



Driving the Electric Revolution – Building Talent for the Future:

Power Electronics Packaging – Training and Upskilling (PEPTUS)

Innovate Project #10018587

An IMAPS-UK 3 month Project

Deliverable #1

Power Electronics Packaging training module scope, structure and content outline.

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Executive Summary

This report is the first deliverable of the IMAPS-UK PEPTUS project. The project is Innovate-UK funded project number 10018587 and is part of the Driving the Electric Revolution (DER) theme of Building the Future (BTF), an ISCF Challenge delivered by UK Research and Innovation. It is a short term 3 month project that commenced on 1st February 2022.

Power Electronics Packaging training and upskilling (PEPTUS) is a requirement that has been expressed strongly by the Power Electronics, Machines and Drives (PEMD) community in the UK and has been a mission for the International Microelectronics Assembly and Packaging society, UK chapter (IMAPS-UK) for a number of years. This project has set out to address this need.

The project has 4 work packages and this report is essentially the results of Work package 1, Training and Upskilling Module Definition. However, work undertaken in the other work packages of contact with the stakeholders and development of course content, contribute significantly to the content.

The report sets out the a realistic programme for a set of training course modules covering basic understanding, intermediate learning and advanced instruction in a set of 12 well-constructed course modules.

The development of a form of widely accepted qualification for course participants will add value to the UK industry and encourage wider take up of the course.

1. Introduction:

This Innovate-UK project is enabling IMAPS-UK (International Microelectronics Assembly and Packaging Society – UK Chapter) to undertake the preparation of an innovative Power Electronics Packaging Training Course based on Basic, Intermediate and Advanced levels to address the industry needs from introduction to power electronics packaging for schools/colleges and Universities through to detailed training to assist in upskilling and reskilling personnel for the design, manufacture and testing of power modules.

The “packaging” aspect of Power Electronic components and sub systems determines the performance, reliability and costs of power modules and is often overlooked at the design process stage. Knowledge of the materials and assembly processes resides within a limited cohort of electronics packaging engineers and there is little visibility of the multi-disciplinary nature of the work at schools/colleges and Universities. Equally, there exists a shortage of engineers/technicians and operators with the requisite skills to understand and handle the precision assembly processes required.

To address these needs, the work being undertaken in this project by IMAPS-UK provides a Power Electronics Packaging Training Course based on Basic, Intermediate and Advanced levels designed for schools/colleges and Universities/HEIs to provide an introduction to Power electronics manufacturing. The course is also designed to provide detailed training material to assist in upskilling and reskilling commercial and industrial personnel for the manufacture and testing of power modules.

The course creators are experts currently involved in leading edge research programmes to develop devices, materials and processes for the manufacture of advanced power electronics modules. They are keen to ensure that these training course modules developed will also reflect the implications of the changing nature of power electronics packaging as it adapts to meet the demands of fast switching, high temperature operation and need for sustainability.

2. Review of the scope of power electronics packaging within the PEMD community

IMAPS-UK is a learned society, charitable organisation run by volunteers and is the trade association of the microelectronics industry. As such the organisation has very strong links with the PEMD in the UK and beyond.

IMAPS-UK is a member based society with a mission to raise awareness and improve networking within the micro-electronic packaging community in the UK. Regular online and face-to-face events are held throughout the year including tutorials, webinars, workshops and conferences. IMAPS-UK is also involved in the Power Electronics Research dissemination activities and has collaborated with the Centre for Power Electronics in organising and delivering an online Research Showcase on Reliability and Health Management in January 2021, the blended Centre for Power Electronics Annual Conference in July 2021 and is helping to organise the Centre for Power Electronics Conference in July 2022 at the University of Warwick.

This project tackles the multi-disciplinary nature of power electronics packaging through the creation of a comprehensive set of training course modules, which brings together the latest knowledge on power electronics assembly materials and assembly processes to address the need of producing high performance, robust and cost-effective modules. These courses will enable the development of individual's manufacturing skills needed to satisfy demand for power electronics modules.

