NASA/TM—2015-218858

An Overview of SBIR Phase 2 Materials Structures for Extreme Environments

Hung D. Nguyen and Gynelle C. Steele
Glenn Research Center, Cleveland, Ohio

August 2015

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI Program provides access to the NASA Technical Report Server—Registered (NTRS Reg) and NASA Technical Report Server—Public (NTRS) thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers, but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., "quick-release" reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Fax your question to the NASA STI Information Desk at 757-864-6500

- Telephone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Program
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM—2015-218858

An Overview of SBIR Phase 2 Materials Structures for Extreme Environments

Hung D. Nguyen and Gynelle C. Steele
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

August 2015

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA STI Program
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-605-6000

This report is available in electronic form at http://www.sti.nasa.gov/ and http://ntrs.nasa.gov/

An Overview of SBIR Phase 2 Materials Structures for Extreme Environments

Hung D. Nguyen and Gynelle C. Steele
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Technological innovation is the overall focus of NASA's Small Business Innovation Research (SBIR) program. The program invests in the development of innovative concepts and technologies to help NASA's mission directorates address critical research and development needs for agency projects.

This report highlights innovative SBIR Phase II projects from 2007-2012 specifically addressing Areas in Materials and Structures for Extreme Environments which is one of six core competencies at NASA Glenn Research Center**.** There are twenty three technologies featured with emphasis on a wide spectrum of applications such as fine-filament superconductor wire, composite oxide cathode materials, nano-composites, high radiation solar cell, wrapped multilayer insulation, thin aerogel, and much more. Each article in this booklet describes an innovation, technical objective, and highlights NASA commercial and industrial applications.

This report serves as an opportunity for NASA personnel including engineers, researchers, and program managers to learn of NASA SBIR's capabilities that might be crosscutting into this technology area. As the result, it would cause collaborations and partnerships between the small companies and NASA Programs and Projects resulting in benefit to both SBIR companies and NASA.

No-Oven, No-Autoclave Composite Processing

Rapid fabrication of large, single-piece composite structures

Very large composite structures, such as those used in NASA's Space Launch System, push the boundaries imposed by current autoclaves. New technology is needed to maintain composite performance and free manufacturing engineers from the restraints of curing equipment size limitations.

Recent efforts on a Phase II project by Cornerstone Research Group, Inc. (CRG), have advanced the technology and manufacturing readiness levels of a unique two-part epoxy resin system. Designed for room-temperature infusion of a dry carbon preform, the system includes a no-heat-added cure that delivers 350 °F composite performance in a matter of hours. This no-oven, no-autoclave (NONA) composite processing eliminates part-size constraints imposed by infrastructure and lowers costs by increasing throughput and reducing capital-specific, process-flow bottlenecks. As a result of the Phase II activity, NONA materials and processes were used to make high-temperature composite tooling suitable for further production of carbon-epoxy laminates and honeycomb/sandwich-structure composites with an aluminum core.

The technology platform involves tooling design, resin infusion processing, composite part design, and resin chemistry. The various technology elements are combined to achieve a fully cured part. The individual elements are not unusual, but they are combined in such a way that enables proper management of the heat generated by the epoxy resin during cure. The result is a self-cured carbon/epoxy composite part that is mechanically and chemically stable at temperatures up to 350 °F. As a result of the successful SBIR effort, CRG has launched NONA Composites as a spinoff subsidiary. The company sells resin to end users, fabricates finished goods for customers, and sells composite tooling made with NONA materials and processes to composite manufacturers.

Applications

NASA

- Space launch systems
- Composite cryotanks
- In-space structures

Commercial

- Private space launch vehicles
- Oil and gas consumables
- Aircraft
- Large marine vessels
- Civil and automotive infrastructure
- Wind blades and towers

Phase II Objectives

- Improve resin processability
- Scale up honeycomb core and sandwich structure fabrication
- Validate NONA as a composite tooling system
- Improve manufacturing readiness
- Plan for technology transition

Benefits

- Eliminates capital-specific process bottlenecks
- Enables single-piece fabrication of large composite structures
- Reduces time in tooling acquisition as well as part fabrication
- Provides high performance in an epoxy at temperatures up to 350 °F
- Allows for on-site manufacturing
- Simplifies fabrication logistics
- Reduces labor time and cost
- Increases composite part throughput
- Eliminates post-cure requirement

Firm Contact

Cornerstone Research Group, Inc.
Michael D. Rauscher
rauschermd@crgrp.com
2750 Indian Ripple Road
Dayton, OH 45440–3638
Phone: 937–320–1877 ext. 1266

Proposal Number: 10-2 X5.03-9924

Out-of-Autoclave Cure Composites

Technology provides excellent balance of mechanical properties and damage tolerance

As the size of aerospace composite parts exceeds that of even the largest autoclaves, the development of new out-of-autoclave processes and materials is necessary to ensure quality and performance. Many out-of-autoclave prepreg systems can produce high-quality composites initially; however, due to long layup times, the resin advancement commonly causes high void content and variations in fiber volume.

Applied Poleramic, Inc. (API), developed an aerospace-grade benzoxazine matrix composite prepreg material that offers more than a year out-time at ambient conditions and provides exceptionally low void content when out-of-autoclave cured. When compared with aerospace epoxy prepreg systems, API's innovation offers significant improvements in terms of out-time at ambient temperature and the corresponding tack retention. The carbon fiber composites developed with the optimized matrix technology have significantly better mechanical performance in terms of hot-wet retention and compression when compared with aerospace epoxy matrices. These composites also offer an excellent overall balance of properties. This matrix system imparts very low cure shrinkage, low coefficient of thermal expansion, and low density when compared with most aerospace epoxy prepreg materials.

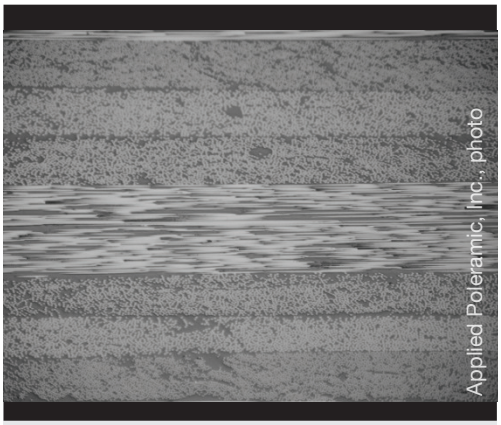
Applications

NASA

- Launch vehicle structures
- Large composite structures
- Composite cryotanks

Commercial

- Military and commercial aircraft
- High-performance composite applications
- Large structures



Phase II Objectives

- Develop matrices with out-of-autoclave processing characteristics
- Develop carbon fiber unidirectional prepreg systems using the novel matrices
- Demonstrate high-quality, low-void content, single vacuum bag oven-cured composites
- Demonstrate long out-times and insensitivity to the layup environment
- Demonstrate aerospace mechanical performance

Benefits

- Long out-time
- Low sensitivity to layup environment
- High modulus
- Damage tolerant

Firm Contact

Applied Poleramic, Inc.
Brian S. Hayes
hayesb1@sbcglobal.net
6166 Egret Court
Benicia, CA 94510–1269
Phone: 707–707–6738

Proposal Number: 09-2 X5.03-9388

Fine-Filament MgB_2 Superconductor Wire

For turboelectric aircraft propulsion systems and numerous commercial uses

Hyper Tech Research, Inc., has developed fine-filament magnesium diboride (MgB_2) superconductor wire for motors and generators used in turboelectric aircraft propulsion systems. In Phase I of the project, Hyper Tech demonstrated that MgB_2 multifilament wires (<10 micrometers) could reduce alternating current (AC) losses that occur due to hysteresis, eddy currents, and coupling losses. The company refined a manufacturing method that incorporates a magnesium-infiltration process and provides a tenfold enhancement in critical current density over wire made by a conventional method involving magnesium-boron powder mixtures. Hyper Tech also improved its wire-drawing capability to fabricate fine multifilament strands.

