Fabrication of a Lower Weight, All 3D Printed Graphene Supercapacitor

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ABSTRACT

Graphene is under intensive study for energy storage devices, such as batteries and supercapacitors, due to its energy density and ability to recharge. These properties make graphene well suited for electric powered UAVs with the advantage of reducing weight and volume of the device [1-5]. However, conventional manufacturing, which depends on the lithography process, has limitations in terms of efficiency, operational costs and scalability. We are optimizing a novel approach for mass production of graphene, using an easily applied graphene oxide film and laser-scribed graphene (LSG), which acts as both electrical insulator and a good ionic conductor [6]. The use of a liquid electrolyte limits the recharging speed and operating temperature. Switching to a solid electrolyte graphene supercapacitor yields enhanced environmental safety and higher energy density, thus a smaller volume needed for UAV aircraft [7-8]. The current research focuses on the ease of production of such supercapacitor through the development of a superior solid electrolyte, and the robustness of 3D printing and robotic assembly.

Keywords: 3D printing, graphene, supercapacitor, laser

1 INTRODUCTION

Unmanned aerial vehicles, or UAVs, have played a dominant role in modern day society. Although UAVs have a variety of routines and are manufactured in different shapes, one aspect remains constant: every UAV must possess a viable, affordable, and efficient power management system that will allow the vehicle to maintain functionality.

The graphene supercapacitor is the core component of the aircraft power storage system with a market in 1.59 Billion in 2016, and projected to reach USD 2.25 Billion by 2022 [9]. This constitutes the long-term application of our innovation, and is being developed in lieu of traditional capacitors due to its higher power-to- weight ratio [10].

We developed the method to fabricate a lower weight, 3D Printed Graphene Supercapacitor. The solid electrolyte was fabricated using PVA/LiCl-H2O system. The electrodes were made using the graphene reduced from graphene oxide (GO) via laser-scribed graphene (LSG). Figure 1 shows the schematics of the 3D printing all-solid-state graphene supercapacitor for use in the power storage system. The new electric storage devices with two to five times improvement in power storage device power-to-weight ratios could enable electric UAVs to compete with internal combustion and jet engine-powered UAVs for long endurance fights.

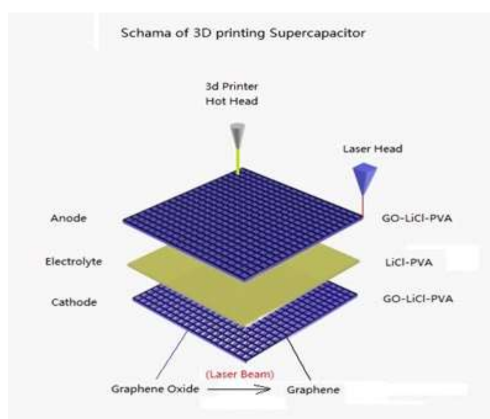
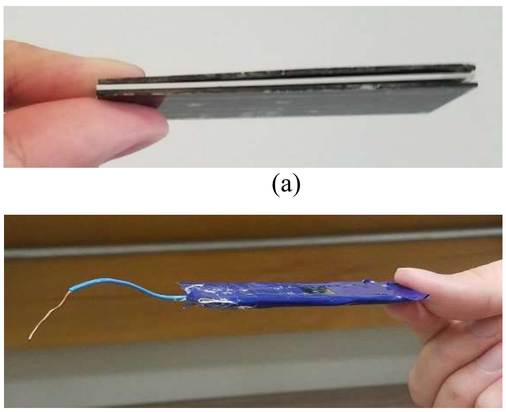


Figure 1: Schematics of the 3D Printing Laser-scribed Graphene Supercapacitor

The overall goal is to 3D print all the components for the supercapacitors and assemble them using robotic methods for mass production.

2 EXPERIMENTAL

The standard model of a capacitor includes 2 conductive plates with a dielectric (Gel Electrolyte) in between. Using any 3D CAD software, design a 75mm x 75mm x 1mm slab, and 3D print 2 slabs using Black Magic 3D conductive graphene filament. Figure 2(a) shows the 3D printed graphene supercapacitor.



(a)

(b)

Figure 2: (a) 3D Printed Supercapacitor, (B) Hand-Assembled Supercapacitor

Fabrication of graphene electrodes

The graphene supercapacitor's electrodes are comprised of graphene, which has been reduced from graphene oxide. The graphene oxide was converted to graphene using laser engraving. A Light scribe Burner (Meterk Laser Engraver Printer, 1500 mW, 405 nm) was utilized to conduct the laser engraving, and two materials were used as plates: aluminum and copper. Each capacitor created possessed the same laser engraving pattern as the electrode shown in Figure 3. The electrode in Figure 4 is a graphene layer atop a copper plate.

Figure 3: Fabrication of Graphene Electrodes Using Laser Engraving

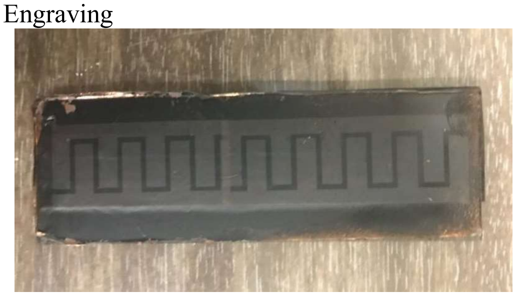


Figure 4: Graphene Electrode on Top of the Copper Plate

Fabrication of gel electrolyte

The gel electrolyte was created by dissolve 1g of polyvinyl alcohol powder (PVA) in 10g of boiled distilled water. The mixture was stirred continuously while keeping the temperature around 85C to 95C. Once the mixture thickens and becomes white, it was cooled down to room temperature. Then 0.8g of phosphoric acid was added to act as a proton donor until the acid is thoroughly mixed with the gel. Using a brush or a probe, spread the gel over the coated side of one of the electrodes (~100uL/cm^2). The side with the laser-engraved pattern will make contact with the gel electrolyte in the supercapacitor, which will act as a separator between the two electrodes.

