BSGN Advanced Materials Accelerator

Your route for new materials development in space

Key theme: Advanced Ceramics

Ceramics are inorganic materials made from combination of metallic and non-metallic elements (mainly oxygen, boron, carbon and nitrogen), which results in oxides, carbides, borides and silicides.

The bonds are ionic, or a combination of covalent and ionic. Synthetic high-quality powders are used for production of advanced ceramics. These raw materials give ceramics the required properties for each application. The microstructure of advanced ceramics is generally fine and uniform.

In addition to having high hardness and high strength, advanced Ceramics also have two other particularly critical and high value characteristics, thermal and electromagnetic. These features have given advanced ceramics a competitive edge over other material types in electronics as well as critical aerospace, space, and defence applications.

Thermal characteristics:
Advanced ceramics possess several important thermal properties required for manufacturing of components that must withstand extreme temperatures. They can retain their shape and function under extremely high temperatures. Advanced ceramics also have other thermal properties such as thermal shock and wear resistance, thermal expansion, and thermal conductivity.

Functional properties:
Advanced ceramics are also able to provide the necessary electromagnetic characteristics that are necessary in different industries, including insulation, conductivity, dielectric and piezoelectricity.

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Opportunity 1 (Click here for more info)
In-space R&D and manufacturing offer the opportunity to manufacture **higher-performance wide-bandgap (WBG) semiconductors** that currently suffer from reduced quality due to the impacts of convection and sedimentation in the manufacturing process. Production and manufacturing of gallium-based, silicon carbide wafers, and diamond-based substrates in space and microgravity offers several advantages than their manufacturing on Earth, including significantly higher quality and less defective final products resulting in greatly enhanced performance.

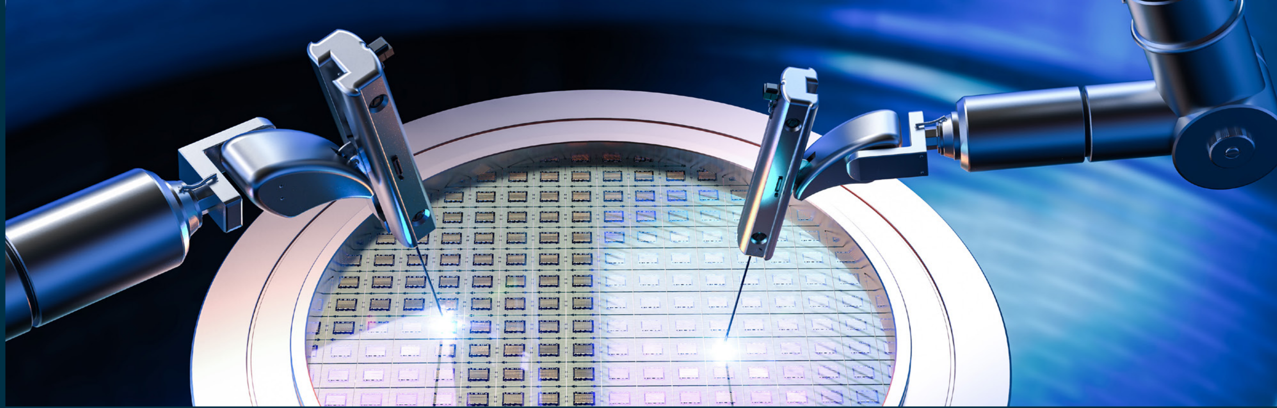
Opportunity 2 (Click here for more info)
Silicon carbide and carbon material classes are of significant interest for **in-space manufacturing** as they are commonly used in space applications due to their low thermal conductivity and good resistance to high temperatures. Developments in the manufacturing of ceramic matrix composites also promise the development of lightweight structural parts for space applications.

Using in-space resources, such as lunar regolith, it is possible to produce water, fuel, and other supplies – this is referred to as in-situ resource utilisation. To develop in-space economies and infrastructures, ceramic materials may be fabricated and used in the manufacture of habitats, radiation shields, semiconductors, and much more. In-space manufacturing, repairability and in-situ resource utilisation avoid the necessity of transporting materials from Earth.

Opportunity 3 (Click here for more info)
Understanding functional ceramic processing and phenomena in microgravity offers the potential development of novel materials and polytypes of existing material systems. By studying ceramics processing and characterisation in microgravity, further understanding of manufacturing phenomena and material physics can be developed and exploited to enhance terrestrial materials production.