In Phase II, the company developed, manufactured, and tested the wire for superconductor and engineering current density and AC losses. Hyper Tech also fabricated MgB_2 rotor coil packs for a superconducting generator. The ultimate goal is to enable low-cost, round, lightweight, low-AC-loss superconductors for motor and generator stator coils operating at 25 K in next-generation turboelectric aircraft propulsion systems.

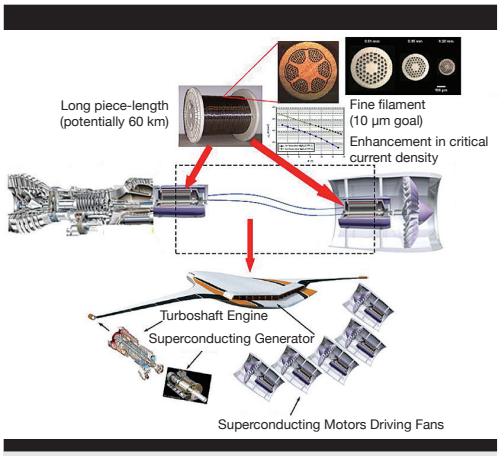
Applications

NASA

- Stator coils for all-electric aircraft
- Generators
- Motors
- Transformers
- Inductors
- Power conditioning equipment
- Magnetic bearings
- Actuators
- Magnetohydrodynamic magnets
- Propulsion engines
- Magnetic shielding in space
- Magnetic launch devices

Commercial

- Rotor coils for motors and generators
- Background magnets for magnetic resonance imaging (MRI) devices
- Inductive-type superconducting fault current limiters
- Resistive fault current limiters
- Low-speed direct-drive wind turbine generators
- Stators for generators and motors (50–400 Hz)
- Transformers
- Reactors
- Inductors



Hyper Tech Research, Inc. illustration

Phase II Objectives

- Develop high-filament-count, single-restack MgB_2 superconductors
- Optimize the double-restack conductor
- Reduce the twist pitch and develop MgB_2 conductors with a reduced number of magnetic components
- Develop MgB_2 superconductors with reduced transport current losses and different versions of MgB_2 cables
- Develop low-AC-loss second-generation MgB_2 superconductor wire
- Characterize the superconductivity and AC losses of MgB_2 wire, cables, and racetrack coils
- Deliver low-AC-loss MgB_2 wire to NASA and other collaborators
- Outline a follow-on Phase III program

Benefits

- Low cost
- Lightweight
- Low density
- Configurable in any critical current as a round wire
- Low AC loss

Firm Contact

Hyper Tech Research, Inc.
Sherrie Cantu
hypertechresearch@gmail.com
539 Industrial Mile Road
Columbus, OH 43228–2412
Phone: 740–517–1938

Proposal Number: 12-2 A3.03-9094

High-Temperature, Wirebondless, Ultracompact Wide Bandgap Power Semiconductor Modules

For space and commercial power systems

Silicon carbide (SiC) and other wide bandgap semiconductors offer great promise of high power rating, high operating temperature, simple thermal management, and ultrahigh power density for both space and commercial power electronic systems. However, this great potential is seriously limited by the lack of reliable high-temperature device packaging technology.

This Phase II project developed an ultracompact hybrid power module packaging technology based on the use of double lead frames and direct lead frame-to-chip transient liquid phase (TLP) bonding that allows device operation up to 450 °C. The new power module will have a very small form factor with 3–5X reduction in size and weight from the prior art, and it will be capable of operating from 450 °C to –125 °C. This technology will have a profound impact on power electronics and energy conversion technologies and help to conserve energy and the environment as well as reduce the nation's dependence on fossil fuels.

Applications

NASA

- Wide operating temperature power semiconductors for space power systems and science missions:
  - Spacecraft orbiting Earth, Venus, Europa, and Titan
  - Lunar Quest Program

Commercial

- Power electronics, along with computer and microprocessor technology:
  - Automobiles, electric utilities, pollution controls, communications, computer systems, consumer electronics, and factory automation
- Hybrid electric vehicles
- Renewable energy conversion
- Power supplies

Phase II Objective

- Develop an ultracompact hybrid power module packaging technology based on the use of double lead frames and direct lead frame-to-chip TLP bonding

Benefits

- Device operation up to 450 °C
- Very high current-carrying capability
- Low package parasitic impedance
- Low thermomechanical stress at high temperatures
- Double-side cooling
- Modularity for easy system-level integration

Firm Contact

Advanced Power Electronics Corp. (ApECOR)
John Elmes
jelmes@apecor.com
3259 Progress Drive, Suite A
Orlando, FL 32826–2930
Phone: 407–275–1174

Proposal Number: 09-2 S3.05-8550

High-Capacity, High-Voltage Composite Oxide Cathode Materials

For use in lithium-ion batteries

This SBIR project integrates theoretical and experimental work to enable a new generation of high-capacity, high-voltage cathode materials that will lead to high-performance, robust energy storage systems. At low operating temperatures, commercially available electrode materials for lithium-ion (Li-ion) batteries do not meet energy and power requirements for NASA's planned exploration activities. NEI Corporation, in partnership with the University of California, San Diego, has developed layered composite cathode materials that increase power and energy densities at temperatures as low as 0 °C and considerably reduce the overall volume and weight of battery packs.

In Phase I of the project, through innovations in the structure and morphology of composite electrode particles, the partners successfully demonstrated an energy density exceeding 1,000 Wh/kg at 4 V at room temperature. In Phase II, the team enhanced the kinetics of Li-ion transport and electronic conductivity at 0 °C. An important feature of the composite cathode is that it has at least two components that are structurally integrated. The layered material is electrochemically inactive; however, upon structural integration with a spinel material, the layered material can be electrochemically activated and deliver a large amount of energy with stable cycling.

Applications

NASA

- Lunar landers
- Extravehicular activities
- Lunar surface systems
- Rovers

Commercial

- Hybrid electric vehicles
- Consumer electronics:
  - Laptops
  - Mobile phones
  - Cameras
  - Camcorders
  - Portable televisions and radios
  - Power tools
- Medical devices
- Electric bicycles and scooters
- Military vehicles

Phase II Objective

- Enhance the kinetics of Li-ion transport and electronic conductivity at 0 °C in composite electrode materials

Benefits

- Maintains high energy and power densities at low temperatures
- Improves battery efficiency
- Stabilizes and enhances battery cell safety

Firm Contact

NEI Corporation
Nader M. Hagh
nmhagh@neicorporation.com
400 Apgar Drive, Suite E
Somerset, NJ 08873–1154
Phone: 732–868–3141

Proposal Number: 08-2 T3.01-9909

Silicon Whisker and Carbon Nanofiber Composite Anode

For spacecraft, electric vehicles, and bulk energy storage units

Silicon is an attractive anode material for lithium-ion (Li-ion) batteries because of its theoretical high-charge capacity; however, silicon anodes have limited applications because silicon's volume changes by 300 percent upon insertion and extraction of lithium, which results in capacity fading.

Physical Sciences Inc., has developed a silicon whisker and carbon nanofiber composite anode for use in Li-ion batteries that provides capacity greater than 1,000 mAh/g for more than 200 cycles (at 100 percent depth of discharge). The innovation's unique silicon architecture and structural reinforcement (made possible by the nanofibers) combine to provide a synergistic improvement in reversible capacity and electrochemical cycling. In addition, the developed powder can be handled and processed into electrodes using established procedures and equipment. The resulting battery system has the capability to provide an energy density of greater than 220 Wh/kg. A scalable synthesis process enables low-cost incorporation into electric vehicles and bulk energy storage units.

