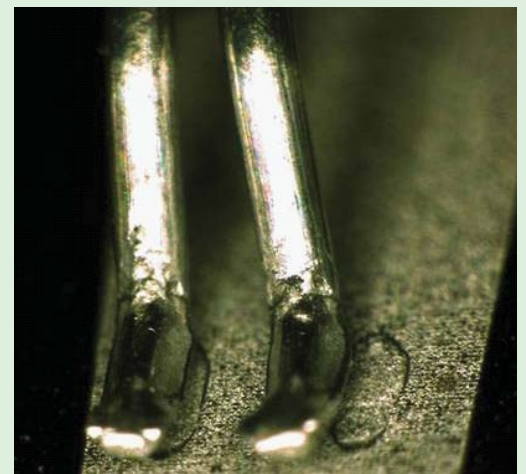
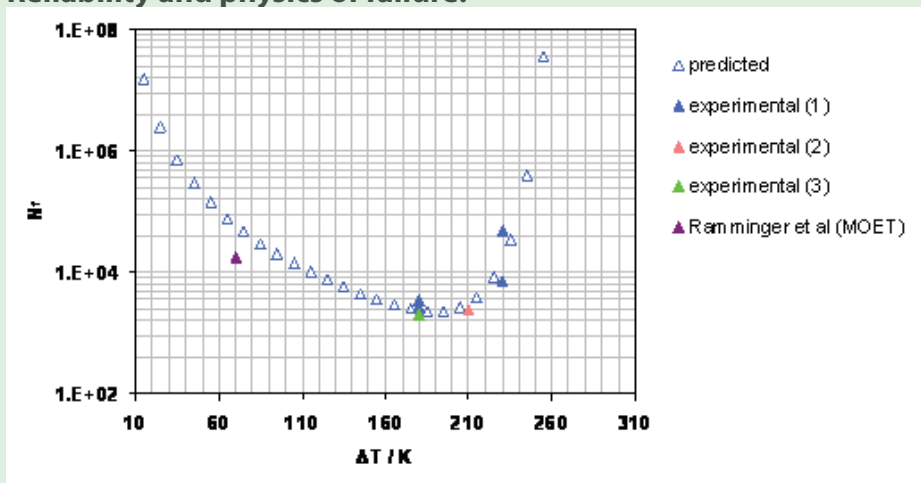


Figure 3: Work on wire bond reliability has shown exposure to high temperatures increases life.

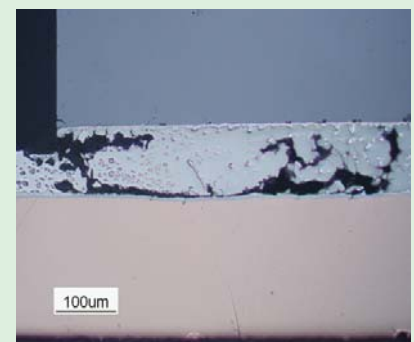
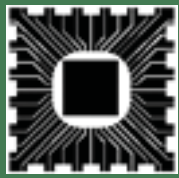


Figure 4: Modelling of the fatigue and creep behaviour of solder has facilitated development of a validated physics of failure model.

Work has concentrated on the identification of the root cause (Physics) of failures in power modules and the development of Physics of Failure models. A combination of modelling and Accelerated Life Testing has been carried out by academic and industrial partners in order to generate validated models. These models have been employed: 1) to assess design options (through the TSB MPM project) and 2) in prognostics and health management (through the IeMRC prognostics and diagnostics project).



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Experimental work at Nottingham has focussed on substrates, solder and bond wires. Of particular relevance has been the observation of apparently anomalous reliability behaviour in bond wires, showing that high temperature exposure leads to the annealing of damage thus prolonging life.

Extensive modelling studies at Greenwich have investigated the behaviour of solder and bond wires during thermal cycling. Damage models, including the effects of creep, fatigue and fracture, have been applied and used to develop physics of failure based models for solder layers and bond wires. The results have been applied in the PowerLife software which has been developed within the MPM programme and subsequently exploited in reliability-driven design of power modules. The same physics of failure models have also been applied in the IeMRC prognostics project.

Advanced packaging:

Work on insulation systems at Manchester has studied the effects of partial discharge within the encapsulating gel used in power modules. By adding a filler to the gel, performance has been improved under both wet (humid) and dry conditions. The work has received follow-on funding from EPSRC and is the subject of a patent application, with good prospects of licensing the technology to a power module manufacturer.

Newcastle has investigated and developed capacitors which are operable to 600°C, with a scalable technology (in terms of voltage and capacitance). The resilience of these devices to high dose (>1Mrad) gamma radiation has been demonstrated along with their capability to provide a means of enabling high temperature energy harvesting and storage. A first demonstration of SiC based ASK and FSK communications, utilising these capacitors has been made.

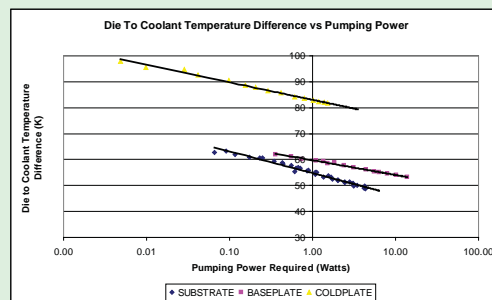


Figure 6: Jet impingement coolers have been shown to offer significant improvements in cooling efficiency.

Work on thermal management technologies at Nottingham and Oxford has investigated both passive and active cooling technologies. Emphasis in active cooling has been placed on achieving high efficiency by minimising the pumping power for a given thermal resistance. Studies of jet impingement systems have shown that by careful design a low overall thermal resistance can be achieved without the need for the heavy heat spreaders often associated with power modules. This has the added advantage of reducing the number of bonded interfaces and hence removing one of the key wear-out mechanisms.

Research into interconnect technologies at Nottingham and Oxford has concentrated on alternative die attach technologies and on enhanced wire bonding. A range of diffusion-based processes, including transient liquid phase (TLP) bonding and sintering have been evaluated with the aim of establishing their viability as a high performance, process compatible alternative to solder. A pressure-less TLP process has been developed that shows good potential for further work and exploitation. Work on wire bonding has shown that bonding at elevated temperature can help to reduce the damage induced at the interface and thus extend the thermal cycling life of the wire.