Dr Paul Evans

University of Nottingham

Overview of Centre for Power Electronics: Tranche 2 Topics

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Underpinning Research

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The Research Projects

- Switch Optimisation
- Converter Architectures
- Heterogeneous Integration
- Reliability and Health Management
- Virtual Prototyping

Supporting development and application of wide band-gap semiconductors

£6M total funding over 3 years.

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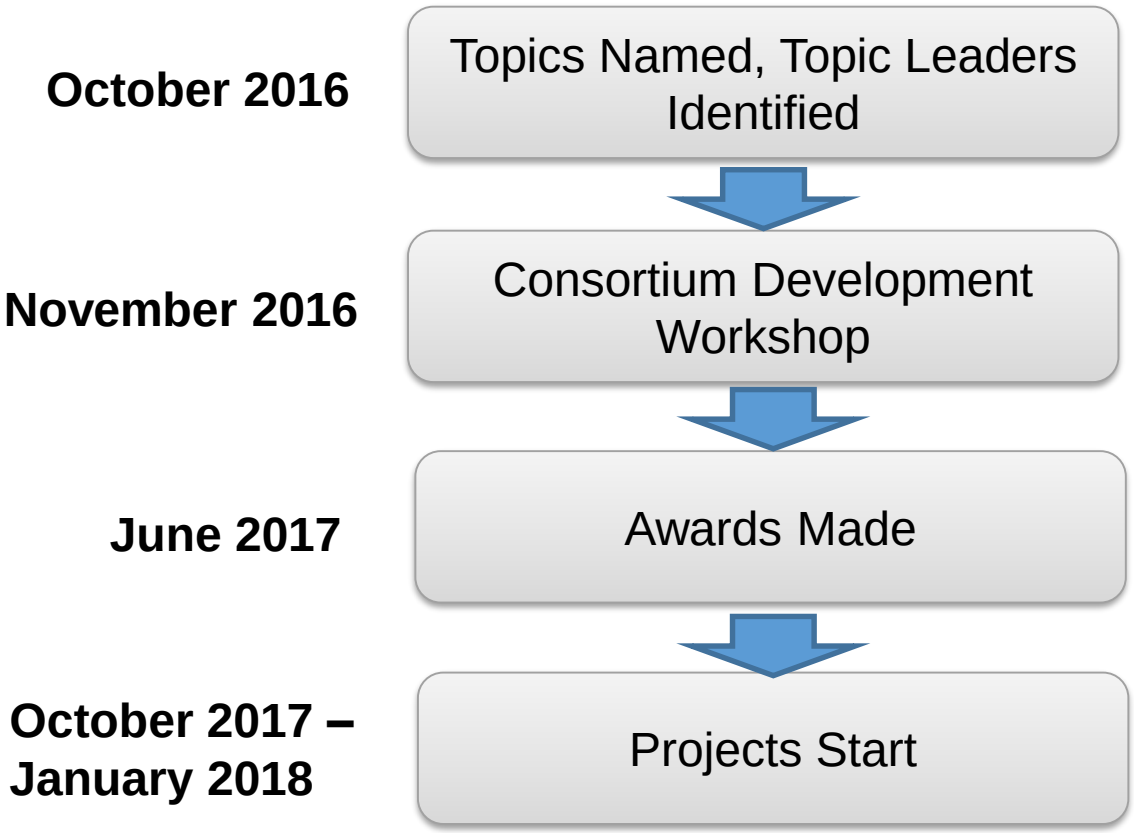
Background to Research Proposals



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Switch Optimisation (SO)

Dr. Peter M. Gammon

SiC IGBT design (5-15kV), processing techniques, testing and benchmarking

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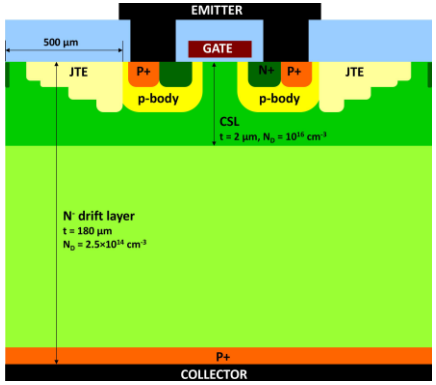
Overview and Motivation (SO)

