Inkjet-Printed Flexible Graphene Based Supercapacitors

Matthew H. Ervin,[1] Linh T. Le,[2] and Woo Y. Lee[2]

[1]US Army Research Laboratory
2800 Powder Mill Road, Adelphi MD 20783-1197

[2] Stevens Institute of Technology, Department of Chemical Engineering and Materials Science, 1 Castle Point on Hudson, Hoboken, NJ 07030

Printed, flexible electronics are desirable as they offer the promise of low cost, readily customizable, rugged, and perhaps wearable electronics along with volume and weight savings. In order to fully realize these advantages a flexible power source must be developed. Presently, batteries are the go-to solution for powering most of the Army's portable electronics; however, there are good reasons for considering the use of electrochemical double layer capacitors (aka, supercapacitors) for some applications. While batteries have superior energy densities, supercapacitors have advantages in power density, cycle life, rapid charging, and good performance over a wide temperature range. Supercapacitors may prove useful as a standalone power source or as part of a hybrid system with a battery depending on the application.

Commercial supercapacitors have electrodes made with activated carbon. Activated carbon has high surface area which yields high specific capacitances, but it is composed of brittle particles that are not highly conductive. As a result, activated carbon electrodes are made with the addition of binders and conductivity enhancers. Graphene, single atom thick graphite sheets, on the other hand, has superior electrical and mechanical properties compared to activated carbon. Graphene is being widely studied for supercapacitor applications, due to its high surface area and high electrical conductivity.[1] Graphene is especially attractive for printing flexible supercapacitors as it is a very strong and flexible material, and its oxidized form (aka graphene oxide) makes a good inkjet printable ink when dissolved in water. Once the graphene oxide is printed onto the substrate, it must be reduced to the conductive graphene form, which we do with a thermal bake.

Previously, we reported good capacitor performance with inkjet printed graphene on metal foil current collectors which were assembled into a prototype device using a Celgard separator and a rigid fluoropolymer clamp as shown in Fig 1A.[2] The achieved specific capacitance of 132 F/g is similar to that obtained for graphene using other electrode fabrication methods. This demonstrates that inkjet printing is a viable method of electrode fabrication. In this work, the next step in printing flexible supercapacitors is undertaken with the printing of graphene electrodes onto flexible Kapton FN substrates which are composed of fluorinated ethylene propylene (FEP) and polyimide layers. The FEP coating of the Kapton is what allows the Kapton to be heat sealed in order to seal the electrolyte in. A prototype flexible graphene/Kapton supercapacitor is shown in Fig. 1B.

While it is expected that eventually the metal current collector, graphene active electrode material, and perhaps the electrolyte and separator will all be inkjet printed, in this initial prototype, the metal current collectors were shadow-masked metal films evaporated onto Kapton FN. The low specific capacitance achieved with this prototype is attributed to the resistance of the evaporated metal current collectors deposited onto the heat sealable Kapton FN. This is due to the FEP being a poor substrate for adhesion. Although low specific capacitance was achieved in the initial device, the observed capacitance was largely maintained during bending of the device through various radii, indicating that flexible devices are possible.

Various considerations that need to be addressed to achieve good flexible supercapacitors will be addressed including: the thermal budget, heat sealing issues, package permeability, printing alignment, etc.

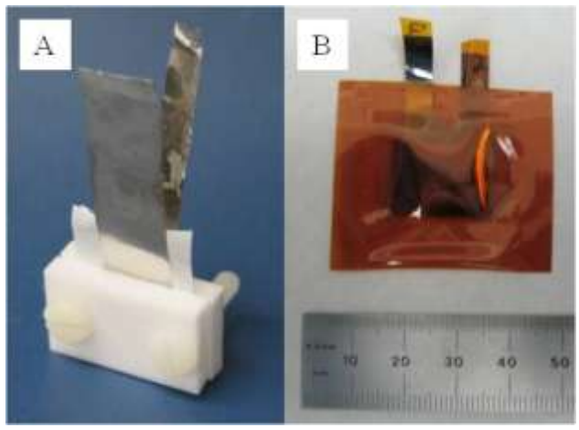

Fig. 1 A) inkjet printed graphene on metal foil current collectors tested in a rigid clamp, B) heat sealed device made with inkjet printed graphene on evaporated metal on Kapton current collectors.

[1] A. Davies and A. Yu, The Canadian Journal of Chemical Engineering, 89 (2011) 1342–1356.

[2] L. T. Le, M. H. Ervin, H. Qiu, B. E. Fuchs, and W. Y. Lee, Electrochemistry Communications, 13 (2011) 355-358.