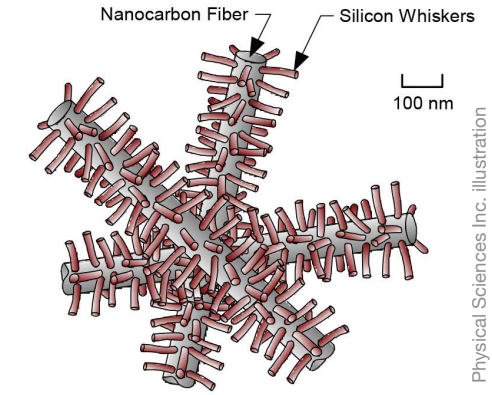
Applications

NASA

- Crew and launch vehicles
- Portable power for landers, rovers, and astronaut equipment
- Storage systems for crew exploration and spacecraft
- Stationary energy storage systems

Commercial

- Hybrid electric vehicles
- Consumer electronic devices



Silicon Whiskers/Nanowires on Carbon Nanofiber J-8382

Phase II Objectives

- Demonstrate production levels of grams per batch
- Achieve full cell anode capacity of >1,000 mAh/g at a charge rate of 10 (C/10) and 0 °C
- Establish a full cell cycle life of over 300 cycles
- Display an operating temperature of –30 °C to +30 °C
- Demonstrate a rate capability of C/5 or higher
- Deliver to NASA three 2.5 Ah cells (energy density >220 Wh/kg)
- Exhibit the safety features of the anode and full cells
- Design a 1 kWh prismatic battery pack

Benefits

- High capacity
- High power
- Improved cycle life
- Low cost

Firm Contact

Physical Sciences Inc.
Christopher M. Lang
lang@psicorp.com
20 New England Business Center
Andover, MA 01810–1077
Phone: 978–689–0003

Proposal Number: 08-2 X6.02-9113

Mesoporous Silicon-Based Anodes

For high-capacity, high-performance lithium-ion batteries

A new high-capacity anode composite based on mesoporous silicon is being developed. With a structure that resembles a pseudo one-dimensional phase, the active anode material will accommodate significant volume changes expected upon alloying and dealloying with lithium (Li). The mesoporosity is created without the aid of a surfactant template using a novel, high-volume synthetic process. The anode composite based on this material is designed to have a reversible Li-ion capacity exceeding 600 mAh/g—or nearly twice that obtainable with graphite anodes—and much higher capacities could be attainable. Phase I successfully demonstrated the synthesis of this new meso-silicon (Si) material as well as its high electrochemical activity and rechargeability. Phase II expanded the investigation of the development of mesoporous Si-based Li-ion anodes. The optimum anode was evaluated in Li-ion cells containing 4-V oxide cathodes.

Phase II Objectives

- Expand the investigation of the development of a mesoporous, Si-based Li-ion anode
- Evaluate the optimum anode in Li-ion cells containing 4-V oxide cathodes

Benefits

- Reversible Li-ion capacity exceeding 600 mAh/g (nearly twice that obtainable with graphite anodes)
- Nonflammable
- Subambient temperature operation

Applications

NASA

- Power for landers, rovers, and extravehicular activities (EVAs)
- Space-related applications in Moon and other planetary habitats

Commercial

The new anodes will result in high-performance Li-ion batteries suitable for the following commercial applications:

- Electric vehicle propulsion
- Portable consumer products:
  - Cellular phones
  - Portable power tools
  - Cameras
  - Laptop computers

Firm Contact

EIC Laboratories, Inc.
Dharmasena Peramunage
pera@eiclabs.com
111 Downey Street
Norwood, MA 02062–2612
Phone: 781–769–9450

Proposal Number: 09-2 X7.01-8568

SiLix-C Nanocomposites

For high energy density Li-ion battery anodes

For this Phase II project, Superior Graphite Co., in collaboration with the Georgia Institute of Technology and Streamline Nanotechnologies, Inc., developed, explored the properties of, and demonstrated the enhanced capabilities of novel nanostructured SiLix-C anodes. These anodes can retain high capacity at a rapid 2-hour discharge rate and at 0 °C when used in Li-ion batteries.

In Phase I, these advanced anode materials had specific capacity in excess of 1,000 mAh/g, minimal irreversible capacity losses, and stable performance for 20 cycles at C/1. The goals in Phase II were to develop and apply a variety of novel nanomaterials, fine-tune the properties of composite particles at the nanoscale, optimize the composition of the anodes, and select appropriate binder and electrolytes. In order to achieve a breakthrough in power characteristics of Li-ion batteries, the team developed new nanostructured SiLix-C anode materials to offer up to 1,200 mAh/g at C/2 at 0 °C.

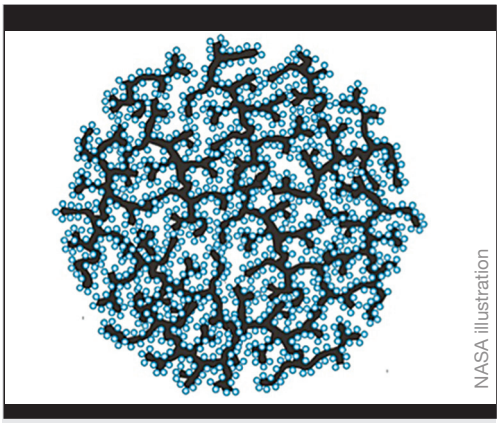
Applications

NASA

- Ascent module of the Altair Lunar Lander
- Lunar extravehicular activity (EVA) suit and integrated portable life support systems
- Lunar surface systems and mobility systems
- Uninterruptable power systems (UPS) for Orion spacecraft, the International Space Station (ISS), and other spaceflight vehicles

Commercial and Military

- Power sources for hybrid electric and electric vehicles (HEV and EV)
- Portable consumer electronics
- Handheld military equipment, exploration robots, and drones



NASA illustration

Phase II Objectives

- Identify ideal combination of binder and electrolyte material to maximize performance for silicon-carbon (SiC) nanocomposite powder at 0 °C using a charge/discharge rate of C/2
- Identify and adjust optimum parameters of SiC nanocomposite powder, such as particle size, thickness, and morphology of the carbon coating; porosity of the adaptive carbon matrix; size of Si crystals; and Si content
- Determine origin of irreversible capacity loss
- Plan and build small pilot plant
- Optimize synthesis process of SiC nanocomposite powders to maximize uniformity and reproducibility
- Develop an anode-based on the novel SiC nanocomposite powder that offers 1,200 mAh/g at C/2 at 0 °C and a long cycle life

Benefits

- High energy density
- Dramatically improved capacity
- Cycling performance

Firm Contact

Superior Graphite Co.
Francois Henry
FHenry@superiorgraphite.com
10 South Riverside Plaza, Suite 1470
Chicago, IL 60606–3700
Phone: 773–209–4793

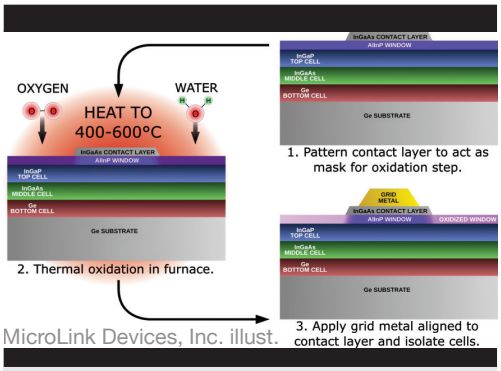
Proposal Number: 08-2 X6.02-8492

Advanced Antireflection Coatings for High-Performance Solar Energy Applications

Integrated technologies significantly increase efficiency

Antireflection coatings are a critical element of high-performance photovoltaic (PV) devices, as they are responsible for coupling light from the cover glass into the top layer of the solar cell. MicroLink Devices, Inc. has explored several techniques to improve antireflection coatings for both triple- and quadruple-junction solar cells to enhance cell efficiency.

In Phase II, MicroLink developed multilayer dielectric antireflection coatings that incorporated lanthanum titanate ($LaTiO_3$) films to achieve significantly improved optical coupling between the cover glass and cell at the ultraviolet and infrared ends of the spectral range of interest. The company also refined a fabrication process to oxidize the aluminum (Al)-containing window layer, reducing light absorption at the short end of the spectral range of interest and providing extra usable photons to the cell. These integrated innovations increase the light coupling between the cover glass and cell, achieving high-performance efficiency in next-generation PV devices containing four or more junctions. These new coatings are expected to increase relative efficiency by at least 7 percent and absolute efficiency by 2.5 percent.