Advanced Ceramics Opportunities:

1. Semiconductors



1. Market opportunity
In-space R&D and manufacturing offer the opportunity to manufacture higher-performance wide-bandgap (WBG) semiconductors that currently suffer from reduced quality due to the impacts of convection and sedimentation in the manufacturing process.

Unlike conventional semiconductors, WBG semiconductors permit devices to operate at much higher voltages, frequencies, and temperatures than conventional semiconductor materials like silicon.

Currently there is significant industry interest in developing next-gen semiconductors for advanced applications such as defence and electric vehicles. Microgravity R&D platforms allow for carrying-out cutting-edge research with the potential for remarkable improvements to semiconductor chips.

2. Why space is of benefit
• Terrestrial semiconductor chip production suffers from the impacts of convection and sedimentation in the manufacturing process. These prevent atoms from settling into their lowest energy states on a wafer, producing defects that interfere with the flow of electricity across the wafer.

• Production and manufacturing of gallium-based, silicon carbide wafers, and diamond-based substrates in space and microgravity offers several advantages than their manufacturing on Earth, including significantly higher quality and less defective final products resulting in greatly enhanced performance.

• Other advantages of in-space manufacturing of semiconductor materials and chips include:

- Significant reduction of the concern of disposal of this toxic waste and by-products – this is of significant relevance to gallium arsenide wafers.
- Potential for reduction of water consumption in manufacturing of gallium-based and other high-value semiconductor material and micro-chips given the vacuum and temperature properties in space. On Earth, unprecedented volumes of water are consumed for cleaning and cooling of their manufacturing processes.

3. Previous experiments in space/successful case studies
• Made in Space: have developed an autonomous, high-throughput manufacturing capability (Industrial Crystal Facility) for production of high quality, lower-cost semiconductor chips at a rapid rate. Fabrication of these in microgravity is expected to reduce the number of gravity-induced defects, resulting in more usable chips per wafer.

• SpaceForge and Varda: Both have plans for manufacturing high-value ceramics and semiconductor materials and chips (potentially gallium-based semiconductors) on board of their-small satellite-based space factories

4. Applications

There are a wide range of applications across established and growing industries: power electronics such as electric vehicles (EVs), electrified industrial technologies (such as industrial heat pumps), renewable energy applications, data centres, and quantum computing.

Currently there is significant industry interest in developing next-gen semiconductors for advanced applications in defence/satcoms and EV:

Defence & Satcoms:

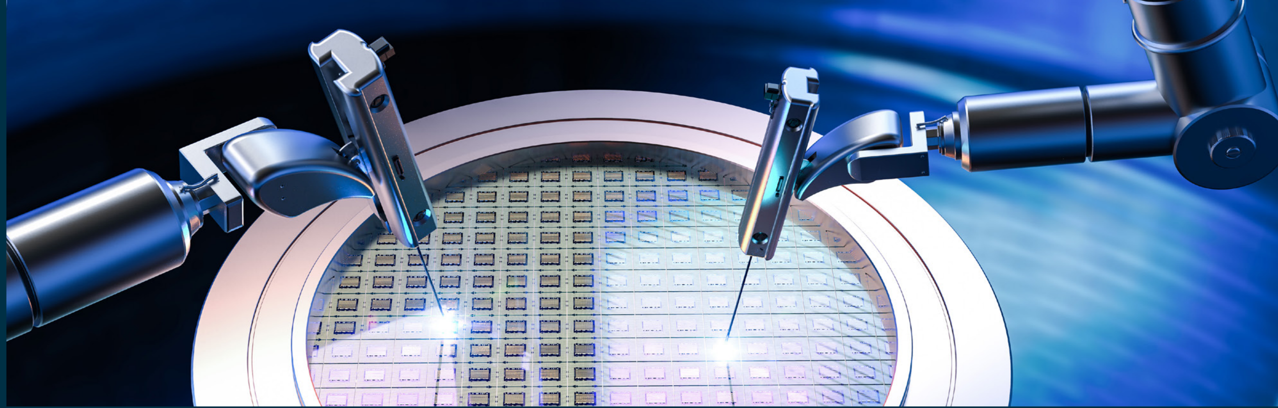
- Driven by investments in outstanding needs in electronic warfare (jammers), radar, communications and UAVs.
- The global military market (excluding radars) for Gallium Nitride devices is expected to reach £1bn by 2024.
- The defence sector is characterised by large vertically integrated multinational corporations such as BAE Systems, Thales, Northrop Grumman, Lockheed Martin, L3, Raytheon, Finmeccanica, MBDA and Cobham, several of whom have specialised in-house semiconductor manufacturing capability but also purchase from external suppliers.

