**PROJECT TITLE: Multifunctional Materials for Building Energy and Power Generation**

**I. PROJECT STATEMENT**

Figure 1. Schematic of the 3-step synthesis of 2D-material aerogels.

**Imagine a home insulation that better insulates your house in the winter and produces electricity from the temperature difference between the indoors and outdoors.** Developing such a multifunctional insulation is the goal of this proposal. Aerogels, highly porous media consisting of fibers or nanometer-sized particles, can act as **superinsulation**, whose insulating power can exceed that of current fibrous insulations. We are proposing to develop such superinsulations with plasma synthesis, a technique based on ionized gases developed at the University of Minnesota. We further propose to coat the highly porous structure of the superinsulation with **thermoelectric** (TE) materials. Such materials turn temperature differences into electrical voltages (the so-called TE effect), and thus are able to produce electricity from the heat that would otherwise be lost to the environment.

Superinsulations will be produced by depositing nanometer-sized particles into highly porous films. The nanoparticles will be produced in a plasma, in which an electric field excites free electrons in a gas to such high energies that they can easily decompose gaseous precursor molecules. This leads to the formation of well-controlled nanoparticles by adjusting parameters such as gas pressure and flow rate. We will produce amorphous carbon particles by decomposing methane or acetylene. By carefully depositing these particles at low velocities, carbon-particle films with large porosities can be produced. Particles will be bound to each other to improve mechanical stability via high-temperature sintering. Such highly porous materials have shown thermal conductivities close to or even lower than that of ambient air, about three times lower than that of current fibrous insulation materials.

To give the superinsulation thermoelectric properties, we will coat the carbon particle porous structure with an atomically thin layer of the so-called two-dimensional (2D) materials. Gas phase deposition processes are known for many 2D materials, and some of the 2D materials have attractive thermoelectric properties. Tin disulfide (SnS2) and tungsten diselenide (WSe2) are suitable materials that we will coat onto the superinsulation with gas phase chemical vapor deposition. In a final step, heating the material to 800-900 degree Celsius may be used to “burn off” the carbon particles. This would leave behind only the structure of 2D materials with the carbon template removed (**Fig. 1**). We hypothesize that this structure will have even better insulating properties, because the heat conduction through the network of carbon particles has been eliminated. Meanwhile, the low heat conduction of the porous 2D material is favored for producing a large temperature difference to generate electricity based on the TE effect. In addition, the electrical properties of 2D materials can be readily improved through doping (the introduction of certain atoms into a material to enhance its electrical properties). Thus, our proposed 2D-material aerogels are multifunctional offering both superinsulation and power generation in one package.

The proposed work will be carried out by a collaborative team leveraging the expertise of two research groups at the University of Minnesota, Twin Cities. Professor **Kortshagen** is a world-renowned expert on plasma synthesis techniques. He will lead the materials synthesis and device fabrication. Professor **Wang** has significant experience in ultrafast-laser-based measurement techniques and multiscale modeling to study the transport properties of materials. She will establish the structure-functionality relationships for the proposed materials, which will serve as guidance for **Kortshagen**’s group to further optimize the materials properties (and thus the performance of superinsulation and thermoelectric devices) via structural engineering.

**II. PROJECT ACTIVITIES AND OUTCOMES**

The materials synthesis, structure and property characterization, and device fabrication will be integrated in an iterative manner between two groups to ensure the success of the proposed work.

|  |  |
| --- | --- |
| **Activity 1:** Initial synthesis and property measurements of 2D-material aerogels |  |

**Description:** In activity 1, the team will synthesize and characterize 2D-material aerogels using a custom-designed template made of carbon particles from plasma synthesis. The team will start with SnS2 and WSe2.

**ENRTF BUDGET: $129,301**

|  |  |
| --- | --- |
| **Outcome** | **Completion Date** |
| *1. Design and Fabrication of SnS2 & WSe2 aerogels*  | *Dec. 31, 2020* |
| *2. Material property characterization to establish the structure-property relationship* | *Jun. 30, 2021* |

|  |  |
| --- | --- |
| **Activity 2:** Performance optimization of 2D-material aerogels |  |

**Description:** In activity 2, the team will focus on optimization of the proposed 2D-material aerogels to achieve the best performance of thermal insulation and the highest efficiency of power generation.

**ENRTF BUDGET: $131,688**

|  |  |
| --- | --- |
| **Outcome** | **Completion Date** |
| *1. Optimization of the superinsulation performance of the proposed 2D-material aerogels*  | *Jun. 30, 2022* |
| *2. Improvement of the power generation efficiency of aerogels via structural engineering* | *Jun. 30, 2022* |

|  |  |
| --- | --- |
| **Activity 3:**Demonstration of multifunctional materials and prototype devices |  |

**Description:** In activity 3 (upon completion), the team will demonstrate superinsulation materials with optimal thermal and electrical performance and a prototype of power generation devices based on 2D-material aerogels.

**ENRTF BUDGET: $134,148**

|  |  |
| --- | --- |
| **Outcome** | **Completion Date** |
| *1. Demonstration of superinsulation materials with optimal performance* | *Jun. 30, 2023* |
| *2. Prototype of thermoelectric devices for power generation* | *Jun. 30, 2023* |

**III. PROJECT PARTNERS AND COLLABORATORS:**

The research modalities and complementary technical backgrounds of both members are uniquely pronounced and undeniably necessary to accomplish project activities. Professor **Wang** is an expert in energy transport, especially in analyzing the transport properties of materials at the atomic and molecular levels. Professor **Kortshagen** is famous for his research accomplishment in the area of plasmas kinetic theory, nonthermal plasmas at atmospheric pressures, and plasma synthesis and functionalization of nanomaterials. In addition, our collaborative team will leverage insights from industry to ensure real-world significance and broad transformative impact. Both team members have proven records of collaborating with industrial companies. For example, **Wang** has been working on projects involving Minnesota-based companies including Seagate and 3M. **Kortshagen**’s group developed a novel plasma technique for materials synthesis in 2005, which is covered by three US patents and was licensed to companies including DuPont-Innovalight and Dow Corning.

**IV. LONG-TERM IMPLEMENTATION AND FUNDING:**

This proposed work has merits in both basic scientific foundation (materials engineering) and applied technology (device performance). In the long run, outcomes of this work also hold promise for large-scale commercialization due to the novelty and scalability of the technology, which can potentially create job opportunities and benefit the state economy. The team requests a three-year duration (from July 01, 2020 to June 30, 2023) to complete this proposed work (with milestones explained above). Results generated by this collaborative proposal will serve as preliminary data to seek for federal funding resources to support continued efforts on this topic. We plan to target agencies with portfolios focused on renewable and sustainable energy, materials sciences, and building energy, including National Science Foundation (Energy for sustainability, Energy, Power, Control, and Networks (EPCN), Thermal Transport Processes (TTP)), Department of Energy (Buildings Energy Efficiency Frontiers and Innovation Technologies), among others.