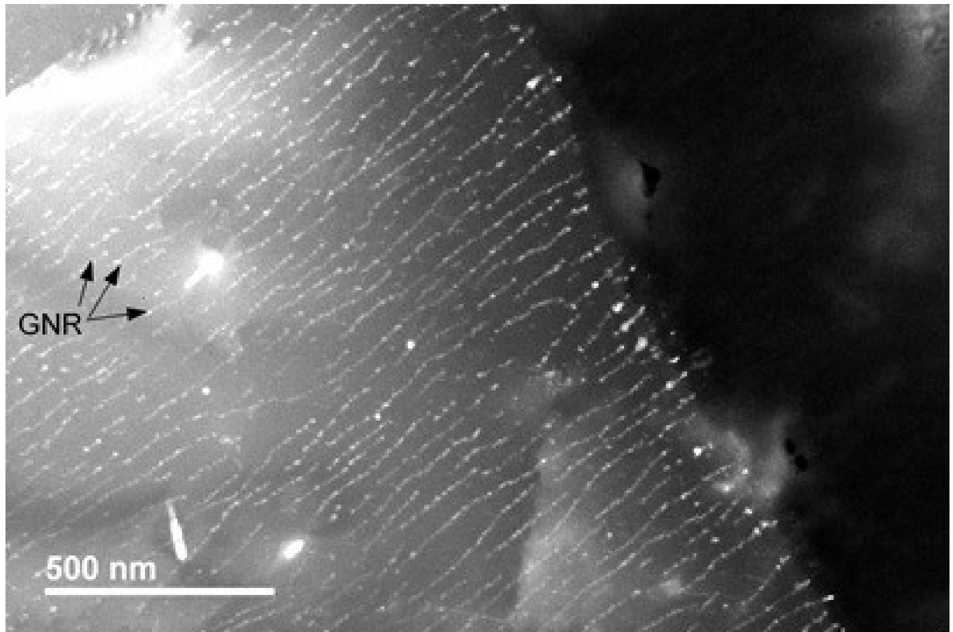
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Advanced Nanocarbon-Metal Composites for Improved Energy Efficiency



Transmission electron microscopy image of an aluminum grain (left) and an amorphous carbon particle (right). Graphene nanoribbons (GNR) emanating from the carbon particle extend through the aluminum grain with a preferred orientation with the aluminum lattice.

Image courtesy of University of Maryland, College Park.

When manufactured at small scales utilizing an electric charge, new composite materials consisting of graphitic carbon and metals have shown remarkable increases (20%-30%) in thermal and electrical conductivity compared to the parent metals. These materials also have similar large increases in strength. This project will develop a reliable and inexpensive process for producing these composites at commercially relevant scales. Ultimately, they could be manufactured by the private sector at large scales and become higher performing replacements for aluminum alloys, copper, and other metals currently used in wiring and other applications.

The extraordinary properties of these new materials—called nanocarbon-metal composites (NCMCs)—are thought to be based on interactions between specific nanocarbon structures (e.g., graphitic carbon in nanoribbons) and the conductive metal. The materials are also known as covetics because the carbon and metal are held together with covalent and metallic chemical bonds.

These properties have been shown in small samples and thin films made in laboratory experiments, but the materials still need to be scaled up and validated to enable commercial-scale manufacturing. In this project, NCMCs will be produced using an innovative electrocharging assisted process (EAP). If successful, the project will show that the EAP process can produce large quantities of NCMCs with uniform distribution of carbon in the metal. The project also seeks to improve the existing reactor design and optimize parameters of the EAP. The project will show that large-scale manufacturing of NCMCs (at kilogram scale) can reliably produce the desired superior thermal, electrical, and mechanical properties.