Opportunity to innovate in field

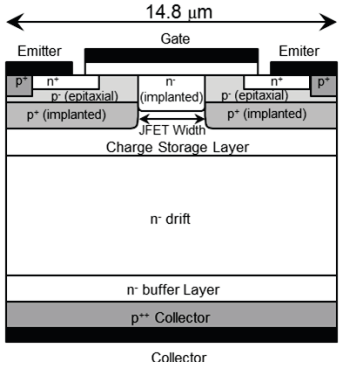
- Only 4 groups internationally have developed SiC IGBTs
- Potential to develop early IP

Opportunities for 11kV grid applications & transport

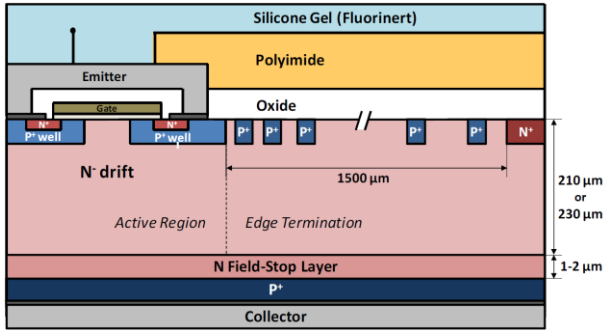
Builds on SiC MOSFET, and Si Trench IGBT work in Tranche 1 project



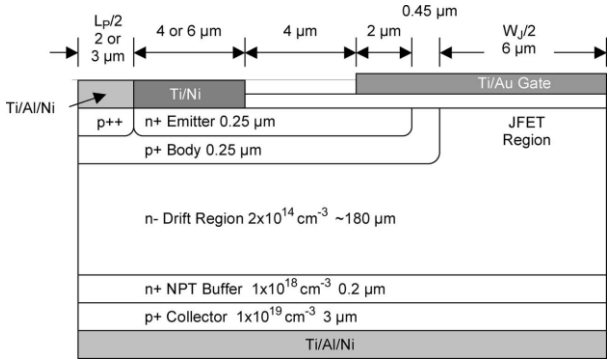
2016: Chowdhury/Chow, RPI, USA (20kV)



2013: Yonezawa, NAIST, Japan (16kV)



2014: Van Brunt, Cree, USA (27kV)



2010: Wang/Cooper, Purdue – the first n-IGBT (20kV)

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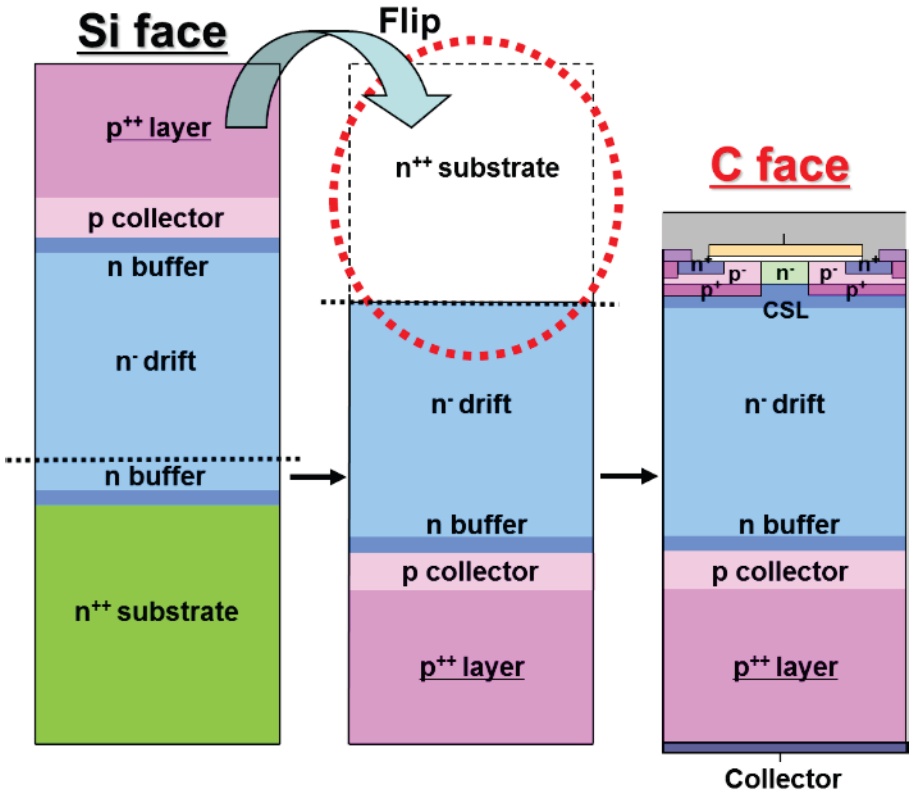
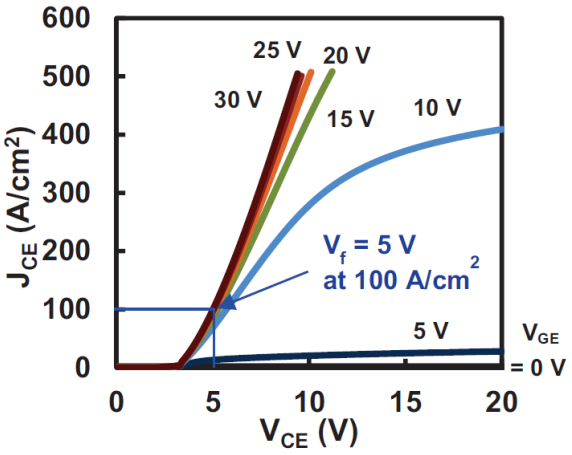
Research Content (SO)