MicroLink Devices, Inc. illust.

Applications

NASA

- Multijunction germanium (Ge)-based solar cells
- Inverted metamorphic solar cells with more than four junctions
- Next-generation solar cells
- Solar cells in unmanned aerial vehicle (UAV) platforms

Commercial

- Multijunction Ge-based solar cells
- Inverted metamorphic solar cells with more than four junctions
- Next-generation solar cells
- Solar cells in UAV platforms
- Power generation for military field deployments and supplementary mobile devices

Phase II Objectives

- Develop and refine antireflection coatings incorporating $LaTiO_3$ as an intermediate refractive index material
- Investigate wet/dry thermal oxidation of Al-containing semiconductor compounds as a means of forming a more transparent window layer with equal or better optical properties than its unoxidized form
- Develop a fabrication process that allows integration of the oxidized window layer and maintains the necessary electrical properties for contacting the solar cell
- Conduct an experimental demonstration of the best candidates for improved antireflection coatings

Benefits

- Enables a new generation of lightweight, high-efficiency solar cells and panels
- Increases the efficiency of solar arrays used in NASA space applications
- Increases the availability of electrical power to satellites
- Improves solar cell performance in UAVs

Firm Contact

MicroLink Devices, Inc.
Noren Pan
npan@mldevices.com
6457 Howard Street
Niles, IL 60714–3301
Phone: 847–588–3001

Proposal Number: 12-2 S3.02-9667

CarbAl™ Heat Transfer Material

Thermal management for space flight systems

The increasing use of power electronics, such as high-current semiconductor devices and modules, within space vehicles is driving the need to develop specialty thermal management materials in both the packaging of these discrete devices and the packaging of modules consisting of these device arrays. Developed by Applied Nanotech, Inc. (ANI), CarbAl heat transfer material is uniquely characterized by its low density, high thermal diffusivity, and high thermal conductivity. Its coefficient of thermal expansion (CTE) is similar to most power electronic materials, making it an effective base plate substrate for state-of-the-art silicon carbide (SiC) super junction transistors.

The material currently is being used to optimize hybrid vehicle inverter packaging. Adapting CarbAl-based substrates to space applications was a major focus of the SBIR project work. In Phase I, ANI completed modeling and experimentation to validate its deployment in a space environment. Key parameters related to cryogenic temperature scaling of CTE, thermal conductivity, and mechanical strength. In Phase II, the company concentrated on improving heat sinks and thermally conductive circuit boards for power electronic applications.

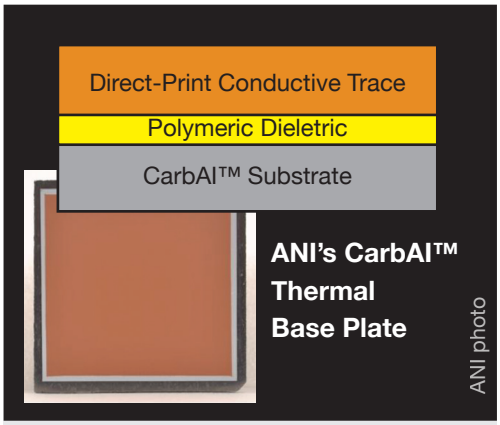
Applications

NASA

- Deep space vehicles
- Electronic and radioisotope propulsion
- Ion thruster technologies
- Lightweight thermal interface materials

Commercial

- Tactical quiet generators
- Hybrid electric vehicle drive systems
- High-power light-emitting diode (LED) luminaries
- Wind power converters
- Electricity transportation and distribution systems
- Marine vessel propulsion



Phase II Objectives

- Refine Phase I thermal model for CarbAl-based thermal packaging that encompasses specific thermal loads of SiC transistors targeted for use in space vehicles
- Fabricate heat sink system for direct current (DC) power conversion module
- Demonstrate bench performance temperature reductions of 8 percent from 160 K to 300 K
- Complete prototype CarbAl heat sink system
- Target flight deployment testing for 2015

Benefits

- Fewer thermal interfaces
- Lower mass-density ratio
- Matched CTE
- Improved thermal resistance

Firm Contact

Applied Nanotech, Inc.
Richard Fink
dfink@appliednanotech.net
3006 Longhorn Boulevard, Suite 107
Austin, TX 78758–7631
Phone: 512–339–5020 ext. 130

Proposal Number: 12-2 S3.04-8357

High-Melt Carbon-Carbon Coating for Nozzle Extensions

Ultrahigh-temperature ceramics enable novel material

Carbon-Carbon Advanced Technologies, Inc. (C-CAT), has developed a high-melt coating for use in nozzle extensions in next-generation spacecraft. The coating is composed primarily of carbon-carbon, a carbon-fiber and carbon-matrix composite material that has gained a spaceworthy reputation due to its ability to withstand ultrahigh temperatures. C-CAT's high-melt coating embeds hafnium carbide (HfC) and zirconium diboride (ZrB_2) within the outer layers of a carbon-carbon structure. The coating demonstrated enhanced high-temperature durability and suffered no erosion during a test in NASA's Arc Jet Complex. (Test parameters: stagnation heat flux=198 BTD/ft^2-sec; pressure= .265 atm; temperature=3,100 °F; four cycles totaling 28 minutes)

In Phase I of the project, C-CAT successfully demonstrated large-scale manufacturability with a 40-inch cylinder representing the end of a nozzle extension and a 16-inch flanged cylinder representing the attach flange of a nozzle extension. These demonstrators were manufactured without spalling or delaminations. In Phase II, C-CAT worked with engine designers to develop a nozzle extension stub skirt interfaced with an Aerojet Rocketdyne RL10 engine. All objectives for Phase II were successfully met. Additional nonengine applications for the coating include thermal protection systems (TPS) for next-generation spacecraft and hypersonic aircraft.

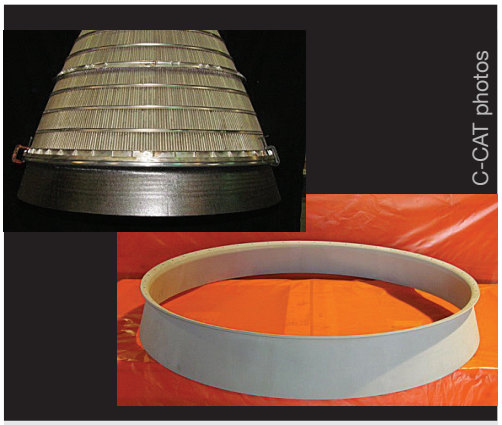
Applications

NASA

- Nozzle extensions for upper- and exoatmospheric operation:
  - Robotic lunar and planetary missions
  - Manned lunar ascent
  - J-2X rocket systems
- TPS for next-generation spacecraft

Commercial

- Lower-cost, high-performance nozzle extensions for commercial launch market
- TPS for reusable aircraft that operate in temperatures in excess of 2,800 °F (a safe operating temperature for repeated use)



Phase II Objectives

- Verify that prototype nozzle extension designs are manufacturable and meet technique requirements
- Design and fabricate layup tools that address ply shrinkage distortion yet maintain dimensional tolerances during processing
- Lay up the nozzle extensions without defects
- Process each nozzle extension through pyrolysis, heat treatment, and coating without defects
- Apply silicon carbide conversion coating to the high-melt material without spalling

Benefits

- Lighter weight than conventional metallic structures
- Able to operate in temperatures in excess of 2,800 °F repeatedly and at higher temperatures for one-time use
- Easy to manufacture

Firm Contact

Carbon-Carbon Advanced Technologies, Inc.
James Thompson
jthompson@c-cat.net
4704 Eden Road
Kennedale, TX 76060–6800
Phone: 817–985–2500

Proposal Number: 09-2 X10.01-8831

High-Performing, Low-Temperature-Operating, Long-Lifetime Aerospace Lubricants

For use in aerospace and terrestrial applications

Long-duration space exploration will require spacecraft systems that can operate effectively over several years with minimal or no maintenance. Aerospace lubricants are key components of spacecraft systems. Physical Sciences Inc., has synthesized and characterized novel ionic liquids for use in aerospace lubricants that contribute to decreased viscosity, friction, and wear in aerospace systems. The resulting formulations offer low vapor pressure and outgassing properties and thermal stability up to 250 °C. They are effective for use at temperatures as low as –70 °C and provide long-term operational stability in aerospace systems. In Phase II, the company scaled several new ionic liquids and evaluated a novel formulation in a NASA testbed.

