PROGRESS AND PLANS OF NATIONAL NANOTECHNOLOGY INITIATIVE (NNI) AGENCIES

March 2020

National Aeronautics and Space Administration (NASA)[1]

Summary

The National Aeronautics and Space Administration support research and development in nanotechnology to advance space exploration and aeronautics research. Successful integration of nanomaterials into various aspects of NASA's missions may be essential to enabling humans to maintain a permanent and sustainable presence in space. Agency activities where nanomaterials are used for space exploration include: lightweight, high-strength structural nanocomposites for lower payload weight, chemical and biological sensors development to support astronaut health or detect signs of potential habitable planets, novel membranes and catalysts for air and water purification, nanoelectronics and damage-tolerant materials for extreme environments, and novel materials for communication devices, power, and energy. Nanotechnology is also advancing aeronautics research through rapid manufacturing of lightweight aircraft structures and the design of advanced propulsion technologies to make flight safer and more efficient. Commercialization of enabling nanotechnologies is being advanced through NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. NASA also invests in cutting-edge, university-led nanotechnology research by training the next generation of scientists and engineers through student fellowships and faculty awards, most of which are funded by the Space Technology Research Grants (STRG) Program in the Space Technology Mission Directorate, in addition to University Leadership Institute (ULI) awards, which are funded through the Aeronautics Research Mission Directorate (ARMD).

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

1a. Nanomanufacturing NSI

NASA continues to make progress in manufacturing scale-up of high-strength carbon nanotubes (CNTs) in partnership with a major CNT company, through a Phase III SBIR contract.[2] The company's material is at the

[2] https://www.sbir.gov/node/1162173, https://www.miralon.com/newsblog/nasa-awards-contract-to-nanocomp-for-continued-development

scale to produce prototype articles to allow better understanding of the manufacturing processes that are required to retain mechanical properties in resulting polymer matrix composites. Researchers at the NASA Langley Research Center continue to advance the development of CNT composite processing methods to retain the mechanical properties of these CNT materials in composites made from them. Computational modeling is being coupled with experimentation to explore non-traditional composite processing techniques.[3]

1b. Nanoelectronics NSI

Researchers at NASA's Ames Research Center continue to develop nanoscale vacuum channel transistors (NVCTs) for space missions (see Figure 1 below). Wafer-scale fabrication of NVCTs has been demonstrated in both silicon and silicon carbide material systems. A vertical configuration along with a surround gate enables fabrication of multiple emitters on the source pad where the drive current linearly scales with the number of emitters. In fiscal year (FY) 2021, logic circuits based on nanoscale vacuum transistors will be developed and tested for their radiation immunity.

NASA Ames is assisting the Air Force Office of Scientific Research with managing and reviewing two of the Air Force's Multi-University Research Initiative (MURI) projects related to nanoscale vacuum electronics, in addition to collaborating with the MURI teams.

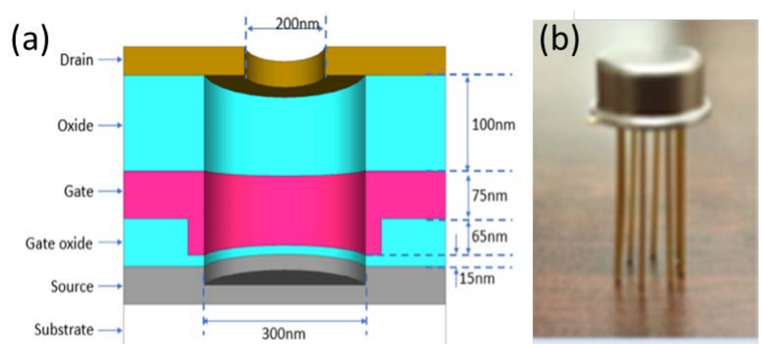

Figure 1. Cross section of a vertical nanoscale vacuum channel transistor (a). Nanoscale vacuum channel transistor in an 8-pin TO-5 package (b). Image credits: NASA Ames Research Center.

1d. Sensors NSI

Researchers at NASA's Glenn Research Center have developed metallic photonic crystal (MPC) structures, which consist of plasmonic gold nanogratings for lab-on-chip biosensing applications. The MPC-structured sensors are coupled to a photonic waveguide, and have been demonstrated to be operational over a wide temperature range, including at cryogenic temperatures.[4] These nanoplasmonic sensors have potential use for ocean worlds exploration and also for Venus upper atmosphere life detection and characterization. Funding for this work was through NASA's Space Technology Mission Directorate, the National Science Foundation (NSF), and the National Institutes of Health (NIH). Upcoming activities for this effort include developing a nanophotonic bio/chemical-sensor platform for cryogenic environments and integrating and testing the sensor elements with an on-chip photodetector.