Assembly of supercapacitor device

A robotic arm and control/vision system has been explored to assemble graphene supercapacitors. By utilizing a robotic arm and control/vision system, we could take advantage of the speed and precision and create a more efficient system for manufacturing supercapacitor components. This technology could replace the role of a human in performing the assembling task. It also avoids human contact, which is essential in avoiding introducing contaminants to the system and creating a safer work environment for those working with the components as hazardous material will be used in the process of making the supercapacitor. If the assembly line is designed and implemented well, robotic methods should improve the mass production that is cost-competitive to existing lithium-ion batteries. Figure 5 shows the automated assembly of supercapacitor.

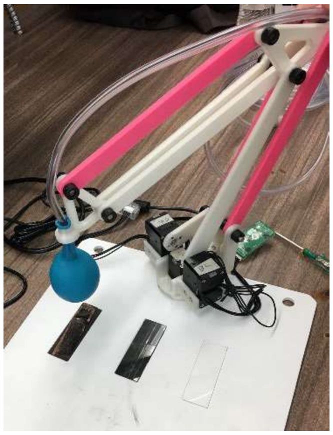


Figure 5: Robotic Arm Picking up Supercapacitor Components

3 RESULTS

Figures 6 shows our typical preliminary results of the cyclic voltammograms (CV) profiles measured using Princeton Applied Research VersaSTAT 4 Potentiostat Galvanostat. The CV curves were measured at different scan rates of 50 mV/s and 10 mV/s. The curves exhibit typical capacitive symmetry shapes along the center. The air gaps in the electrolyte or the uneven spreading of the electrolyte could be causing the non-square profile shape.

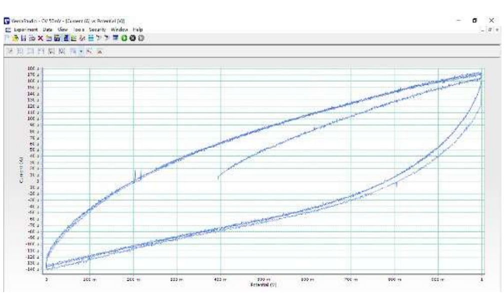


Figure 6: Graphene Supercapacitor Cyclic Voltammograms (CV) Curves in the Range of 0 to 1 V.

For the 3D printed electrodes and electrolyte, different thicknesses were used for the electrodes and electrolyte. One crucial aspect of the capacitance derives from the distance between the plates, or the thickness of the electrode. A larger distance will lower the capacitance of our device.

4 DISCUSSION

Our preliminary results indicate that the technique of graphene enhanced supercapacitor can be applied to electric powered UAVs. Taking advantage of the technology allows printing of a supercapacitor which can take any shape programmable in a computer model. Thus, it can be fabricated automatically in one touch, and integrated with any device with a specific structure, and enhance energy storage capacities, voltage range, and cycling properties. Most of all, our approach will ensure that, with the use of lasers in the 3D printing process, all material properties, of pure graphene will be maintained.

5 CONCLUSION

We developed a supercapacitor fabrication method, in which the solid electrolyte was fabricated using PVA/LiCl-H2O system. The electrodes were made using the graphene reduced from graphene oxide (GO) via laser-scribed graphene (LSG). We expect the new electric storage devices with two to five times improvement in power storage device power-to-weight ratios could enable electric UAVs to compete with internal combustion and jet engine-powered UAVs for long endurance fights.

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REFERENCES

[1] Z. Wang, J. Wu, and S. Huang. "A hybrid power system for unmanned aerial vehicle electromagnetic launcher." In AIP Conference Proceedings, vol. 1971, no. 1, p. 040011. AIP Publishing, 2018.

[2] P. G. Sai, S. R. Chapala, and U. R. Nelakuditi.

"Implementation of Power Optimization Technique for UAVs." Materials Today: Proceedings 5, no. 1 (2018): 132-137.

[3] V. Trenev, M. Mladenov, K. Kanev, E. Petrov, and I. Chavdarov. "Unmanned Aerial Vehicle Energy Efficiency Improvement by Batery-Supercapacitor System." In Proceedings of the 19th International Conference Batch Production Automation ADP 2010, pp. 476-481. 2010.

[4] N. Shah, and D. Czarkowski. "Supercapacitors in Tandem with Batteries to Prolong the Range of UGV Systems." Electronics 7, no. 1 (2018): 6.

[5] P. Simon, Y. Gogotsi, B. Dunn, Materials science. “Where do batteries end and supercapacitors begin?” Science, 2014, 343(6176):1210.

[6] W. Gao, N. Singh, L. Song, et al. “Direct laser writing of micro-supercapacitors on hydrated graphite oxide films.” Nature Nanotechnology, 2011, 6(8):496.

[7] A. K. Geim, K. S. Novoselov, “The rise of graphene.” Nature Materials, 2007, 6(3):183-91.

[8] C. Liu, Z. Yu, D. Neff, et al. “Graphene-based supercapacitor with an ultrahigh energy density.” Nano Letters, 2010, 10(12):4863.

[9] Markets and Markets. “Graphene Market,” 2015.

[10] S. Dobbs, Z. Yu, K. Anderson, J, Franco, A. Deravanessian, A. Lin and A. Ahn, “Design of an Inflight Power Generation and Storage System for Use in UAVs”, IEEE Conference on Technologies for Sustainability (SusTech) in Long Beach, CA, (2018)