N-channel SiC IGBT Development



Our own **SiC IGBTs** will include:

- **15 kV demonstrators,** comparable to SOA.
- **5-10kV designs**, lower than current SOA, benchmarking to SiC MOSFETs
- **Experimental designs:** Trench gates, field stop regions, integrated MOSFET.



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Switch Optimisation Theme Workshop

SiC power semiconductor devices:

The current landscape and the challenges of scaling to 10 kV+

- **Are SiC devices realising their promise?** What are the applications in which market penetration is occurring?
- **What weaknesses are holding back current devices?** Reliability, cost, proven legacy, voltage range?
- **What does the future hold?** Reliability, scaling processes, scaling up voltages.

Discussion of the above with panel made up from industry and academia: Dr Hamada, **Toyota**; Dr Sharma, **Dynex Semiconductor**; Dr Trajkovic, **Cambridge Microelectronics**; and Prof Richard McMahon, **University of Warwick**.

Details of the **CPE SO THEME**: developing 10kV+ SiC IGBTs.

Converter Architectures (CA)

University of BRISTOL

Professor Xibo Yuan

Imperial College London

MANCHESTER 1824
The University of Manchester

Enabling technologies for higher voltage, higher power and high frequency WBG power conversion

IXYS UK WESTCODE

GaN Systems

Rolls-Royce

CONVERTER TECHNOLOGY

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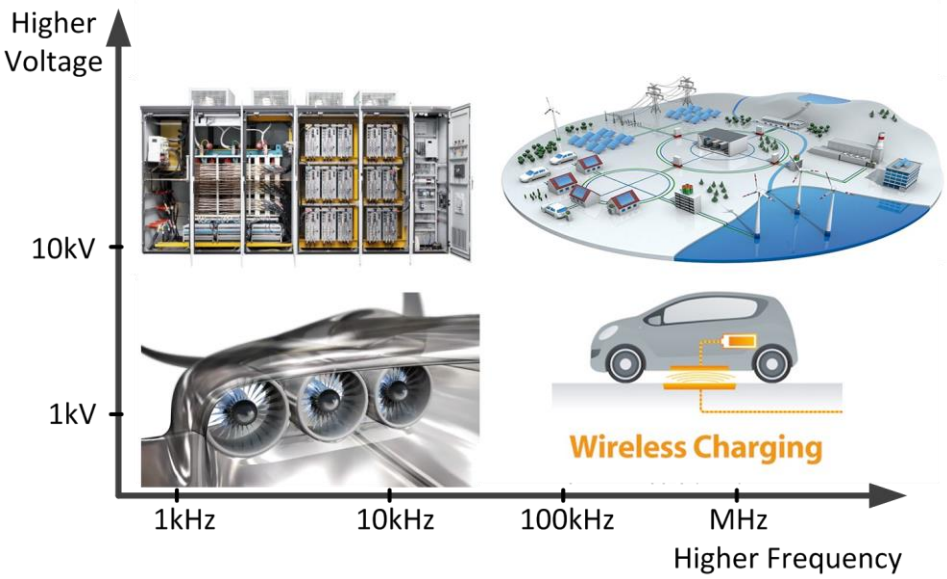
Overview and Motivation (CA)