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[3] Jensen, B D; Kim J-W; Sauti, G; Wise, K E; Dong, L; Wadly, H N G; Park, J G; Liang, R; Siochi E J. Toward Ultralight High Strength Structural Materials via Collapsed Carbon Nanotube Bonding, *Carbon* **2020**, 156, 538 – 548.

[4] Palinski, T J; Hunter, G W; Tadimety, A; Zhang, J X; Metallic photonic crystal-based sensor for cryogenic environments, *Opt. Express* **2019**, 27, 16344 – 16359.

1e. Water NSI

NASA initiated a new subtopic in its STTR program solicitation for FY ‘19 and FY ‘20 under the focus area for life support and habitation systems for human spacecraft: “Spacecraft Water Sustainability through Nanotechnology,” which sought innovations in nanotechnology for water management applications. The subtopic included three areas of scope that aligned with the three thrusts of the Nanotechnology Signature Initiative on Water Sustainability through Nanotechnology: (1) water recovery from wastewater and removal of problematic contaminants from processed wastewater; (2) stabilization of water and water recovery system hardware, including management and monitoring of biocides in potable water; and (3) enabling next-generation water monitoring systems with nanotechnology. Water recovery from wastewater sources is key to long-duration human exploration missions. Without substantial water recovery, life support system launch weights are prohibitively large. The solicitation sought improvements to reduce complexity, decrease size and consumable mass, improve safety and reliability, and achieve a higher degree of spacecraft autonomy.

Engineers at NASA's Johnson Space Center are working closely with the NSF’s Nanosystems Engineering Research Center for Nanotechnology-Enabled Water Treatment (NEWT) at Rice University. Of particular interest to NASA is the use of nanoparticle silver for use as a biocide in potable water for human spacecraft applications. Researchers at Rice have unique expertise in the stability, efficacy, and detection of nanoparticle silver in water systems.

PCA 2. Foundational Research

NASA’s Ultra-strong Composites (US-COMP) by Design program, led by Michigan Technological University, is a collaboration between investigators at eleven universities, industry, NASA, and the Air Force Research Laboratory under the Space Technology Research Institutes (STRI) program. This five-year, $15 million institute is focused on the fundamental understanding of CNT processing methods to enable the design of CNT reinforcements and composites with mechanical properties that significantly exceed those of state-of-the-art aerospace-grade carbon fiber reinforced composites. The US-COMP program has recently completed 2.5 years of research to advance computationally-guided maturation of structural CNT composites. The teams have worked across universities and have afforded students opportunities to collaborate with their peers at member universities. The structure of the NASA STRI program and its projects has increased interactions among students, where participants testified that these would not have happened otherwise. Members of the US-COMP program were scheduled to attend the Space Technology Research Grants (STRG) Tech Day, scheduled for December 2019, where faculty and students from the US-COMP program presented recent findings from this collaboration. NASA’s Established Program to Stimulate Competitive Research (EPSCoR) program awarded several grants in FY ‘19 related to investigating the properties of novel two-dimensional quantum materials in microgravity, high-energy-density batteries for low-temperature applications, thin-film solar cells, and plasma-jet printing of nanoelectronics for in-space manufacturing and *in-situ* resource utilization.

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

The ability to produce on-demand embedded electronics is an essential capability necessary for sustainable space exploration, and has potential to greatly enhance mission capabilities. Under NASA’s In-Space Manufacturing (ISM) program, printed versions of the NASA Ames chemsensor, biosensor, and supercapacitor will be developed using carbon nanomaterial inks and compared with previous wafer-scale prototypes that are produced by conventional microfabrication techniques.

