Taking the heat out of space applications

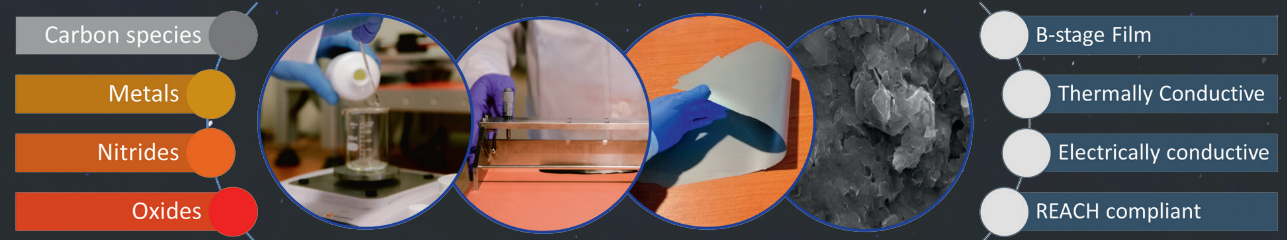
Effective thermal management of the new generation of high-power components is essential if their capabilities are to be fully exploited in space applications. We spoke to **David Nevo**, **Erich Neubauer**, **Piotr Śpiewak**, **Szymon Bednarski**, **Arno Hoogerwerf**, **David Hien**, **Laurent Letteron** and **Athanasios Baltopoulos** about the work of the HEATPACK project in developing new packaging solutions.

A lot of progress has been made over recent years in the development of high-power semiconductors, with powerful and efficient gallium nitride (GaN) transistors now available. As this technology has developed, a parallel need has emerged for efficient techniques to fully exploit its potential and improve the thermal management of these components. "We see that there is a gap here, between progress at the active component level, and at the packaging level," says David Nevo, an engineer at Thales Alenia Space. This is an issue the Heatpack project, a consortium bringing together academic and commercial partners from across Europe (including Thales Alenia Space) aims to address. "The intention in the project is to explore some innovative packaging solutions for high-power components," outlines Nevo. "It's not only a matter of thermal efficiency, it's also a matter of performance and reliability of the components. Keeping the components as cold as possible will have a huge impact on their reliability, and their lifetime."

Packaging solutions

The main area in which it is envisaged these packaging solutions will be applied is the space domain, with satellites today generating large amounts of heat. Satellites today have more capacity and more capabilities, and telecommunications applications require a lot of power. "This means increased thermal fluxes need to be handled inside the payload," explains Nevo. A number of technologies at different levels of maturity are being investigated in the project, with Nevo and his colleagues aiming to demonstrate that they are reliable and can be used in the space domain. ""For the realisation of the electrical demonstrators, and the validation of the packages – based on the technologies developed by the partners – we will use already available components such as GaN power transistors," says Szymon Bednarski, an engineer at Alter Technology UK, a member of the project consortium. "We're developing better packaging solutions, to improve performance for the space market."

This includes research into the use of diamond-based composite materials for use as baseplates, replacing composites such as tungsten-copper, or molybdenum-copper. Diamond is being used primarily for its outstanding thermal properties, yet Nevo says it also has some drawbacks. "It has a very low coefficient of thermal expansion, so it is difficult to match it with other common packaging materials," he explains. This is a challenge researchers at Warsaw University of Technology (WUT) and the RHP technology research institute, both members of the project consortium, are dealing with in the development of composite materials based on diamond particles. "We use diamond powders or diamond particles, which are characterised by a high thermal conductivity and a low coefficient of expansion. These materials are well-suited for use as a filler in a metallic matrix," says Erich Neubauer of RHP. "We are creating a composite material, consisting of either a silver matrix, or a copper matrix."



Matching materials with functions and processes: multi-functional Thermal Interface Materials in film form developed under HEATPACK project

The diamond particles are then embedded in this matrix in a high concentration, which should in theory result in a material with excellent thermal performance. However, the main problem with metal-diamond composites - in particular copper-diamond - is the interface. "Essentially copper and diamond do not like each other. So we need to modify the interface, so that there is good compatibility between the metal and the diamond," outlines Neubauer. "To prevent graphitisation of diamonds during thermal processing, at WUT we developed copper-diamond composite using Pulse Plasma Sintering powder metallurgy technology," says Piotr Śpiewak, a researcher at WUT.

This issue has been resolved to a degree, yet a further challenge lies in shaping and machining the composite material effectively. "A metal which contains a lot of diamond particles is really difficult to machine," says Neubauer. "We cannot use standard milling or cutting operations, so we are using laser-cutting and other cutting techniques. We need to identify the best techniques for the cutting operations, so that we meet the geometric tolerance requirements."

The University of Bristol, a partner in HEATPACK, is involved in the thermal characterisation of these metal-diamond composites, as well as the other materials under development in the project. Researchers at Bristol are experts in this area and are developing a method called Frequency Domain ThermoReflectance (FDTR), tailored to measure the thermal conductivity of these materials. "This method is well suited to the measurement of 'sandwich' composites in particular, such as the diamond-based materials produced in the project," outlines Nevo.