- Higher voltage devices switching faster
  - Topologies to mitigate *d*v/*d*t effects
  - Topologies for medium voltage power conversion
  - Topologies for MHz power conversion
- Passive components at HF, high power density
- High bandwidth digital control
- Deliver high profile demonstrator platform

13MHz, 500W
wireless power converter



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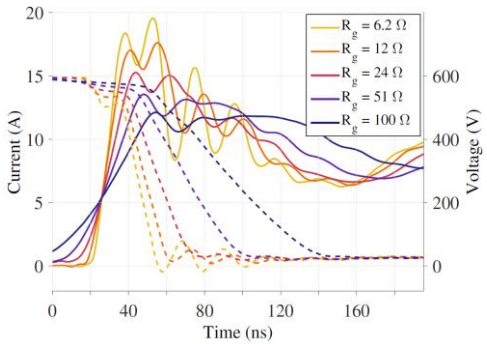
Research Content (CA)

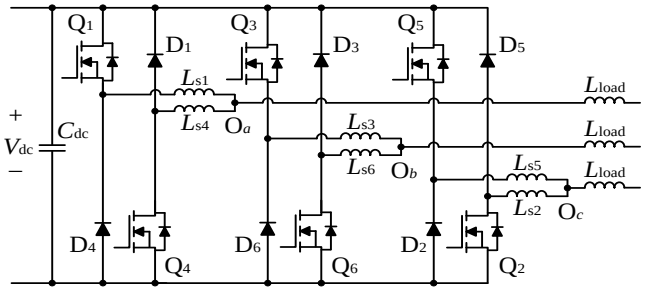
WP1: Converter Topologies

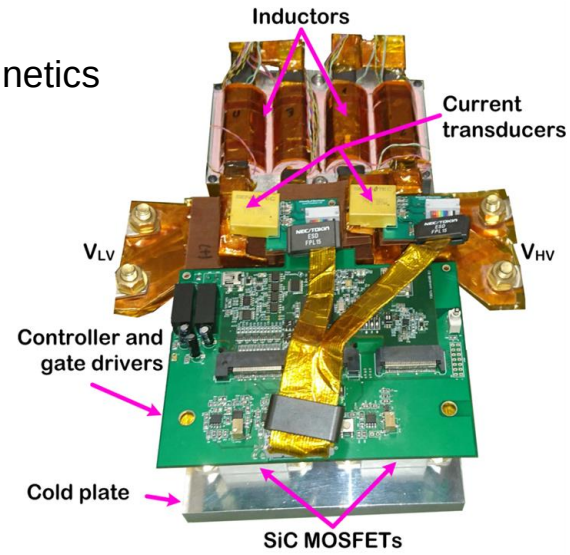
- Topology modification for HF
- New HF topology development
- Parasitic optimization
- Multilevel topologies



WP2: Passive Components

- Topology specific conventional magnetics
- Air cored magnetics

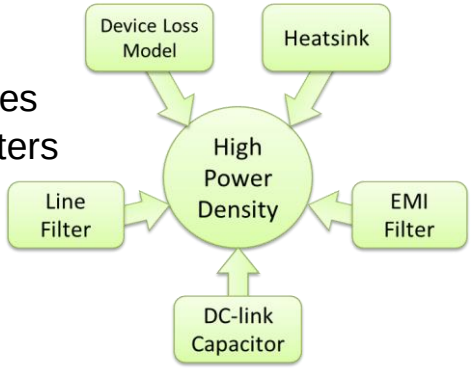




80kW DC/DC converter

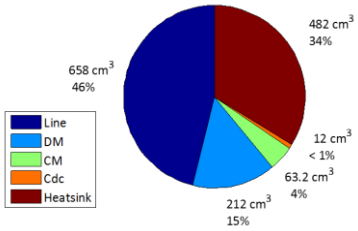
WP3: Advanced Control

- Digital control at high frequencies
- Strategies for multilevel converters



WP4: Holistic Design Optimization

- Identify design tradeoffs
- Produce optimal design guidelines: efficiency, power density



WP5: Demonstrator

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Workshop

- Hear about capabilities of state-of-the-art WBG converters and recent achievements of the Centre's converters theme.
- Find out how we push the frequency/voltage/power boundaries.
- Discuss emerging applications for WBG converters.
- Participate and define the WBG converter demonstrator of the Converter Architecture project.