The resulting lubricant compounds will offer lower volatility, decreased corrosion, and better tribological characteristics than standard liquid lubricants, particularly at lower temperatures.

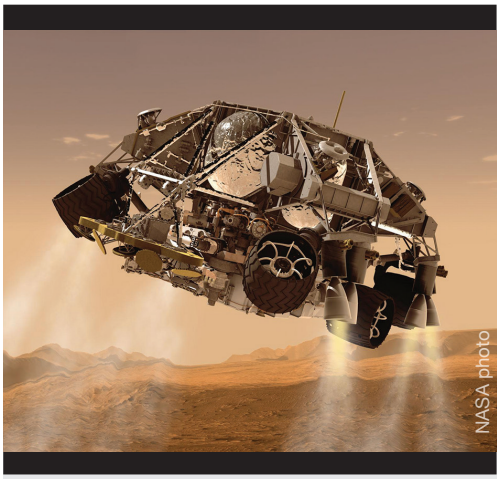
Applications

NASA

- Aerospace systems that require minimal or no maintenance over extended periods of time:
  - Rovers
  - Machinery used to construct lunar habitats

Commercial

- Industrial transportation systems
- Construction vehicles
- Military vehicles and equipment
- Gyroscope bearings on satellites



Phase II Objectives

- Synthesize and characterize 12 novel (>98 percent purity) ionic liquids
- Establish vapor pressures $<10^{-7}$ Torr at 25 °C and stability up to 250 °C
- Demonstrate a reduction in corrosion and a 20 percent viscosity decrease from –70 °C to +60 °C
- Demonstrate a lower coefficient of friction (COF) and a reduction of wear effects of lubricant formulations
- Scale four ionic liquids to 25 grams each
- Achieve a lower COF and reduced wear and volatility in a NASA testbed

Benefits

- Low volatility
- Chemically stable
- Excellent tribological characteristics at low temperatures

Firm Contact

Physical Sciences Inc.
Prakash Joshi
joshi@psicorp.com
20 New England Business Center
Andover, MA 01810–1077
Phone: 978–689–0003

Proposal Number: 08-2 X4.01-9712

Nontoxic Ionic Liquid Fuels for Exploration Applications

For safer, less expensive propulsion systems

The toxicity of propellants used in conventional propulsion systems increases not only safety risks to personnel but also costs, due to special handling required during the entire lifetime of the propellants. Orbital Technologies Corporation (ORBITEC) has developed and tested novel nontoxic ionic liquid fuels for propulsion applications. In Phase I of the project, the company demonstrated the feasibility of several ionic liquid formulations that equaled the performance of conventional rocket propellant monomethylhydrazine (MMH) and also provided low volatility and low toxicity.

In Phase II, ORBITEC refined the formulations, conducted material property tests, and investigated combustion behavior in droplet and microreactor experiments. The company also explored the effect of injector design on performance and demonstrated the fuels in a small-scale thruster. The ultimate goal is to replace propellants such as MMH with fuels that are simultaneously high-performance and nontoxic. The fuels will have uses in NASA's propulsion applications and also in a range of military and commercial functions.

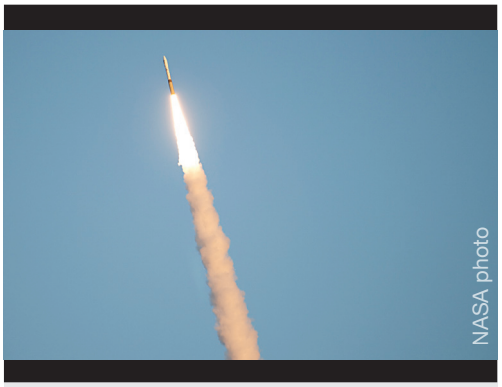
Applications

NASA

- Propulsion systems
- In-space science missions
- Lunar and planetary exploration activities
- Satellites

Commercial

- Launch systems
- Missiles
- Ballistic defense systems
- Satellites


NASA photo

Phase II Objectives

- Synthesize ionic liquid fuels that ignite hypergolically with nitrogen tetroxide
- Characterize ignition and combustion through drop and microreactor tests
- Measure the material properties of the candidate fuels
- Determine the molecular structures via nuclear magnetic resonance spectroscopy
- Predict performance and analyze integration into propulsion systems
- Scale up synthesis
- Investigate the effects of the injector design on ignition and combustion
- Determine the influence of chamber size on combustion efficiency
- Conduct ignition tests and small rocket test firings to demonstrate performance

Benefits

- Increased performance
- Reduced toxicity
- Reduced cost
- Increased safety

Firm Contact

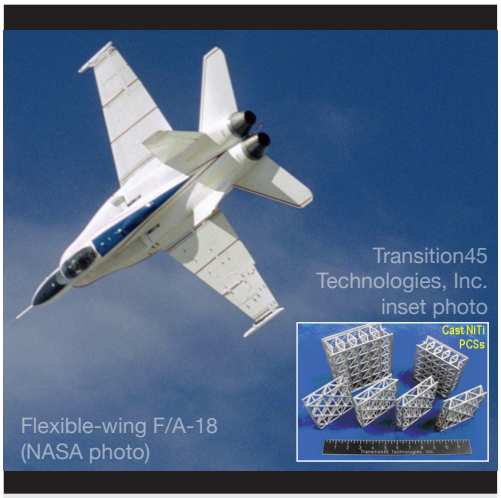
Orbital Technologies Corporation
Millicent Coil
coilm@orbitec.com
1212 Fourier Drive
Madison, WI 53717–1961
Phone: 608–229–2812

Proposal Number: 09-2 X10.01-9473

Periodic Cellular Structure Technology for Shape Memory Alloys

Unique approach offers low-cost fabrication method

Shape memory alloys are being considered for a wide variety of adaptive components for engine and airframe applications because they can undergo large amounts of strain and then revert to their original shape upon heating or unloading. Transition45 Technologies, Inc., has developed an innovative periodic cellular structure (PCS) technology for shape memory alloys that enables fabrication of complex bulk configurations, such as lattice block structures. These innovative structures are manufactured using an advanced reactive metal casting technology that offers a relatively low cost and established approach for constructing near–net shape aerospace components. Transition45 is continuing to characterize these structures to determine how best to design a PCS to better exploit the use of shape memory alloys in aerospace applications.



Applications

NASA

- Engine and airframe components:
  - Actuators
  - Flexible wings
  - Nozzles
  - Ballistic impact–resistant structures

Commercial

- Structural building and bridge components that resist explosions and earthquakes
- Armor
- Automobile spoilers
- Shipboard structures
- Biomedical implants
- Firefighting equipment
- Heating, ventilation, and air conditioning (HVAC) equipment
- Sporting goods

Phase II Objectives

- Design, exploit, and maximize the performance benefits of cast shape memory alloys in the form of PCSs and solids
- Examine how well PCSs of various designs perform in recovery compared with a solid of the same alloy
- Quantify structural benefits of PCS technology

Benefits

- Lightweight
- Acoustic dampening
- Impact resistant
- Flexible
- Strong

Firm Contact

Transition45 Technologies, Inc.
Edward Y. Chen
transition45@sbcglobal.net
1963 North Main Street
Orange, CA 92865–4101
Phone: 714–283–2118

Proposal Number: 09-2 A2.01-8248

Braided Composite Technologies for Rotorcraft Structures

To reduce weight, noise, and vibration

A&P Technology has developed a braided material approach for fabricating lightweight, high-strength hybrid gears for aerospace drive systems. The conventional metallic web was replaced with a composite element made from A&P's quasi-isotropic braid. The 0°, +/–60° braid architecture was chosen so that inplane stiffness properties and strength would be nearly equal in all directions.