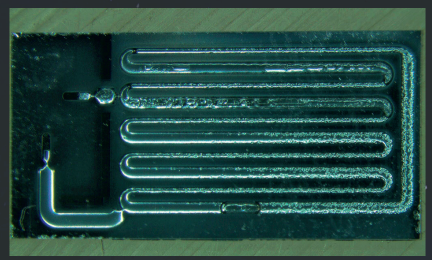
Thermal interface materials

A further aspect of the project's research involves the development of thermal interface materials (TIMs), which are located between the active components and the package. One part of this work centres around developing a silver sintering based TIM. "The aim is to develop a better, more flexible material, in relation to performance as well as to component assembly," says Bednarski. One of the major challenges here is in achieving the best possible thermal conductivity of the material, while at the same time keeping the assembly methods as simple as possible, a topic which is being addressed by researchers at WUT. "Our colleagues at WUT are developing a sintered paste, which combines the advantages of a solder and a glue, while achieving very good thermal efficiency of the joint, about two times better than the brazing material currently in use," says Nevo.

However, the usual presence of air voids (pores) during the sintering of silver-based pastes diminishes their thermal conductivity and, therefore, their performance. "Currently we are working on optimising process parameters that reduce the voids during the chips assembly," summarises Śpiewak.

A second TIM under development in the project is an adhesive film which is intended to be both thermally and electrically conductive. TIMs provide an effective path for the heat to transfer given that transfer through air (convection) is not available in space due to vacuum conditions. To succeed in this high thermal conductivity, particles are employed in adhesives. "Over recent decades research and innovations in production technologies have brought to the market a plethora of nanomaterials, offering a variety of sizes, shapes, properties and functionalities. Materials with a 2-dimensional architecture, such as Graphene and Boron Nitride, are promising to push the performance of TIMs and are being investigated within HEATPACK in combination with traditional materials," notes Thanos Baltopoulos of Adamant Composites. The objective here is to achieve improved thermal performance, compared to commercially available films. "For us the challenge is not only to come up with a solution that meets the package application requirements (e.g. conductivity, temperature, vacuum compatibility); but that our film is compatible with all the production processes employed by our industrial partners for realizing the packages," adds Baltopoulos. "This kind of interface has a role to play in structural assembly, as well as in handling some possibly important thermal expansion mismatches even with large parts" outlines Nevo.

A filled active cooler ready for use.

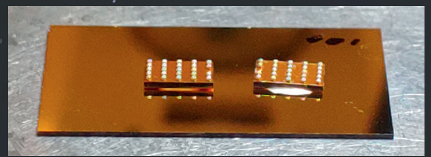


Active cooling

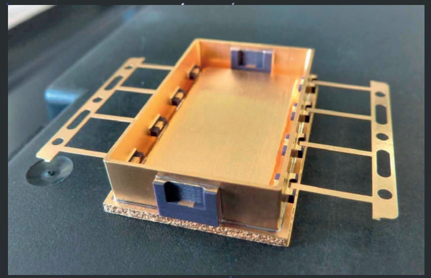
The project's agenda also encompasses the development of solutions designed to cool down the components, helping to ensure they can operate effectively for longer. Based at the Swiss Centre for Electronics and Microtechnology (CSEM), Arno Hoogerwerf is developing active cooling solutions. "With the device that we're making the semiconductor heats up a liquid underneath it. The liquid vaporises, it forms a bubble. The bubble moves to the cold side of the package where it condenses and becomes a liquid again. So you have physically moved the bubble, with a lot of heat in it, to the cold side," he outlines. This procedure has been shown to be very effective, providing excellent cooling performance - better than copper or silver - through the use of relatively low-cost materials.

"The advantage with active cooling is that you can achieve good cooling performance,

SiC-Lid bonded with silver sintering on the back-side of GaN Switch ICs.



High power package developed in the frame of EC funded project AGAPAC, implementing a diamond based composite baseplate.



HEATPACK

New generation of High thErmAl efficiency componenTs PACKages for space

Project Objectives

HEATPACK project aims to develop and validate critical technology building blocks for enabling transformative packages for space applications with very low thermal resistance.

Project Funding

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Project Partners

9 partners from 7 differentcountries:

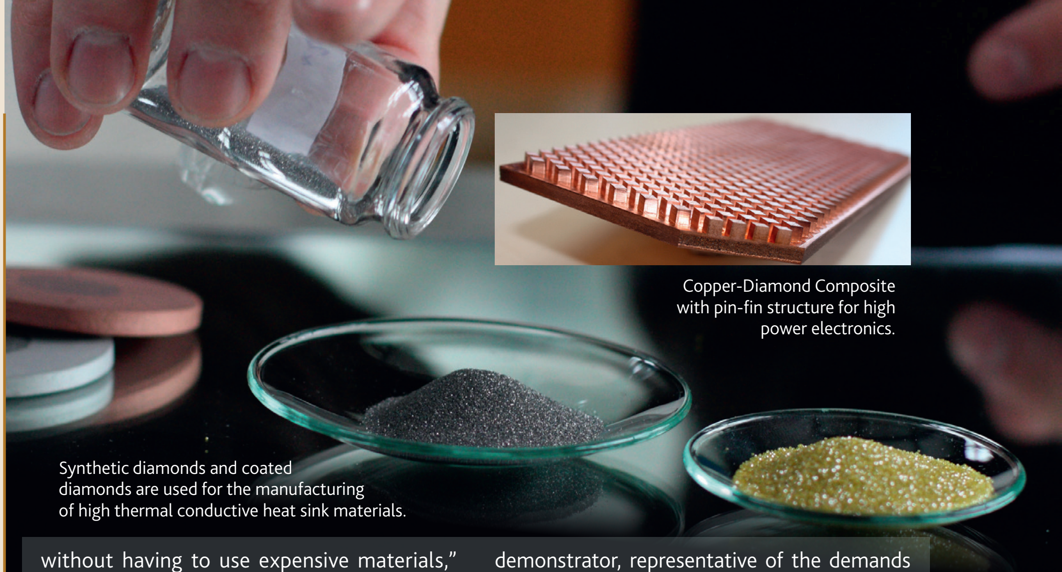
- Thales Alenia Space (Coordinator) - David Névo
- Adamant Composites - Mr Athanasios BALTOPOULOS, baltopoulos@adamant-composites.com and Mr Nicolas BLASAKIS, blasakis@adamant-composites.com
- CSEM - Mr Arno HOOGERWERF, arno.hoogerwerf@csem.ch
- Alter Spain - Juan Moreno, juan.moreno@altertechnology.com
- University of Bristol - Prof. Martin Kuball, martin.kuball@bristol.ac.uk
- Egide - Mr Laurent LETTERON, lletteron@fr.egide-group.com and Mr David HIEN, dhien@fr.egide-group.com
- Alter UK - Mr Szymon BEDNARSKI, Szymon.Bednarski@uk.altertechnology.com
- RHP - Mr Erich NEUBAUER, e.ne@rhp.at
- Warsaw University - Mr Piotr SPIEWAK, piotr.spiewak@pw.edu.pl and Mr Ryszard KISIEL, ryszard.kisiel@pw.edu.pl

Contact Details

Project Coordinator,
David Névo
Thales Alenia Space
Région de Toulouse, France
T: +33 5 34 35 72 15
E: david.nevo@thalesaleniaspace.com
W: https://heatpack.eu/

David Névo

David Névo is a senior engineer at Thales Alenia Space Toulouse, France. His activities are focused on packaging, advanced components and material solutions engineering for microwave space applications, with an expertise in Printed Circuit Board technology and Electromagnetics applied to microwave packaging and interconnects.



Synthetic diamonds and coated diamonds are used for the manufacturing of high thermal conductive heat sink materials.

Copper-Diamond Composite with pin-fin structure for high power electronics.

without having to use expensive materials," says Hoogerwerf.

Manufacturing packages

These different building blocks of the overall solutions – active cooling, diamond composites, and the two TIMs – will be evaluated by the partners during the project, then engineers at the Egide group will manufacture two packages, one dedicated to a Ka-band RF application with an output power of more than 20W for each unit, and an LF ("Low Frequency") package dedicated to DC-DC conversion applications. "At Egide, we have been developing and manufacturing hermetic packages for more than 30 years. We use our expertise in special alloys, plating, chemistry, mechanics, electronics, RF modelling and ceramics to protect our customers' ICs," says David Hien, Director of Business Development at Egide.

The packages are much smaller than previous generations, with researchers working to ensure that the active components within a package keep running for a long time, so that a satellite can remain operational. In general, hermeticity is a key requirement because the active components are highly sensitive to moisture and their performance can degrade over time, although more and more non-hermetic/plastic components are used even in the space industry mainly to drive down costs. "The LF package is not required to be fully hermetic," says Laurent Letteron, Research & Development and Engineering Manager at Egide.

These packages, implementing the building blocks developed, will undergo rigorous testing to assess their suitability for space applications. "They will also be put into an electrical demonstrator, representative of the demands of space applications, and will also be subjected to some thermo-mechanical stresses, deep analysis, by our partner Alter Technology at their site in Spain," outlines Nevo. "

This is part of the wider goal of securing a European supply chain for high-power, high thermal efficiency packages. While the project has primarily focused on space applications, some of the building blocks could be used down here on earth. "We are working on a lot of different projects right now, for defence, opto-electronics and power packaging. Through participating in projects like Heatpack we can showcase our expertise, challenge ourselves to find new solutions, and then bring them to other markets," says Hien. Once it has been demonstrated that these packages and solutions are able to withstand the constraints of the space environment, this could lead to the identification of other potential applications, although some technologies are closer to market readiness than others. "The various technologies are at different maturity levels. For example, the TRL of active cooling may not be as high at the end of project as for diamond composites, so further development will be needed there," continues Nevo.

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First steering comittee meeting organised with the consortium in Warsaw.