Electric Vehicles:

- Automotive electronics and radars are set to become one of the fastest-growing parts of the RF and microwave applications market.
- In 2019 semiconductors (WBG and conventional) comprised about 4% of the value of a new premium car. By 2030, they are expected to comprise >20% of the value (Intel, 2021)
- Autonomous vehicles will also rely on communications (probably via 5G) with road information and telematics systems.

Advanced Ceramics Opportunities:

2. Manufacturability & reparability in space



1. Market opportunity

Ceramic materials are used for several applications in space, particularly in thermal prtection systems or heat shields as they can withstand and radiate heat. For future missions, requiring the return-to-earth of larger items, in-orbit manufacturing of heatshield may become an optimised solution.

Similarly, the replacement of components in space is a highly difficult process requiring signification human intervention – in-situ reparation in the space environment is therefore of high interest.

Silicon carbide and carbon material classes are of significant interest for in-space manufacturing as they are commonly used in space applications due to their low thermal conductivity and good resistance to high temperatures. Additionally, they both have a good radiation resistance. Developments in the manufacturing of ceramic matrix composites also promise the development of lightweight structural parts for space applications.

Using in-space resources, such as lunar regolith, it is possible to produce water, fuel, and other supplies – this is referred to as in-situ resource utilisation. To develop in-space economies and infrastructures, ceramic materials may be fabricated and used in the manufacture of habitats, radiation shields, semiconductors, and much more.

2. Why space is of benefit

The microgravity environment may offer numerous benefits in the manufacturing of ceramic materials:

- Single-step additive manufacturing exploiting microgravity to negate necessary secondary processing to acquire suitable material integrity and mechanical properties.
- No need for additives to avoid sedimentation of ceramic particles in precursor formulations.
- In-situ resource utilisation avoid the necessity of transporting material from Earth.
- Enable temperature-resistant, reinforced ceramic parts with better performance due to a reduction in defects caused by gravity, such as sedimentation and composition gradients that occur in terrestrial manufacturing.

3. Previous experiments in space/successful case studies

- Made in Space: The Turbine Ceramic Manufacturing Module (Turbine CMM) investigates the capability to produce ceramic matrix composite single-piece turbine blisks using stereolithography in microgravity for commercial use on Earth.

3. Previous experiments in space/successful case studies (continued)

Bundesanstalt für Materialforschung und -prüfung (BAM):

- LSDzero - Powder-based additive manufacturing under reduced gravity conditions
- 3D printing in space: parabolic flight experiments provide new insights into component quality

There is a growing body of research on In-situ resource utilisation, the use of lunar regolith with 3D printing equipment to reduce the risk and cost of lunar missions.

- Paper example: Additive Manufacturing of Functionally Graded Materials from Lunar Regolith
- Article: 'Project Moonrise: Scientists 3D print lunar regolith-based zero gravity structures'
- NASA: Contour Crafting Simulation Plan for Lunar Settlement Infrastructure Build- Up.
- Giovanni Cesaretti, et al. Building components for an outpost on the Lunar soil by means of a novel 3D printing technology.

3D printing in zero-G: printing spares, maintenance, and reparation products.

4. Applications

Defence and space:

- Combustion and turbine section components of aero-propulsion and land-based gas turbine engines
- Carbon brakes

Space vehicles:

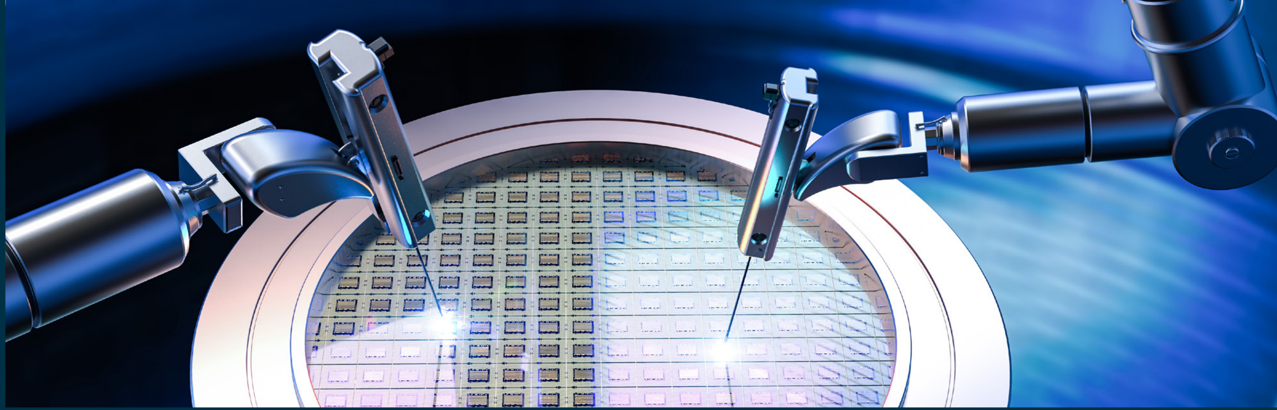
- Thermal protection systems, thruster nozzles, reusable rocket nozzles, and turbopump components for space vehicles
- Atomic oxygen and erosion-resistant coating