Heterogeneous Integration (HI)

University of Nottingham
UK | CHINA | MALAYSIA

Prof. Lee Empringham

Loughborough University

Developing Integrated Commutation Cell Modules

Highly optimised power conversion building blocks that underpin system level application of WBG devices: better performance, lower cost, improved reliability.

Overview and Motivation (HI)

Immediate environment around semiconductors is key:

- Electromagnetic design
- Thermal management
- Mechanical design and assembly

Develop Integrated Modules

- Power Devices
- Filtering and Shielding
- Thermal management
- Gate-driving & control.

A modular approach for end users

- Converter in package

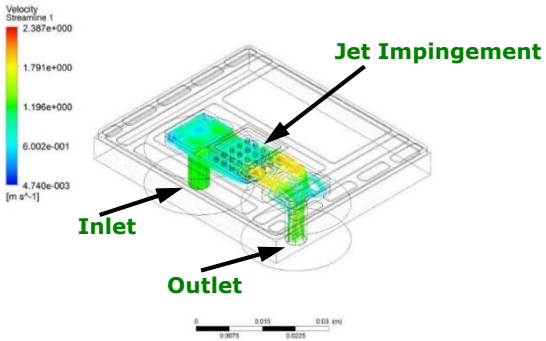
Manufacturing and Assembly

- Design for manufacture, cost

Research Content (HI)

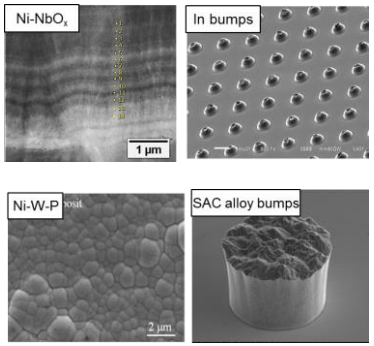
WP1: Design and Modelling

- Concurrent Electromagnetic, Thermal, Mechanical
- EMI, stress optimization



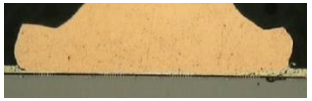
WP2: Materials and Interconnection

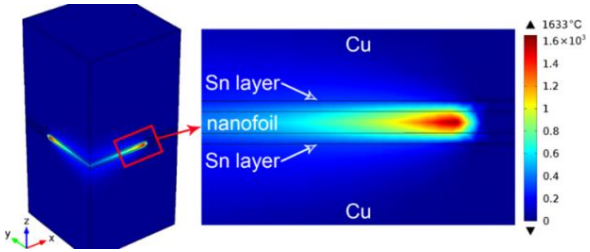
- Interconnect techniques
- Additive/subtractive manufacturing processes
- Material interactions



WP3: Structural Embedding Process

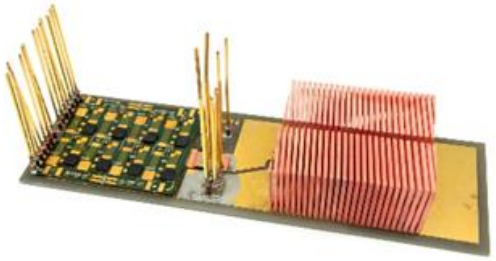
- 3D layered/ laminated structures
- Embedded actives, passives
- Manufacturing process development





WP4: Demonstrator

- Demonstrator modules
- Showcase developments in WP1-WP3



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Workshop

Presentation

- Outline the need for higher levels of integration in order to fully utilise WBG semiconductors
- Hear about the aims, present and future work of the HI theme.

Group Discussion

- Discuss the different levels of integration and their implications
  - How much integration is appropriate for different industries / applications.

- Discuss the key issues and technological barriers to be faced
  - How important are the issues
  - Discuss and identify Industry derived requirements

Engage

- Build links with researchers working on the project and discover ways to get involved.