A new two-year Convergent Aeronautics Solutions (CAS) project through NASA's Aeronautics Research Mission Directorate was initiated in FY '20 with the goal to develop novel solid-state batteries to power urban air mobility vehicles (UAMs). The bi-polar pack solid-state battery design that will be developed through this program is predicted to be lightweight, non-flammable, and possess higher specific power and energy densities than current state-of-the-art Li-ion batteries. Through this program, NASA researchers are interested in investigating the use of novel formats of graphene as a cathode material to improve recharge rates in the solid-state battery. This CAS project is led out of Glenn Research Center and is a multi-NASA center effort between Glenn, Langley, and Ames research centers. The advanced solid-state battery project also involves collaboration with Department of Energy-funded researchers from Argonne and Pacific Northwest National Laboratories, as well as multiple industry partners.

Under NASA's ARMD Advanced Air Transport Technology (AATT) program, efforts to design next-generation aircraft propulsion technologies for lower carbon emissions, noise, and fuel burn have already been enhanced through nanotechnology. Researchers at the NASA Glenn Research Center continue to investigate the use of exfoliated boron nitride nanosheets (BNNS) as a thermally conductive dielectric material to improve thermal management in high-power-density electric motors, which are anticipated to operate at higher voltages, switching frequencies, and temperatures than current aviation propulsion systems. BNNS is known to possess exceptional inherent thermal conductivity and good electrical insulating properties, which makes it an ideal dielectric filler to use with polymer insulators to keep the electric motor cooler. Experimental work to scale up exfoliated BNNS production and integrate BNNS into polymers is expected to continue in FY '21, in addition to improving understanding of composite insulation performance in the anticipated operating environment.

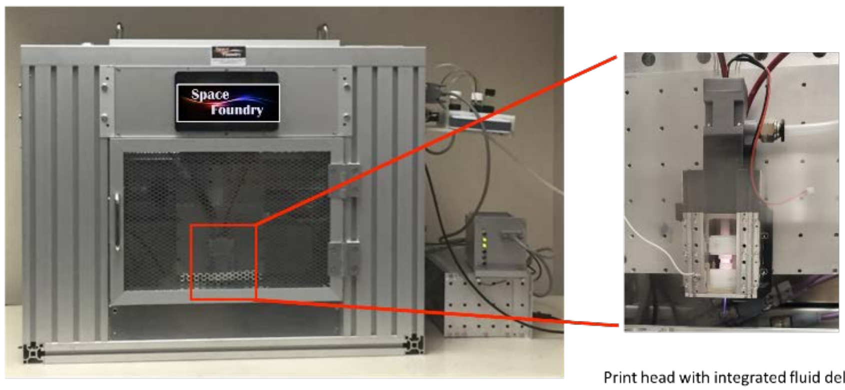
Soft magnets are used in electronic power components such as inductors and transformers to enhance magnetic fields in motor windings. NASA Glenn researchers are developing novel soft magnetic nanocomposite core materials for megawatt-class electric motors for the AATT program, which will allow the soft magnets to operate at significantly higher frequencies than traditional soft magnets. The use of soft magnetic nanocomposites also enables the electric motor to produce more power at a smaller, more compact size, which will save weight and increase efficiency. The advanced soft magnetic nanocomposite alloys developed by NASA researchers have demonstrated more than 30x lower AC electrical losses compared to bulk soft magnetic alloys. In addition, researchers have identified processing methods to make the soft magnetic ribbons more scalable. NASA is currently collaborating with industry to further scale up the fabrication process for developing advanced soft magnetic nanocomposite ribbons.

Key Technical Accomplishments by NNI Goal

Goal 2. Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

NASA regularly coordinates regional economic development activities to facilitate the transfer and commercialization of various technologies, including those enabled by nanotechnology, through partnerships with local and regional companies. NASA's Strategic Technology Partnerships Initiative establishes public-private partnerships to generate economic impact and benefit to companies that are located in economically distressed regions throughout the country. Through these agency-wide activities, NASA shares its expertise with organizations to assist the companies with solving specific technical challenges that could lead to progress on process improvement or product development.

Nanomaterials play a key role in the emerging fields of printed and flexible electronics and devices, fueled by the demands of the Internet of Things (IoT). The most commonly used technique is inkjet printing, followed by aerosol printing, both of which can deposit onto polymer, paper, and textile substrates. An annealing step is often needed to obtain consolidated thin films, which limits the use of certain substrates. NASA Ames has been working with a small business under NASA's SBIR program to develop an atmospheric pressure plasma tool, which enables single-step printing; thus eliminating the need for a post-annealing or sintering step (Figure 2). In addition to simplicity, cost savings are also expected through implementation of this technology, which are considerations for in-space manufacturing. The company has already begun selling the plasma printers to early adopters.[5]



Print head with integrated fluid delivery

Figure 2. Plasma Printer developed by Space Foundry, Inc., under NASA's SBIR Program. Image credit: NASA Ames Research Center.