The test results from the Phase I Small Spur Gear program demonstrated satisfactory endurance and strength while providing a 20 percent weight savings. (Greater weight savings is anticipated with structural optimization.) The hybrid gears were subjected to a proof-of-concept test of 1 billion cycles in a gearbox at 10,000 revolutions per minute and 490 in-lb torque with no detectable damage to the gears. After this test the maximum torque capability was also tested, and the static strength capability of the gears was 7x the maximum operating condition. Additional proof-of-concept tests are in progress using a higher oil temperature, and a loss-of-oil test is planned.

The success of Phase I led to a Phase II program to develop, fabricate, and optimize full-scale gears, specifically Bull Gears. The design of these Bull Gears will be refined using topology optimization, and the full-scale Bull Gears will be tested in a full-scale gear rig. The testing will quantify benefits of weight savings, as well as noise and vibration reduction. The expectation is that vibration and noise will be reduced through the introduction of composite material in the vibration transmission path between the contacting gear teeth and the shaft-and-bearing system.

Applications

NASA

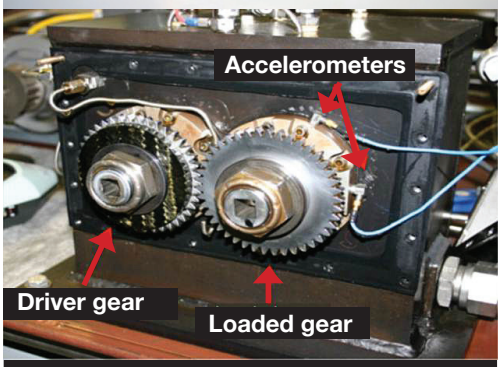
- Rotorcraft systems

Commercial

This technology could be applied to gears across many consumer industries, including:

- Aviation
- Industrial
- Automotive

A&P Technology photos



Phase II Objectives

- Determine operating conditions for a gear in a rotorcraft gearbox
- Develop, fabricate, and optimize full-scale composite/metal hybrid gears for full-scale validation testing
- Evolve analytical tools to enable design optimization

Benefits

- Decreased weight in rotorcraft gearboxes
- Reduced noise and vibration

Firm Contact

A&P Technology
Nathan Jessie
4595 East Tech Drive
Cincinnati, OH 45245–1055
Phone: 513–688–3200
Fax: 513–688–3201

Proposal Number: 11-2: A2.09-8194

High Radiation Resistance IMM Solar Cell

For efficient, lightweight, radiation-resistant solar power

Due to high launch costs, weight reduction is a key driver for the development of new solar cell technologies suitable for space applications. This project is developing a unique triple-junction inverted metamorphic multijunction (IMM) technology that enables the manufacture of very lightweight, low-cost InGaAsP-based multijunction solar cells. This IMM technology consists of indium (In) and phosphorous (P) solar cell active materials, which are designed to improve the radiation-resistant properties of the triple-junction solar cell while maintaining high efficiency. The intrinsic radiation hardness of InP materials makes them of great interest for building solar cells suitable for deployment in harsh radiation environments, such as medium Earth orbit and missions to the outer planets. NASA Glenn's recently developed epitaxial lift-off (ELO) process also will be applied to this new structure, which will enable the fabrication of the IMM structure without the substrate.

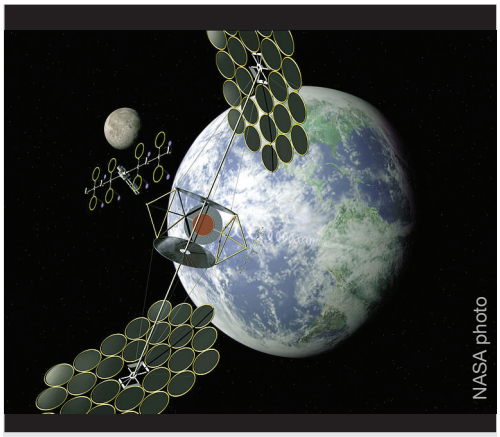
Applications

NASA

- Medium Earth orbit missions
- Outer planet missions
- Satellite power systems

Commercial

- Concentrator photovoltaic (CPV) systems to provide terrestrial solar power



Phase II Objectives

- Reduce efficiency degradation to less than 10 percent
- Develop solar cells with efficiency greater than 30 percent
- Maintain high end-of-life performance

Benefits

- Suitable for harsh environments
- Reduces or eliminates the heavy cover glass materials as required on conventional gallium-arsenide (GaAs)-based cells
- Uses the quaternary InGaAsP subcell rather than the GaAs subcell, allowing the use of a set of bandgaps that better match the solar spectrum
- Reuses multiple times, and ultimately recycles, the GaAs substrate on which the solar cell is grown via the ELO process

Firm Contact

MicroLink Devices, Inc.
Noren Pan
npan@mldevices.com
6457 West Howard Street
Niles, IL 60714–3301
Phone: 847–588–3001 ext. 13

Proposal Number: 09-2 S3.03-8143

Lightweight IMM PV Flexible Blanket Assembly

For high-voltage solar electric propulsion missions

Deployable Space Systems (DSS) has developed an inverted metamorphic multijunction (IMM) photovoltaic (PV) integrated modular blanket assembly (IMBA) that can be rolled or z-folded. This IMM PV IMBA technology enables a revolutionary flexible PV blanket assembly that provides high specific power, exceptional stowed packaging efficiency, and high-voltage operation capability. DSS's technology also accommodates standard third-generation triple junction (ZTJ) PV device technologies to provide significantly improved performance over the current state of the art.

This SBIR project demonstrated prototype, flight-like IMM PV IMBA panel assemblies specifically developed, designed, and optimized for NASA's high-voltage solar array missions.

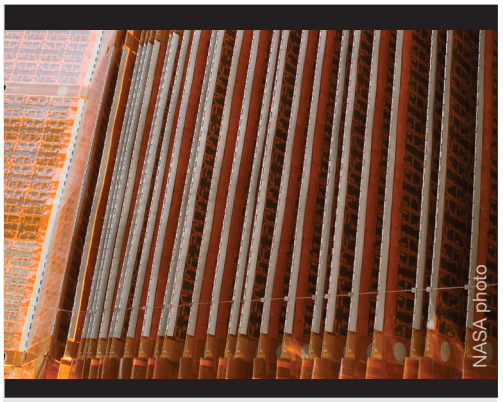
Applications

NASA

- Near- to medium-term NASA Discovery, Flagship Outer-Planets, and New Frontiers–class science missions
- Interplanetary comet rendezvous and solar electric propulsion science missions
- Low Earth orbit (LEO), geosynchronous Earth orbit (GEO), planetary or celestial-body lander, planetary orbiter, and/or deep space applications

Commercial and Military

- Power and energy production for fixed-ground, mobile, and roof-mounted consumer applications
- High-altitude airship applications
- LEO surveillance, reconnaissance, communications, commercial mapping, and other critical payload/equipment satellites
- GEO commercial and Defense Department communications and critical payload/equipment satellites


NASA photo

Phase II Objectives

- Demonstrate and validate prototype IMM PV IMBA panel assemblies specifically developed, designed, and optimized for NASA's high-voltage solar array missions
- Develop scalable analytical models and correlate with test results to validate IMM PV IMBA prototype hardware
- Develop technology and manufacture infrastructure

Benefits

- High-voltage operability
- High specific power (>1,000 W/kg beginning of life [BOL] at the blanket subsystem level; >500 W/kg BOL at the array level)
- Compact stowage volume (>50 kW/m^3)
- Rollable or z-foldable for stowage
- Flexible and durable
- Adaptable to all existing industry flexible blanket solar array products

Firm Contact

Deployable Space Systems
Brian Spence
Brian.Spence@DeployableSpaceSystems.com
75 Robin Hill Road, Building B2
Goleta, CA 93117–3108
Phone: 805–805–1313

Proposal Number: 09-2 S3.03-8863

InGaN High-Temperature Photovoltaic Cells

For high-temperature, high-radiation environments

This Phase II project developed Indium-Gallium-Nitride (InGaN) photovoltaic cells for high-temperature and high-radiation environments. The project included theoretical and experimental refinement of device structures produced in Phase I as well as modeling and optimization of solar cell device processing. The devices have been tested under concentrated air mass zero (AM0) sunlight, at temperatures from 100 °C to 250 °C, and after exposure to ionizing radiation. The results are expected to further verify that InGaN can be used for high-temperature and high-radiation solar cells.