Reliability and Health Management (RHM)

Dr. Layi Alatise

WARWICK
THE UNIVERSITY OF WARWICK

University of BRISTOL

Newcastle University

University of Nottingham
UK | CHINA | MALAYSIA

Enhancing reliability in high power density WBG converters using on-line condition monitoring and health management

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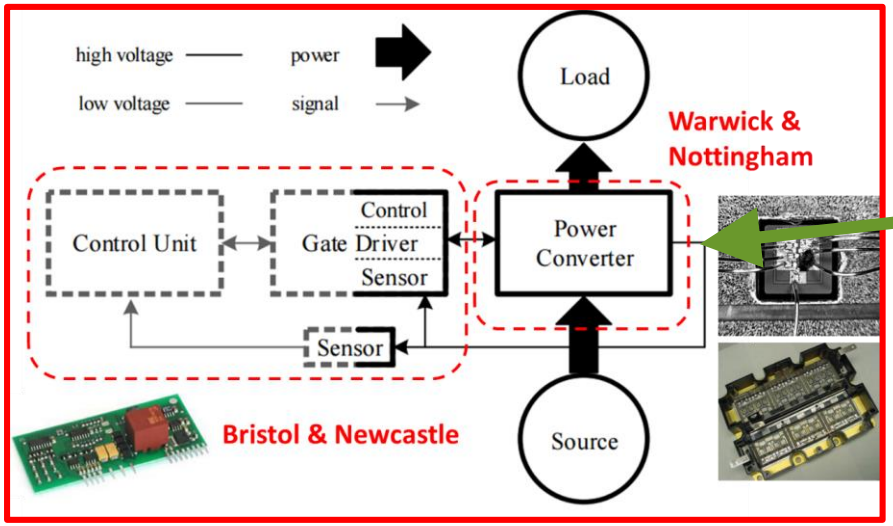
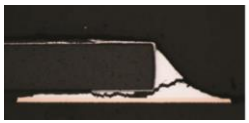
Overview and Motivation (RHM)

System Wide, Multi-Level Challenge

Enable power converters with in-built technologies for lifetime estimation and failure prediction





Solder Cracks

Wirebond Lift-off

Electrothermal
Failure

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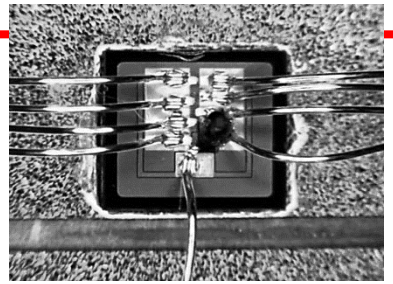
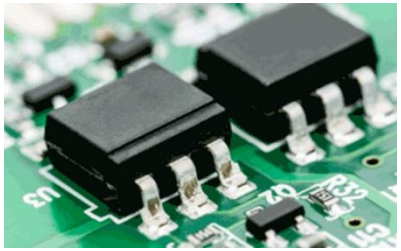
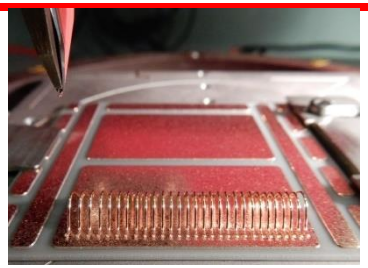
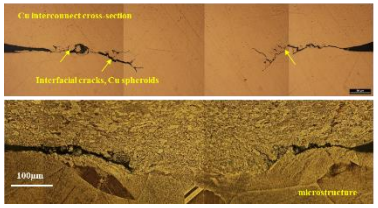
Research Content (RHM)



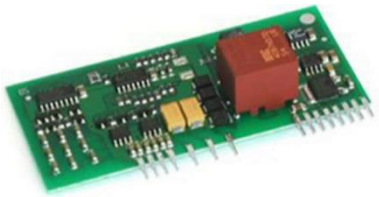


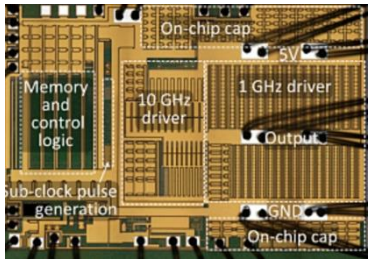
Discrete Device
WP1



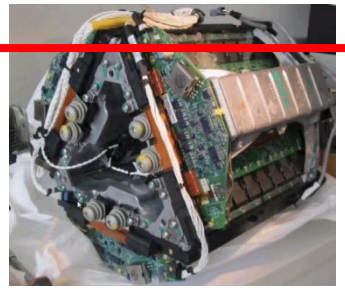


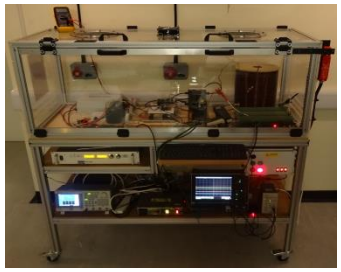
Module level
WP2





Gate Driving
WP3





Converter application
demonstrator WP4

- Identify and characterise degradation indicators in GaN and SiC devices
- Package level reliability assessment
- Gate-drive integrated condition monitoring and health management
- System level demonstrator