Benefits for Our Industry and Our Nation

The adoption of NCMCs is expected to lead to significant benefits and large savings in materials and energy, including:

- Increased tensile strength of at least 30% (with no loss of electrical conductivity) compared to aluminum alloys
- Increased thermal conductivity of at least 10% with no loss in electrical conductivity compared to copper
- Increased electrical conductivity of at least 10% compared to standard alloys, resulting in reduced losses in transmission and distribution power lines and microchips

Applications in our Nation's Industry

Cables and wires made of high conductivity metals such as aluminum and copper are essential to transfer power to our homes, businesses, and industry. The transmission and distribution (T&D) system in the United States includes nearly 160,000 miles of high-voltage power lines, millions of miles of low-voltage power lines, and distribution transformers that step down the voltage of electricity from power plants to the level needed by the nation's 145 million customers. In addition, these high conductivity metals can be used to make the nanometer-sized interconnects found in integrated circuits (ICs) that are the basis of all modern electronics, including computers and mobile phones. Electricity losses in the T&D system and ICs total billions of dollars each year. Thus, even a small increase in the electrical conductivity of the metals could result in significant monetary savings to the economy of the United States. Electric motors, which are extensively used in nearly all manufacturing operations, are another application area where NCMCs show great promise.

Project Description

The aim of this project is to manufacture commercially relevant quantities of high-performance NCMCs via EAP. This process will allow for inclusion of carbon nanostructures in metals at concentrations far above the solubility limit. The process will initially be applied to aluminum alloys relevant to transmission lines and microchips. In this project, various EAP process parameters, such as electric current, temperature, and residence time, are varied and optimized to produce the highest performing (e.g., highest thermal or electric conductivity, and tensile or yield strength) NCMCs. If successful, the project will show that the EAP process can be used to produce aluminum NCMCs with replicable properties.

Barriers

- Obtaining a uniform distribution of carbon in the metal that can be correlated to performance
- Lack of standardized methods for determining the level of converted carbon
- Procedures demonstrating a successful conversion are cumbersome, involving microscopy, spectroscopy, and evaluation of thermophysical properties
- Hot deformation processing of material is necessary to consolidate porosity

Pathways

This project is organized into three phases. The first phase will focus on identifying the optimum parameters in the EAP process to obtain uniform distribution of carbon in the NCMC metal alloys with no loss in the electrical and thermal properties.

The second phase will focus on depositing films by a variety of techniques, such as sputtering and pulsed laser deposition. NCMC samples will be analyzed by various spectroscopy and microscopy methods, including Raman scattering, x-ray photoelectron spectroscopy, x-ray powder diffraction, and transmission electron microscopy.

The third phase will focus on the design of a metal flow reactor for the large-scale manufacturing of NCMCs. Fabrication of NCMCs will also continue in order to optimize the process and obtain alloys with ≥ 10% increase in the electrical and/or thermal properties and an increase of ≥ 30% in ultimate tensile strength.

Milestones

This three-year project began in July 2018:

- Crucible geometries are tested and the best is selected as the model for a reactor with liquid metal flow (completed)
- Incorporation of a graphene sponge and/or pre-welded carbon nanofibers gives rise to a better network in the metal without breakage and with improved mechanical properties (2020)
- Optimum parameters are obtained for a metal flow reactor for NCMC fabrication with uniform carbon distribution, 10% increase in electrical or thermal conductivity, and 30% increase in ultimate tensile strength (2021)
- Design of a pilot reactor for NCMC alloys (2021)

Technology Transition

After a successful demonstration, the project team plans to continue work with industrial partners on any issues that may arise during scale-up, such as improving the homogeneity of the carbon phase and the microstructure of the carbon phase. Continuous improvement of the structure and thermophysical properties is expected, as well as incremental improvements due to incorporation of additional alloying elements. Once repeatable high performance samples are achieved, further scale-up of the high throughput reactor is anticipated to be performed by GDC Industries. General Cable, one of the largest power cable suppliers in the United States, has a Joint Development Agreement (JDA) with GDC. The JDA contemplates initial production of samples by GDC, followed by implementation of a high throughput reactor at one of General Cable's rod production facilities under a license agreement.

Project Partners

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