DESCRIPTION OF THE RESEARCH PROJECT FOR THE 2018 SUMMER RET SITE

Project 2: Energy Storage Devices Based on Three Dimensional (3D) Graphene: Case Supercapacitors and Lithium–Sulfur (Li-S) Batteries

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Project Summary

What is the nature of the proposed RET project and the questions it answers.

The *big idea* for this project is the National Academy of Engineering Grand Challenge to "Make Solar Energy More Economical." The fast development of renewable and sustainable energy techniques such as solar cells and wind turbines requires efficient energy storage systems to offset the fluctuations in power availability caused by clouds or varying winds. The central *challenge* or objective of this RET project is to develop technology to produce a seamless 3D graphene structure called a **Graphene Pellet (GP)** that is synthesized through chemical vapor deposition (**CVD**) using inexpensive nickel powder as catalyst template [1, 2]. GP is an important new platform for fabricating high performance supercapacitors, which is the first application of GP we intend to pursue. GP possesses well-controlled pore size (~2 nm), high electrical conductivity (148 S/cm) and good electromechanical properties. After electrochemical coating with manganese dioxide (**MnO_2**), the GP/MnO_2 electrode shows specific and volumetric capacitance up to 415 F g^{-1} and 235 F cm^{-3}, respectively, with capacitance retention of 90% after 5000 charge-discharge cycles. Moreover, when GP/MnO_2 electrode is assembled with GP/polypyrrole electrode, the fabricated full cell prototype (supercapacitor) shows a superior electrochemical performance with a maximum energy density of 22.3 Wh/kg, maximum power density of 16.4 kW/kg, and very good cycle life that was able to power a light emitting diode (**LED**). These performance characteristics compare favorably to existing supercapacitors.

What work needs to be conducted to achieve the objectives?

This research answers the *guiding question: How do we fabricate multiple supercapacitors and batteries with reproducible properties?* To answer this guiding question, following 6 tasks are proposed to be undertaken:

- Purchase of 20 commercially available housing of supercapacitors and batteries.
- Synthesis of 3D graphene.
- Manufacturing of the positive electrodes of the supercapacitors and batteries.
- Manufacturing of the negative electrodes of the supercapacitors and batteries.
- Assembling the supercapacitor and battery devices.
- Electrochemical testing the supercapacitor and battery devices.

What research facilities will be used to conduct the research?

The Nanoworld Laboratory at University of Cincinnati (http://www.min.uc.edu/nanoworldsmart) will be used for the RET research project. It is a college laboratory for material and device development, teaching, and demonstrations. Nanoworld is an internationally recognized laboratory for trailblazing and road mapping innovation, translating the discoveries to industry, and training a next generation workforce that will be in high-demand.

Four labs form the Nanoworld Labs at University of Cincinnati:

- NANOWORLD, Main Lab 414A, 414B & 413 Rhodes Hall, Ph. 513-556-4652
- Nanocomposite Materials and Characterization Lab, Rhodes 507
- Substrates and Nanomaterials Processing Laboratory, 581 Engineering Research Center (ERC)
- Pilot Microfactory for Nanomedicine Devices Lab, 587 ERC

Nanoworld may be the largest nanotube research laboratory in an academic setting with three commercial nanotube reactors to synthesize nanotube materials and transition the processes to industry. Nanotube reactors are in continuous operation along with post-processing and characterization equipment. Magnesium (**Mg**) single crystal manufacturing and coating systems are also used for developing biodegradable implants.

University of Cincinnati Nanoworld supports research for undergraduate and graduate students from across the university. Prof. Vesselin Shanov of the Department of Chemical and Environmental Engineering (**DCEE**) and Prof. Mark Schulz of the Department of Mechanical and Materials Engineering (**DMME**) direct the Nanoworld lab. Faculty members from across the University and from the University of Cincinnati College of Medicine collaborate with Nanoworld.

The main nanotechnology research in Nanoworld is in the field of synthesis, processing and characterization of carbon nanostructured materials, fibers, metal nanowires, nanocomposites, smart structures, electromagnetic devices, and sensors. Nanoworld is also developing innovations in medicine including Mg materials for biodegradable implants, microsensors and devices for interventional cardiology and cancer, and smart biodegradable implants.

Nanoworld is also comprehensively involved in education and is frequently used to host middle school and high school students along with their science teachers. Nanoworld leads teaching two undergraduate nanotechnology courses at University of Cincinnati and one graduate course. These courses use state-of-the-art instrumentation in Nanoworld to perform lab modules. Also, students from other courses tour Nanoworld and learn about nanotechnology, biodegradable metals, biosensors, biomedical devices, and other advanced topics. Undergraduate through Ph.D. students, post-doctoral fellows, faculty members, and industry collaborators all work together in Nanoworld. Hundreds of people visit Nanoworld each year. The faculty members affiliated with Nanoworld bring a great deal of expertise and time to mentoring the students to assure the education and research experience is successful.