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RHM Workshop

- Industrial speakers from Grid and Automotive industries
- ***Prospects for Condition Monitoring in Automotive Traction Applications*** by Dr George Petkos, AVL Powertrains UK Ltd
- ***Prospects for Condition Monitoring for Grid Connected Converters*** by Dr Saeed Jahdi, GE Grid Solutions UK Ltd
- Discussion and panel debate on the possibilities and prospects for condition monitoring

Virtual Prototyping (VP)

University of Nottingham
UK | CHINA | MALAYSIA

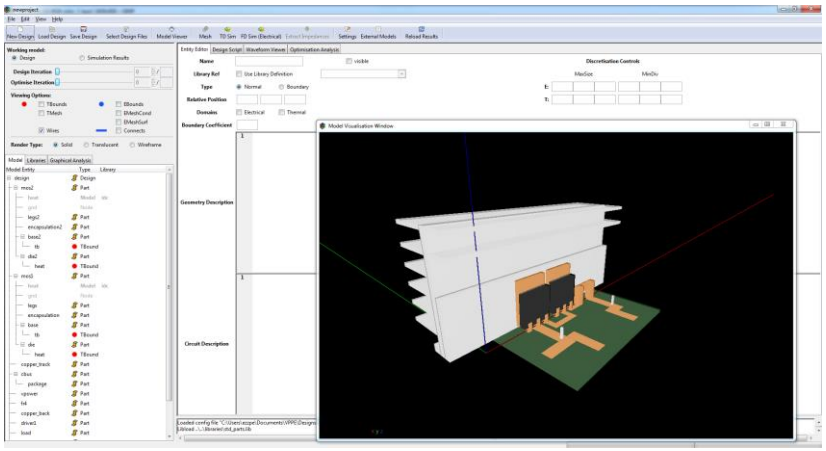
Dr. Paul Evans

University of BRISTOL

UNIVERSITY of GREENWICH

Develop design methods for fast multi-domain simulation and optimisation of power electronic systems

Demonstrator in form of software application



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Overview and Motivation (VP)