The large commercial solar cell market could benefit from the hybridization of InGaN materials to existing solar cell technology, which would significantly increase cell efficiency without relying on highly toxic compounds. In addition, further development of this technology to even lower bandgap materials for space applications would extend lifetimes of satellite solar cell arrays due to increased radiation hardness. This could be of importance to the Department of Defense (DoD) and commercial satellite manufacturers.

Applications

NASA

- Missions near the Sun:
  - Solar Orbiter
  - Solar Sentinels in the Living with a Star (LWS) Program
- Missions in high-radiation environments

Commercial and Military

- Terrestrial DoD applications

Phase II Objectives

- Refine single-junction device structures
- Optimize the processing of single-junction devices
- Demonstrate two-junction devices
- Verify the stability of InGaN solar cells at high temperatures and high radiation environments

Benefits

- Remains stable in high-temperature and high-radiation environments
- Extends lifetime of satellite solar cell arrays

Firm Contact

Integrated Micro Sensors, Inc.
David Starikov
dstarikov@imsensors.com
10814 Atwell Drive
Houston, TX 77096–4934
Phone: 713–748–7926

Proposal Number: 08-2 S3.03-9731

High-Volume Production of Lightweight Multijunction Solar Cells

Reduces the cost of cells via a 6-inch gallium arsenide (GaAs) epitaxial lift-off and substrate reclaim process

MicroLink Devices, Inc., has transitioned its 6-inch epitaxial lift-off (ELO) solar cell fabrication process into a manufacturing platform capable of sustaining large-volume production. This Phase II project improves the ELO process by reducing cycle time and increasing the yield of large-area devices. In addition, all critical device fabrication processes have transitioned to 6-inch production tool sets designed for volume production. An emphasis on automated cassette-to-cassette and batch processes minimizes operator dependence and cell performance variability. MicroLink Devices established a pilot production line capable of at least 1,500 6-inch wafers per month at greater than 80 percent yield. The company also increased the yield and manufacturability of the 6-inch reclaim process, which is crucial to reducing the cost of the cells.

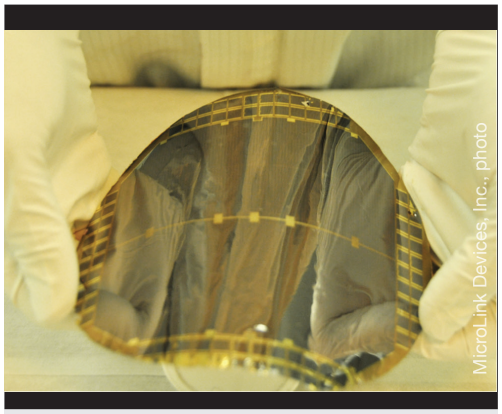
Applications

NASA

- Solar electric propulsion programs

Commercial and Military

- Electric-powered unmanned aerial vehicles (UAVs)
- Commercial and military satellites
- Portable solar electric power chargers



Phase II Objectives

- Improve the manufacturability and reduce the cost of the 6-inch ELO process for fabricating high-efficiency, large-area multijunction solar cells
- Optimize the 6-inch ELO process for high throughput and yield (greater than 80 percent)
- Use automated process tool sets capable of more than 1,500 6-inch wafers per month
- Establish a production-ready 6-inch GaAs substrate reclaim process

Benefits

- Produces lightweight and high specific power multijunction solar cells
- Offers an inexpensive and streamlined manufacturing process

Firm Contact

MicroLink Devices, Inc.
Christopher Youtsey
cyoutsey@mldevices.com
6457 West Howard Street
Niles, IL 60714–3301
Phone: 847–588–3001

Proposal Number: 11-2 X8.04-9001

Optimization of the Roll-Out Solar Array (ROSA) and Mega-ROSA

High-efficiency photovoltaic power production

The Mega-ROSA is a new, highly modularized, and extremely scalable self-deployed solar array that provides immense power level range capability, from 100 kilowatts to several megawatts. Mega-ROSA, an enhancement of NASA's ROSA, will enable extremely high power spacecraft and solar electric propulsion powered missions, including space tug and large-scale planetary science and lunar/asteroid exploration missions. Mega-ROSA/ROSA is adaptable to all photovoltaic and concentrator flexible blanket technologies.

This Phase II project optimized the Mega-ROSA/ROSA technology and deployable structural system. More specifically, the project optimized the elastically deployable slit-tube thin-shell boom structures through advanced composites design, development and analytical modeling, materials design and development, innovative and affordable manufacturing processes, and the development of accurate engineering methodologies to rapidly allow for new material properties and design performance characterizations. The team developed new and innovative structural sections/configurations, such as section closeout and root reinforcement. Finally, the team developed and refined innovative and affordable composite structure fabrication processes.

Applications

NASA

- Solar electric propulsion:
  - Appropriate for NASA missions that require high-efficiency photovoltaic power production through deployment of an ultralightweight and highly modular structural system

Commercial

- Solar electric propulsion
- Low Earth orbit (LEO) surveillance, reconnaissance, communications, commercial mapping, and other critical payload/equipment satellites
- Medium Earth orbit (MEO) satellites and space tugs
- Geosynchronous orbit (GEO) communications and critical payload/equipment satellites
- Fixed-ground and deployable/retractable mobile ground-based systems


NASA photo

Phase II Objectives

- Optimize Mega-ROSA/ROSA solar array materials and structures
- Characterize creep/relaxation phenomena
- Perform analytical modeling
- Optimize the array's manufacturing process

Benefits

- Inexpensive
- Ultralightweight
- Compact stowage volume (< 50 kW/m^3 for very large arrays)
- High strength and stiffness
- Capable of providing power levels from 60 kW to more than 300 kW
- Operates in high-voltage and high- or low-temperature environments
- Radiation tolerant
- Scalable

Firm Contact

Deployable Space Systems, Inc.
Brian Spence
Brian.Spence@DeployableSpaceSystems.com
75 Robin Hill Road, Building B2
Goleta, CA 93117–3108
Phone: 805–722–8090

Proposal Number: 11-2 T3.01-9785

Thin, Flexible IMM Solar Array

Offering higher efficiencies and lower mass and flexibility

NASA needs solar arrays that are thin, flexible, and highly efficient; package compactly for launch; and deploy into large, structurally stable high-power generators. Inverted metamorphic multijunction (IMM) solar cells can enable these arrays, but integration of this thin crystalline cell technology presents certain challenges. The Thin Hybrid Interconnected Solar Array (THINS) technology allows robust and reliable integration of IMM cells into a flexible blanket comprising standardized modules engineered for easy production. The modules support the IMM cell by using multifunctional materials for structural stability, shielding, coefficient of thermal expansion (CTE) stress relief, and integrated thermal and electrical functions. The design approach includes total encapsulation, which benefits high voltage as well as electrostatic performance.

In Phase I of this project, the THINS design was refined for enhanced environmental durability and integration into a large deployment structure such as Mega Roll-Out Solar Array (Mega-ROSA) or MegaFlex. Phase II advanced the THINS technology, incorporating advanced IMM solar cells into THINS modules and then integrating these modules into the MegaFlex deployable structure where it underwent environmental testing, including launch vibration, thermal vacuum deployment, and electrostatic discharge/plasma testing. The THINS technology is further enhanced by automated manufacturing activities being performed under a Phase II SBIR with NASA, focusing on reducing manufacturing costs and scale-up. This technology is expected to provide tens to hundreds of kilowatts to enable outer planetary missions, allow improved solar electric propulsion performance during cruise, and provide significant power (i.e., hundreds of watts) despite the minimal sunlight available at the asteroid belt, Jupiter, and beyond.