An SBIR contract on "Detecting Life in Ocean Worlds with Low Capacitance Solid-state Nanopores" has completed a Phase I SBIR[6] and begun a Phase II contract.[7] The company is working on the fabrication of solid-state nanopore membranes and arrays with different pore diameters that are tailored to detect multiple types of biomarkers depending on their sizes and expected properties (i.e., DNA, charged proteins, amino acids, etc.). Further development of this effort includes nanopore chip integration with microfluidics and on-chip electronics to produce a compact, integrated, and self-contained platform that is small, portable, and robust for long-duration space missions.

NASA's SBIR/STTR program is also funding a company to work with NASA's Johnson Space Center to develop the next generation of materials to improve astronaut protection in space suits for lunar and Mars exploration.[8] The research and development uses smart materials based on concentrated nanoparticle suspensions that can instantly and reversibly switch between a liquid-like or a solid-like state, depending on the applied shear rate/shear stress. The company has engineered these smart, shear-thickening fluids (STFs, Figure 3) to create textile treatments that can substantially increase the energy absorption of a variety of performance textiles while still maintaining flexibility of the base fabric. Through a Phase II STTR, the company collaborated with the University of Delaware and industry to develop durable, puncture-resistant space suit outer fabric layups that were found to be effective in mitigating the negative effects of lunar or Martian dust, which is currently a major challenge for suit development. On another NASA Phase II SBIR, the

[5] http://www.spacefoundry.us/technology.html

[6] https://www.sbir.gov/sbirsearch/detail/1560223

[7] https://www.sbir.gov/sbirsearch/detail/1670513

[8] https://www.sbir.gov/sbirsearch/detail/1561515

company is collaborating with the University of Delaware and industry to develop advanced composite materials for the space suit hard upper torso, which will offer extreme impact resistance and damage tolerance.[9] The support of the NASA SBIR/STTR program has enabled the company to engineer the nanoparticles and other components of the STF to meet the challenging thermal and vacuum environment conditions in space and apply them to space suit fabrics. These smart textiles are currently being flight-tested as part of the Materials on the International Space Station Experiment to explore how the materials will respond in low Earth orbit.[9]

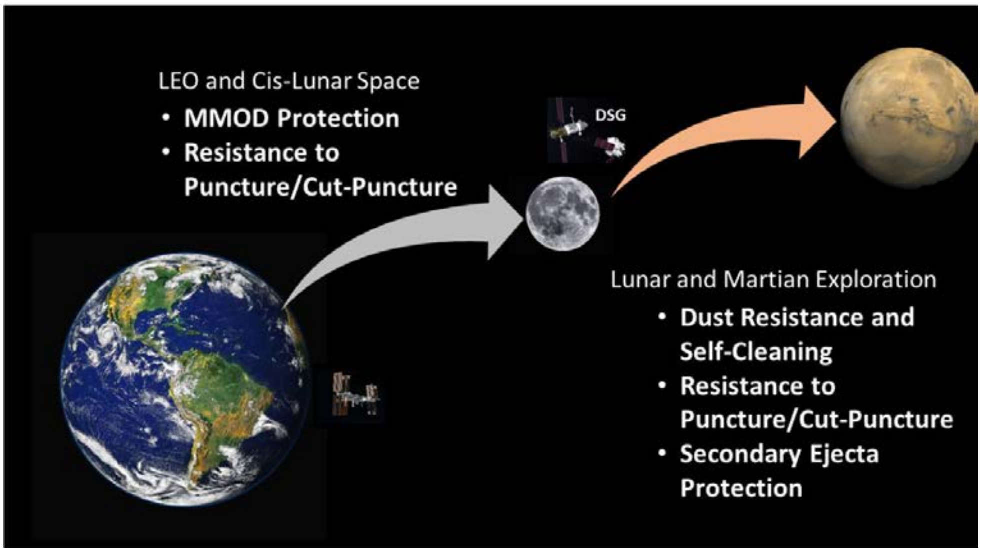


Figure 3. Benefits of STF to improve space suit protection for lunar and Mars exploration. Image credit: adapted from STF Technologies, LLC.

[9] https://www.sbir.gov/sbirsearch/detail/1670863