High frequency, high power density designs sensitive to physical design

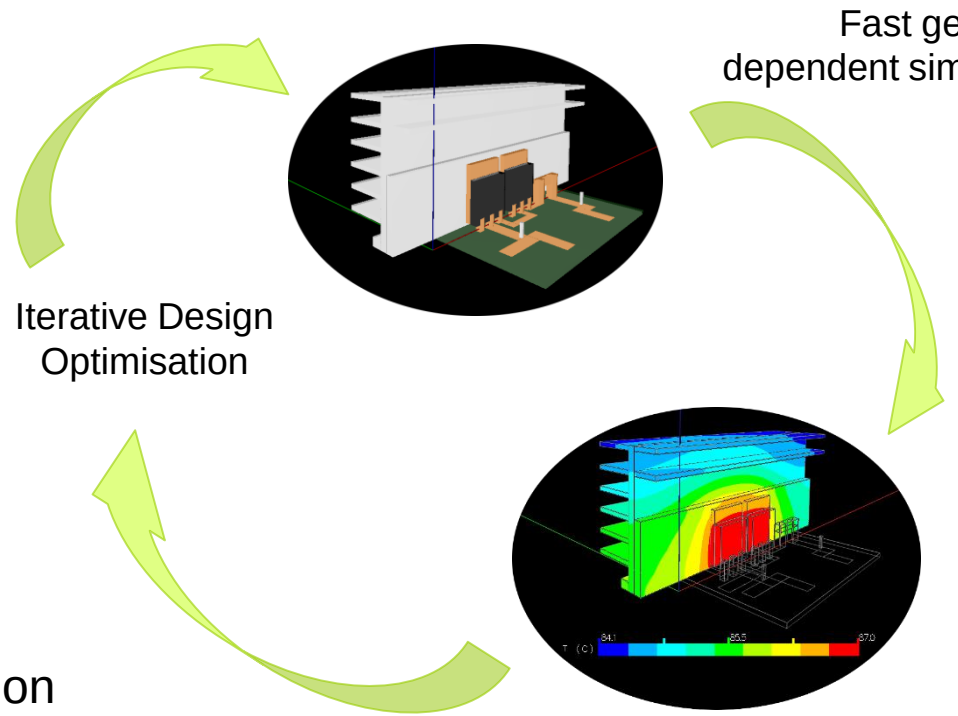
Coupled, Multi-Domain Effects

- Semiconductor
- Electrical/Electromagnetic
- Thermal
- Mechanical/Reliability

Need design tools that can predict these effects

Accelerated time-domain simulation

Fast design tools for non-specialist



Coupled analysis in Electrical, Electromagnetic, Thermal and Mechanical Domains

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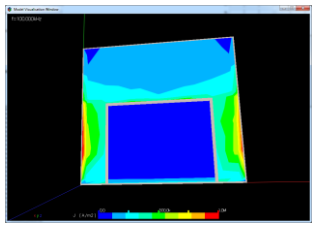
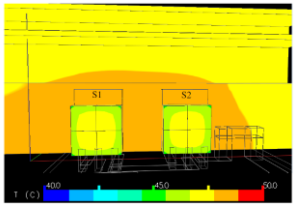
Research Content (VP)

WP1: Fast Electro-Thermal Modelling

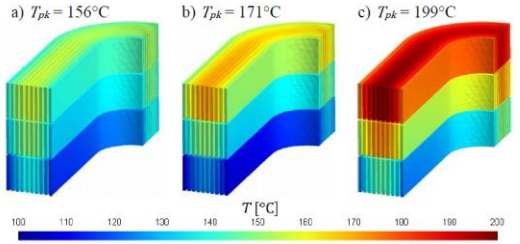
- 3D-physical electromagnetic-thermal system models using MOR techniques.
- Embedding non-linear passive component models.





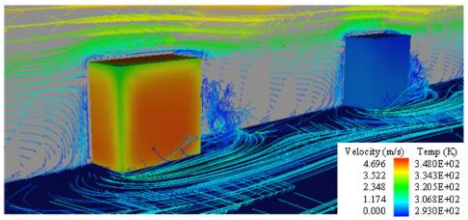
WP2: Magnetic Component Loss Models

- Estimate losses in magnetic materials/components using lumped parameter methods.



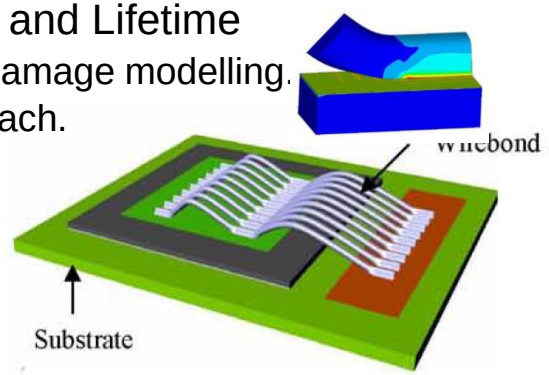
WP3: Convective Heat Transfer

- Flow networks.
- Localised, “Ultra-Fast” CFD.

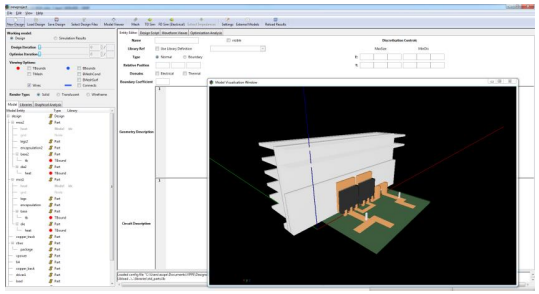


WP4: Mechanical and Lifetime

- Stress-strain & damage modelling.
- Multiscale approach.



WP5: Demonstrator



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VP Workshop

Virtual Prototyping: Developing design and simulation tools for future power electronic systems

Presentation

- Hear about the VP project in more detail.

Discussion

- How are design tools currently used, what limitations are present in current commercial offerings?

- What does the ideal power electronic design/simulation tool look like? Help guide the project.

Future Engagement

- Build links with researchers working on the project and register to gain access to project outputs.

Five coupled projects with common goal

One workshop per project after break

Choose one to attend

- Switch Optimisation
- Converter Architectures
- Heterogeneous Integration
- Reliability and Health Management
- Virtual Prototyping

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