Applications

NASA

- Solar electric propulsion (SEP)
- Electric and magnetic field instruments used on NASA science spacecraft:
  - Time History of Events and Macroscale Interactions during Substorms (THEMIS)
  - Magnetospheric Multiscale (MMS) mission
  - Mars Atmosphere and Volatile Evolution (MAVEN) space probe
  - Direct-drive SEP approaches

Commercial

- Commercial spacecraft

NASA illustration

Phase II Objectives

- Fabricate and performance test a full-scale module
- Test module coupons in the most stressing simulated space environments
- Develop and fabricate a deployment demonstration of a THINS MegaFlex array containing a complete photovoltaic array blanket comprising THINS modules with some active cells
- Demonstrate full-scale deployment at ambient, hot, and cold temperatures

Benefits

- Designed for manufacturability using mature semiconductor industry standard equipment and processes
- Fits tens of kilowatts in a compact stowage envelope
- Improves process control
- Enables smaller, more economical launch vehicles
- Uses total encapsulation and continuity of cover glass materials to create a continuous grounded, shielded enclosure

Firm Contact

Vanguard Space Technologies, Inc.
Nicholas Walmsley
nwalmsley@vst-inc.com
9431 Dowdy Drive
San Diego, CA 92126–4633
Phone: 858–587–4200 ext. 1849

Proposal Number: 10-2 X8.04-9431

Wrapped Multilayer Insulation

Thermal insulation for cryogenic piping

New NASA vehicles, such as Earth Departure Stage (EDS), Orion, landers, and orbiting fuel depots, need improved cryogenic propellant transfer and storage for long-duration missions. Current cryogen feed line multilayer insulation (MLI) performance is 10 times worse per area than tank MLI insulation. During each launch, cryogenic piping loses approximately 150,000 gallons (equivalent to $300,000) in boil-off during transfer, chill down, and ground hold. Quest Product Development Corp., teaming with Ball Aerospace, developed an innovative advanced insulation system, Wrapped MLI (wMLI), to provide improved thermal insulation for cryogenic feed lines.

wMLI is high-performance multilayer insulation designed for cryogenic piping. It uses Quest's innovative discrete-spacer technology to control layer spacing/density and reduce heat leak. The Phase I project successfully designed, built, and tested a wMLI prototype with a measured heat leak 3.6X lower than spiral-wrapped conventional MLI widely used for piping insulation. A wMLI prototype had a heat leak of 7.3 W/m^2, or 27 percent of the heat leak of conventional MLI (26.7 W/m^2).

The Phase II project is further developing wMLI technology with custom, molded polymer spacers and advancing the product toward commercialization via a rigorous testing program, including developing advanced vacuum-insulated pipe for ground support equipment.

Applications

NASA

- New NASA vehicles
- Orbiting fuel depots
- Vacuum-insulated pipe used to transfer cryogens

Commercial

- Food, research, medical, and industrial applications:
  - Transfers of cryogenic liquid into and from cryogenic dewars for liquid nitrogen (LN_2), hydrogen (LHe), and oxygen (LOX)
- Industrial:
  - Handling LN_2, LOX, and liquefied natural gas (LNG)
  - Handling piping, automatic filling equipment, dewar manifolds, and gas panels
- LNG:
  - High-performance insulated cryogenic transfer piping to reduce LNG losses from vaporization during liquid transfer
- LN_2 equipment:
  - Semiconductor, electronics, and aerospace environmental temperature testing
  - Special effects (fogging), biological freezing applications, inerting of food and beverage containers, container pressurization, and food freezing

Phase II Objectives

- Design and develop a custom, molded polymer spacer
- Further develop assembly and installation processes
- Develop and test wMLI for three different piping diameters
- Conduct testing to optimize spacer and wrap geometries
- Perform thermal testing on 12 different wMLI test configurations
- Perform thermal testing on advanced "clam-shell" netting MLI
- Design, develop, and test MLI in a vacuum-insulated pipe prototype for use in ground support equipment

Benefits

- Low heat leak (3.6X less than conventional MLI)
- Easy assembly
- Few layers
- Low cost
- Less mass

Firm Contact

Quest Product Development Corporation
Scott A. Dye
sdye@quest-corp.com
6833 Joyce Street
Arvada, CO 80007–7570
Phone: 303–670–5088 ext. 12

Proposal Number: 09-2 X8.01-8258

Thin Aerogel as a Spacer in Multilayer Insulation

For cryogenic space applications

Cryogenic fluid management is a critical technical area that is needed for future space exploration. A key challenge is the storability of liquid hydrogen (LH_2), liquid methane (LCH_4), and liquid oxygen (LOX) propellants for long-duration missions. The storage tanks must be well-insulated to prevent overpressurization and venting, which can lead to unacceptable propellant losses for long-duration missions to Mars and beyond.

Aspen Aerogels had validated the key process step to enable the fabrication of thin, low-density aerogel materials. The multilayer aerogel insulation (MLAI) system prototypes were prepared using sheets of aerogel materials with superior thermal performance exceeding current state-of-the-art insulation for space applications. The exceptional properties of this system include a new breakthrough in high-vacuum cryogenic thermal insulation, providing a durable material with excellent thermal performance at a reduced cost when compared to longstanding state-of-the-art multilayer insulation systems. During the Phase II project, further refinement and qualification/system-level testing of the MLAI system will be performed for use in cryogenic storage applications.

Aspen has been in discussions with United Launch Alliance, LLC; NASA's Kennedy Space Center; and Yetispace, Inc., to test the MLAI system on real-world tanks such as Vibro-Acoustic Test Article (VATA) or the Cryogenic Orbital Testbed (CRYOTE).

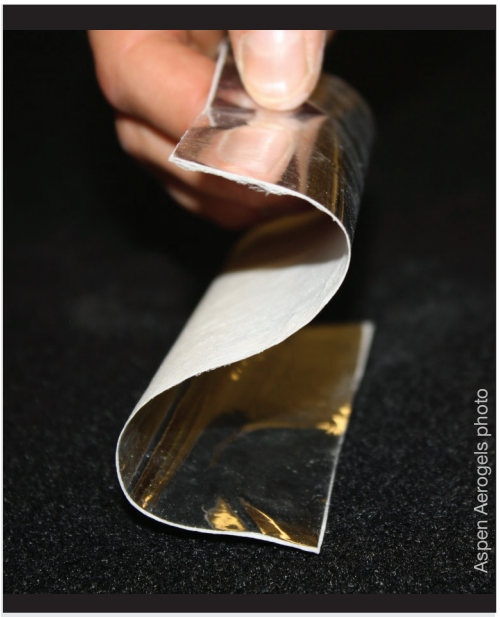
Applications

NASA

- Insulation for cryotanks and cryogen transfer pipelines for ground processing
- Cryogen storage insulation for in-space applications
- Satellite thermal management
- Extravehicular activity (EVA) suits
- Internal insulation on future generations of reusable launch vehicles

Commercial

- Durable and reliable insulation systems for any cryogenic, high-vacuum, or thin and flexible applications:
  - Appliances
  - Airliner fuselage
  - Liquid natural gas fuel storage tanks and transfer lines
  - Apparel



Phase II Objectives

- Refine low-density and thin aerogel formulations
- Optimize thin aerogel scale-up process and MLAI system fabrication
- Assess MLAI prototype performance:
  - Cryostat 500 (size 8-in diameter) testing
- Large-scale testing of optimum MLAI system:
  - Cryostat 100 (2 x 4-ft size)
  - System-level testing at Ball Aerospace & Technologies Corp.

Benefits

- More durable and robust multilayer insulation system that is easy to install
- Improved process for manufacturing thin, low-density aerogel materials
- Superior thermal insulation for cryogenic applications

Firm Contact

Aspen Aerogels
Nancy Moroz
contracts@aerogel.com
30 Forbes Road, Building B
Northborough, MA 01532–2501
Phone: 508–691–1161

Proposal Number: 11-2 X10.01-9295