Illustration of the current results related to this research project.

Figure 1. displays achievements related to the proposed research, which also have been recently published [1-4].

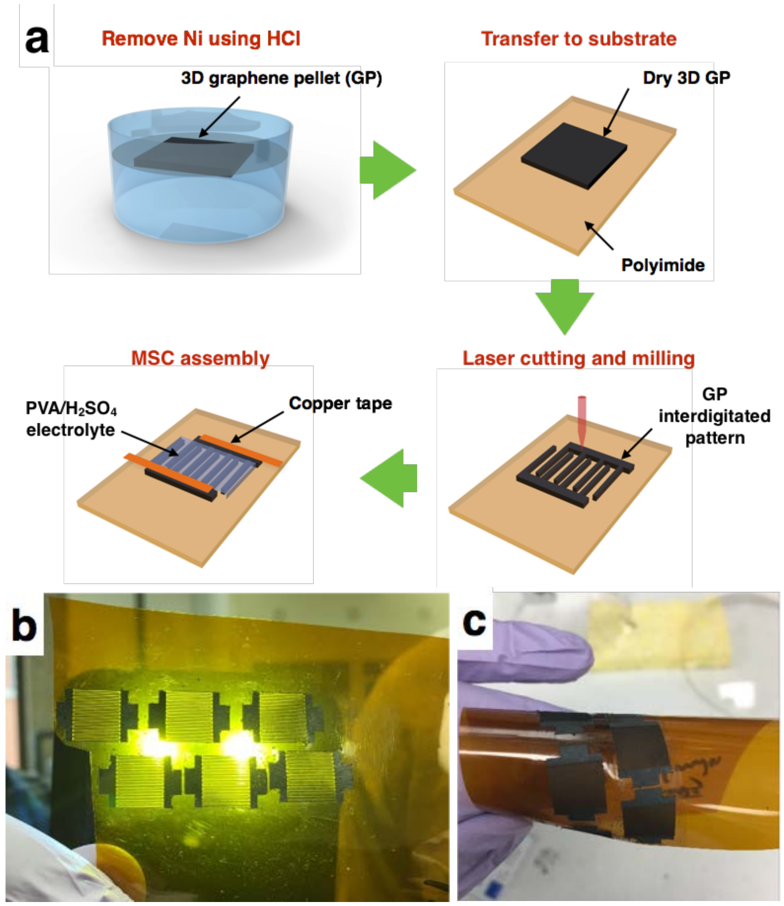

Figure 1: (a) Schematic diagram showing the fabrication process for a GP-MSC. After etching the Ni catalyst with HCl acid, the obtained GP was transferred onto a Kapton (polyimide) film and dried at 50˚ C for 12h. A good adhesion between GP and Kapton substrate was created due to van der Waals forces and the unique morphology of the 3D graphene. Laser engraving was then introduced to form interdigitated pattern, followed by drop-casting a gel electrolyte PVA/H_2SO_4 to complete the GP-MSC. Copper tape was used for interfacing the device with the instrument for electrochemical characterization; **(b, c)** The fabricated multiple GP-MSCs are flexible and can be produced on virtually any substrate of interest.

Who will be the Industrial Advisor for this project?

Mr. Larry Christy, Production Engineer, General Nano LLC, will join Prof. Vesselin Shanov, Prof. Mark Schulz and the Graduate Research Assistant in increasing awareness of the real-world applications of the proposed research.

<u>Possible Ideas for Classroom Implementation</u>

Making small supercapacitors and Li-based batteries for energy storage is technically possible in a Classroom. The students can assemble flexible devices as shown in **Figure 1(c)** and power a light emitting diode. University of Cincinnati can provide the needed electrode material and the housing for 5 batteries annually. The ***big idea*** is to use an existing energy storage device (supercapacitor or battery) that can be electrically charged for a short time, is light weight and has long cycling life, especially in generating power and specific energy. These devices will help to power portable electronics, including lap tops, cell phones and tablets and recharge them for a short time. The current charging time of these devices is hours and needs to be shortened to seconds. The end user of this technology is any person that is dealing with portable electronics, including cell phones, tablets and lap tops. In addition, military personal and first responders who are heavily equipped with electronic devices are expected to benefit from our light weight, long lasting and fast recharging energy storage devise. Finally, persons with implanted (in body) medical devices, such as pace makers, will enjoy a long lasting power supply that may be rechargeable remotely (without surgically explanting the battery).

References

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