As stated, the course creation is developed from the expertise available in leading edge research programmes already underway to develop devices, materials and processes for the manufacture of advanced power electronics modules. The independence of this approach enables the knowledge to be generated and disseminated without commercial and technical bias. Further, IMAPS-UK members are able to provide the framework for the review and accreditation of the training course modules as representatives from industry and academia.

The project has initially established routes to reach the PEMD Community by promotion through IMAPS-UK, the Centre for Power Electronics, Power Electronics UK and the Knowledge Transfer Network (KTN).

Additionally IMAPS-UK has a broad contact base which has been utilised to approach and attract stakeholders from the PEMD community. This work is ongoing (as part of Work Package 2), however, it has generated considerable interest with initial feedback providing insight to the needs for training modules, the content and the acceptability.

a. PEMD community needs:

Based upon research and discussion with IMAPS-UK members and the wider PEMD community, the PEPTUS project addresses the following:

- Outreach and engagement material focussing on PEMD – through open access “Introduction to Power Electronics Packaging” awareness material
- Defining and filling key gaps in the UK’s PEMD workforce and training capability – through engagement with key stakeholders and creation of a comprehensive training module framework
- Supporting and promoting EDI – through creating a level playing field for personnel receiving training from diverse background

b. PEMD Thematic Areas:

It is clear from the PEMD feedback that there are needs for:

- Basic training modules that can generate interest in the whole Power Electronics Packaging (PEP) process and create an “Early Learning” platform to encourage continued development and engagement with the microelectronic assembly community.
- Intermediate training options to enable building of real interest and expertise in PEP, resulting in a further desire to develop knowledge and expertise for participants.
- An advanced, in-depth training course to ensure development of well skilled and adaptive personnel capable of meeting the needs of industry for a viable resource in a rapidly expanding technology environment.

c. PEMD impact:

For the PEMD Community, it is expected that the following impacts will be achieved:

- Raised awareness of power electronics packaging with at least 50 Universities/HEIs offering courses in electrical and electronic engineering, mechanical engineering, materials science, mathematics, physics and chemistry at an undergraduate level
- 250 new registrants for IMAPS-UK website and 25 new student Members of IMAPS-UK
- 150 attendees trained at Intermediate and Advanced Level in 2022, 300 attendees in 2023 and continuing pipeline onwards
- Although not yet quantified, it is expected that there will be new opportunities for collaborative R&D through running training courses using the modules.

- In the short-term the PEMD economy should benefit from improved productivity and reduced costs in the manufacture of power modules. If a 1% improvement can be achieved for an inverter module costing £500 and a production volume of 10,000/year, this would represent a cost saving of £50,000/year for one product alone.
- For the longer term impacts, the Training Courses will provide a source of trained personnel able to contribute to the burgeoning power electronics manufacturing capability in the UK.

Through this project, it is expected that IMAPS-UK will reach out to an additional 250 new registrants from the PEMD Community within 6 months of project completion (+25% of current database of 1000).

d. PEMD gains:

The PEPTUS project has set out to deliver:

- Raised awareness of power electronics packaging within Universities/HEI currently offering courses in electrical and electronic engineering and relevant subjects at undergraduate level
- The creation opportunity for events and courses where attendees will be trained at Basic, Intermediate and Advanced Level during 2022 and extend the opportunity through to 2024, in order to create a continuing pipeline of competent, knowledgeable and skilled personnel.

3. Development of the basic, intermediate and advanced levels of power electronics packaging related to target audience

The PEPTUS project has been designed prepare and introduce a Power Electronics Packaging Training Course based on Basic, Intermediate and Advanced levels to address the identified needs from introduction to power electronics packaging for schools/colleges and Universities through to detailed training to assist in upskilling and reskilling personnel for the manufacture and testing of power modules.

IMAPS-UK covers the whole of the UK and the benefits this Training will be applied across the entire UK. The project also directly addresses the need to re-skill personnel to the manufacture of power modules building on existing employment skills in line with Government directives.

The outreach activities at the Basic Level for Power Electronics Packaging will include Schools, Colleges and Universities/HEIs as well as the general electronics manufacturing community. It is the aim to encourage further interest in the mechanical engineering, materials science and general industrial communities as well as making some information open access for the public.