Nuclear:

- Nuclear fission and fusion reactors as fuel cladding and radiation blankets
- Space nuclear reactors suppliers.

Advanced Ceramics Opportunities:

3. Understanding functional ceramic processing & phenomena in microgravity



1. Market opportunity
The field of functional ceramics is vast, including material categories such as dielectrics, piezoelectrics, ferroelectrics, ion and mixed ion-electron conductors, superconductors, and magnetics.

Experimentation in microgravity offers the potential development of novel materials and polytypes of existing material systems and by studying ceramics processing and characterisation in microgravity, further understanding of manufacturing phenomena and material physics can be developed and exploited to enhance terrestrial materials production. One such example of this is the possible development of higher-temperature superconductors, either through enhancing our understanding of the fundamental science or by creating novel materials.

2. Why space is of benefit
• Containerless melt processing has proven to be a novel technique for gaining valuable information about the phase relationships, particularly in oxide superconductor systems.
• Ability to grow large-grain microstructures thus improving the performance of functional ceramics where grain boundaries have detrimental effects.
• Purity control due provided by the avoidance of contamination.

3. Previous experiments in space/successful case studies
• Factories in space: Superior high temperature superconductors capable of higher currents thanks to larger crystals. Hypothetical dream for the future about maybe being able to make room-temperature superconductors only in microgravity.

• Naomichi Sakai et al. Fabrication of large-grain bulk superconductors in microgravity environment: The experiment to fabricate large-grain RE–Ba–Cu–O (RE: Rare-Earth element) bulk superconductors in microgravity environment were in the Unmanned Space Experiment Recovery System project

• Naomichi Sakai et al. Experiment for growing large Gd–Ba–Cu–O–Ag bulk superconductor: Unmanned space experiments were performed with the aim of growing large grain Gd–Ba–Cu–O superconductors in space.

• Wake Shield Facility: The development of photo-assisted MOCVD has resulted in the ability to grow high quality YBa2Cu3O7-x (YBCO) superconducting films at very high growth rates (exceeding 1 micron/min). These rates are conductive to the production of thick films of YBCO and are being applied to the integration of YBCO to flexible metallic substrates for applications as thick film superconducting wires with high critical current densities.

4. Applications

Functional ceramics are ubiquitous in everyday modern life from electronic devices to communications, energy conversion and storage, and automation.

With respect to superconductors, there are many applications:

- Generators, particle accelerators (large Hadron Collider), and potentially fusion power.
- Transportation such as maglev trains, and electric motors.
- Power transmission over long distances.
- Computing applications including quantum computing.
- Superconductors mainly used for creating powerful electromagnets for magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) testing. They can also be used to separate magnetic and non-magnetic materials.

The BSGN Advanced Materials Accelerator Call for Proposals is now open. Apply by 30 Nov 2022.

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About the BSGN Advanced Materials Accelerator
The BSGN Advanced Materials Accelerator has been established to support innovators and enterprises developing new products, technologies, and services at the intersection of advanced materials and microgravity engineering. The accelerator promotes opportunities for engineering novel materials in microgravity, and the contract is carried out under the BSGN programme of and funded by ESA, the European Space Agency.
The accelerator is coordinated by the Satellite Applications Catapult in collaboration with Innovate UK KTN, the National Composites Centre (NCC), the Technological Institute of Plastics (AIMPLAS), the DLR Institute of Material Research (DLR) and the Centre for Process Innovation (CPI). Learn more about BSGN here.

For inquiries, please get in touch at BSGNmaterials@sa.catapult.org.uk.