The project has been set up with 4 work packages. The first two work packages are designed build the framework of the Training Courses and engage with key stakeholders representing schools/colleges, Universities/HEIs and industry to gain feedback on the approach proposed. The section 2 above covers the initial feedback that is directing the content requirement for continuation in workpackages 2 and 3.

This section of the report is effectively the summation of workpackage 1 , “Introduction to Power Electronics Packaging” supported by the initial preliminary work undertaken in work packages 2 and 3 enabling a clear focus on the course module requirements.

Based upon the inputs from the PEMD and from expertise within the project team, this project will create and introduce a set of training modules specifically addressing power electronics packaging at three levels, basic, intermediate and advanced.

- a. Basic:
Raising awareness of power electronics packaging ranging from School/Colleges to Universities/HEIs through an open access introduction video and presentation material explaining the fundamentals and significance of power electronics packaging in the drive towards electrification.

Additionally the basic level will include an introduction video and presentation material explaining the fundamentals and significance of PEP thereby raising awareness of students in the identified Academic environments. It is considered that these aspects will also appeal to personnel in a range of UK industries as identified in section 2. This open access information will be available at the end of the project in April 2022.

b. Intermediate:

Enabling interested parties to gain understanding of the details of PEP, for example, in the following themes:

- Packaging Options
- Design Issues
- Materials and Processes
- Understanding the Supply Chain

These intermediate courses will be targeted towards participants needing re-skilling from adjacent industries or who are already working in the field of power electronics, but require more knowledge to understand the multi-disciplinary nature of the challenges faced in designing, manufacturing and testing of power modules.

Course content for 2 off Intermediate Training Modules will be delivered at the end of this project in April 2022, with a further 2 off Intermediate Training Modules to be completed before the end of 2022.

c. Advanced:

Assisting participants in the implementation of power electronics packaging in Research and Development, prototyping and manufacturing, including the following topics:

- Step-by-step Analysis of Packaging Processes including costs and value chain
- Device Packaging Constraints
- Advanced Packaging Developments
- Testing, Modelling Reliability, Failure Analysis and Lifetime Prediction

Course content for the first Advanced Training Module will be delivered at the end of this project in April 2022, with a further 2 off Advanced Training Modules to be completed by the end of 2022.

Additional Intermediate and Advanced Training Modules will be prepared and delivered in 2023, based on the plan developed in the project with feedback from the key stakeholders.

4. Overview of PEP training modules course titles and levels assigned

The project has set out the need for a syllabus of the course comprising an Introductory Video and 3 key stages of training covering Basic, Intermediate and Advanced Packaging Technologies as introduced in section 3 of the report. The video will be aimed at developing interest and awareness of PEP in general and then the actual training course stages are to be developed with a set number of modules that will encompass the basic PEP Principles, intermediate learning aspects and ending with development of specialised advanced aspects.

Based upon discussions with IMAPS-UK members and the wider PEMD community, the course modules have been defined as follows:

a) Basic PE Packaging Principles

A set of four modules (1-4) are to be developed to cover the basic technology requirements:

- **MODULE 1: Introduction to PEP**

A module to cover the introductory aspects of Power Electronics with a course lasting around 2 hours with additional time for Questions etc. This module is to be split into 3 segments:

- a) “Why Package” - a 45 Minute introduction to package technologies
- b) “What is the driver” - a 30 minute overview of package and application needs
- c) “The basic packaging process” – a 45 minute overview of the main packaging process steps.

- **MODULE 2: Making of PEP**

The second course module takes the next step and introduces a basic overview of Power packages and ways in which they are manufactured in a 2 hour plus session of 3 segments:

- a) Assembly Equipment – a 45 minute overview of the typical packaging equipment found in the assembly facility
- b) Standard Power Packages – a 30 minute review of PEP types and styles
- c) How are they made – a 45 minute overview of how basic packages are fabricated

- **MODULE 3: Design for PEP**

The next stage in the course is that of finding about developments in package technology specifically looking at how design of PEP is related to the application requirements. A 2-3 hour (with Questions etc) course module in 3 segments:

- a) Application Specific Packaging – a 45mins look at why PEP varies with key applications
- b) Package design aspects- a 45 mins review of design guidelines and software design tools
- c) Which one to choose – a 30 mins overview of PEP relating applications to package possibilities

- **MODULE 4: Developing PEP**

The final course module of the Basic set is a 2-3 hours (with Questions etc) session looking at an introduction to testing and reliability and outlining potential future developments and trends matching the expected needs of PEP development. The 3 segments of this are:

- a) Testing and Reliability Aspects – a 45 mins session covering key reliability & quality requirements
- b) Package Roadmaps — a 45 mins overview of the Power Electronics and Heterogeneous Integration Roadmaps aspects relating to PEP
- c) Trends to Advanced Packaging – a 30 minute session looking at PEP future expectations.

b) Intermediate PE Packaging Aspects

A further four course modules (5-8) are to be developed that will cover the next stages of learning about the needs for manufacturing of PEP.

- **MODULE 5 – Developing PEP Options**

Four 1 hour sessions, each of 45 mins plus discussion time per session are required to cover the aspects related to development of PEP technology:

- a) Selection of devices (Si, SiC, GaN) and significance of voltage, $R_{ds(on)}$ and device topology
- b) Discrete packaged devices/bare chip on substrate/wafer level packaging
- c) Selection of substrates (PCB, IMS, DBC, etc) and heatsinks
- d) Integrated power modules (gate drivers, passives, etc)

- **MODULE 6 - Design issues:**

To cover further aspects of design need six 40 minute sessions (30 mins plus discussion per session) are required:

- a) Why Power Electronics Packaging is different
- b) Design aspects (including thermal/mechanical/electrical simulation) and guidelines
- c) Understanding Power Switching and Parasitics (L, C, R)
- d) Thermal Management and High Temperature Operation
- e) Hermeticity and Voltage Isolation/breakdown Power electronics testing and reliability overview

- **MODULE 7 - Materials and Processes**

PEP utilises a wide range of materials and knowledge of their related process aspects is an important requirement. This module will address these aspect in four 1 hour sessions (45 mins plus discussion per session) covering:

- a) Die attach – Solder/Sinter
- b) Die Interconnection – Wire/ribbon bond, Clips/studs, sinter, solder
- c) Encapsulation – silicones, epoxy moulding, potting
- d) Terminal Connections – Ultrasonic/Laser/Solder/Mechanical

- **MODULE 8 -The Supply Chain**

A knowledge of the many aspects of the supply chain is to be addressed in five 45 min sessions (40 mins plus discussion per session) covering:

- a) Equipment
- b) Devices and Passive Components
- c) Materials
- d) Services – testing, failure analysis
- e) OSATs

c) [Advanced PE Packaging aspects](#)

The advanced part of the PEPTUS course comprises four in depth training modules (9-12) which address the main aspects of package production in a level of detail that reinforces and extends the knowledge gained form the basic and intermediate modules.

- **MODULE 9 - Understanding the Packaging Processes**

This module is to be made up of three 60 min sessions (50 mins plus discussion per session) that will look into the manufacturing and assembly process stages in depth, covering:

- a) Step by process step - A 'walk thorough' of the whole assembly process
- b) From Wafer/Substrate to Module – a review of the different options available for Advanced. PEP
- c) Material/Manufacturing/Test Costs and Value Chain considerations of the cost effectiveness of the materials and processes involved

- **MODULE 10 - Device Packaging Constraints**

Parasitics such as inductance capacitance and resistance will affect the performance of devices and equipment in different ways. It is therefore vitally important to have knowledge of the effects of packaging and how to mitigate for issues arising. This module will have three 60 min sessions (50 mins plus discussion per session) to address the key topics of:

- a) Effects of Packaging on devices and modules
- b) Effects of devices on Packages and packaging
- c) Design Rules and Options

- **MODULE 11 - Advanced Packaging Developments and Relevance to PEP**

PEP generally utilises tried and tested as well as legacy technologies. However rapid advancement in packaging technology will necessitate an understanding of the new options in order to enable advanced more efficient products. This module will offer five 45 min sessions (40 mins plus discussion per session) covering:

- a) Double sided assembly
- b) 3D
- c) TSV
- d) Chiplets
- e) Heterogeneous Integration

- **MODULE 12 - Testing, Modelling, Reliability and Lifetime Prediction for PEP**

A key aspect of any manufacturing process is that of quality and reliability. For PEP this topic is probably one of the most important yet difficult to learn. Hence this module will comprise five 50 min sessions (40 mins plus discussion per session) addressing the following aspects in depth;

- a) Failure modes – device and package related
- b) Functional, Characterisation and Environmental Tests
- c) Failure analysis techniques and limitations
- d) Lifetime predictions and assessment
- e) PEP Qualification and Certification

5. Allocation of Module developments

The PEPTUS project is very short term and hence not all of the modules detailed in section 4 can be developed within the 3 month timescale. The project is committed to deliver:

- An Introductory Video
Preliminary work is ongoing for the production of the video using expertise from production company MoMO. It will utilise media and details supplied from IMAPS-UK members and stakeholders. It is mainly a workpackage 3 activity and hence outside the scope of this report.
- Basic Modules:
The project team has agreed to produce all four basic units -
 - **Module 1 – Allocated to PandA Europe**
 - **Module 2 - Allocated to PandA Europe**
 - **Module 3 – Allocated to Tribus-D**
 - **Module 4 - Allocated to Tribus-D**
- Intermediate Modules:
Only two of the modules (#5 and #7) will be worked on
 - **Module 5 – Allocated to PandA Europe**
 - Module 6 – For post project production
 - **Module 7 – Allocated to Tribus-D**
 - Module 8- For post project production
- Advanced Modules;
Just one module (#12) will be produced as a deliverable:
 - Module 9 – For post project production
 - Module 10 - For post project production
 - Module 11 – For post project production
 - **Module 12 – Allocated to SiCology**

6. Training Course accreditation

The course content will be validated by a Steering Group drawn from academic and industrial IMAPS-UK Members. The independence of this approach will enable the knowledge to be generated, certified and disseminated without commercial and technical bias.

The project will look at the potential of setting up an IMAPS-UK “Academy” to enable a certification that

- Industry will support and apply
- Academia will validate
- Membership will approve and vet

Preparation of qualification aspects will be looked into and it is planned to involve the University of Warwick through partner SiCology and other stakeholders such as the CSA Catapult and the MTC Catapult. It will also be possible to Poll the IMAPS-UK membership for “Advisory ” support and acceptance.

One course of action being considered is that of setting up an “IMAPS-UK ACADEMY” PEP Competence Certification, where the qualification is awarded after completion of the course. Verification of the course completion being by undertaking a 1 hour “examination” and Feedback Interview (with IMAPS Members/stakeholders). The examination would be done by creation of a set of questions having Multi choice answers in order to enable a percentage success mark to be given.

7. PEPTUS Impact

This project will create and introduce a set of training modules specifically addressing power electronics packaging at three levels, basic, intermediate and advanced.

Interest will be monitored through the viewing of the “Introduction to Power Electronics” Video on platforms such as You Tube.

For the Intermediate and Advanced Level Training Modules, the market will be focused on the 71 UK Universities offering electronic engineering courses and over 400 companies operating within the Power Electronics sector.

The project will also deliver two main outcomes for IMAPS-UK:

- Raising Awareness – through open access “Introduction to Power Electronics Packaging” video and presentation material for Schools, Colleges and Universities/HEIs and interested parties
- Specific Training Courses – the predicted £10k income in 2022 and £20k in 2023, will be re-invested in the creation of the complete set of training modules

For the wider impacts of the project on the quality of life; the following benefits will accrue:

- Re-skilling and upskilling of personnel for sustainable high value jobs of the future
- Raising awareness of power electronics packaging which is a hidden topic in current courses delivered in schools, colleges and Universities
- Providing up-to-date knowledge and training to enable everyone, regardless of background, to work in and contribute to the power electronics community
- Reducing the environmental impact through the deployment of electrically powered modules, reducing gaseous and particulate emissions and assisting in achieving Net Zero goals