Uncovered

Graphene – transition metal oxide hybrid materials

Hybrid structures for energy storage

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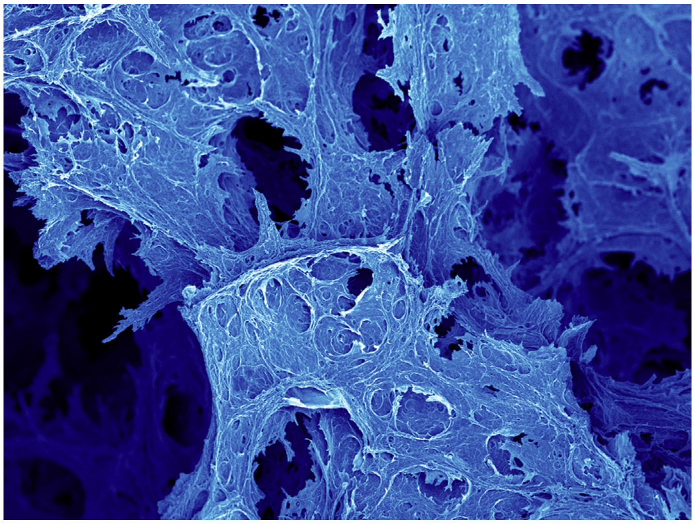

With the interest of researchers shifting from other carbon materials and nanostructures towards graphene, it is not surprising that the number of papers on graphene has been increasing exponentially since 2005. With much of the initial excitement being in the physics community, the chemistry of graphene has been receiving increased attention in the past few years [1], leading to synthesis of a large variety of graphene-based materials. Among these, graphene-supported metal oxide particles form a very large family of new materials with applications ranging from solar cells, to catalysis (including photocatalysis), to battery and supercapacitor electrodes [2]. Graphene provides a substrate that makes oxide nanoparticles accessible to the environment, allowing them to better perform their functions. Graphene also adds conductivity to oxides, which are usually poor conductors, enabling applications in battery and supercapacitor electrodes, as well as electrocatalysis [2]. Titanium dioxide supported on carbon has received the most attention due to the very broad range of applications of titania. However, other transition metal oxides can offer useful properties that can be enhanced by using graphene substrates. Electron injection from graphene into oxides increases concentration of holes in graphene and may increase the conductivity of the entire hybrid material. One of the important applications of graphene–metal oxide materials is their use as electrodes in electrochemical capacitors (ECs), also called supercapacitors. ECs are devices with very large capacitance (hundreds to thousands of Farads compared to microFarads or milliFarads for solid state and electrolytic capacitors). The energy density of ECs is lower than that of batteries, but they can store and deliver the energy much faster (in seconds) and have a much longer cyclic lifetime [3]. Most of the current commercially available ECs are so known as electrochemical double layer capacitors (EDLCs). They store charge electrostatically at the interface of high surface area carbon electrodes and an electrolyte. The other type, pseudo-capacitors or redox capacitors, store charge through fast surface and near-surface redox reactions or the intercalation of ions. Transition metal oxides are frequently used as pseudo-capacitive materials [3]. Due to the chemical charge storage mechanism, pseudo-capacitors show higher energy density and storage capacity, but usually have a slow charge storage and limited lifetime. Increasing the energy density of EC electrodes without losing their power density and rate capability is a challenge that can be addressed by a rational design of the electrodes and producing hybrid carbon-oxide structures.

This issue's cover shows one example of such a hybrid structures that consist of ~10–20 nm nanoparticles of Nb_2O_5 deposited on a three-dimensional (3D) graphene aerogel. The material is designed this way to decrease the diffusion limitations for electrolyte ions moving through the electrode and increase electrode conductivity, two factors that determine the overall power performance of ECs. The crystalline network of orthorhombic niobium oxide (T-Nb_2O_5) offers two-dimensional transport pathways for fast

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intercalation of lithium ions, leading to its high and rate-independent intercalation capacitance [4]. Unlike many other metal oxides, T-Nb_2O_5 can be charged in a short period of time, making it suitable as a supercapacitor electrode material. So far, the excellent performance of T-Nb_2O_5 has been demonstrated for thin film and microelectrodes. However, for practical applications in supercapacitors, thick electrodes with large mass loadings are necessary. Making a 200–300 μm thick electrode of Nb_2O_5, however, increases the ohmic losses in the electrodes and also introduces limitations for the diffusion of Li ions. We have addressed these issues by the synthesis of 3D structures of graphene coated by nanocrystalline Nb_2O_5. These hybrid structures were fabricated using a hydrothermal synthesis route, in which the reduction of graphene oxide, deposition of Nb_2O_5 and formation of the 3D structures all occurred in one synthesis step. In the resulting freestanding electrodes, the 3D graphene network acts as a highly conductive and porous support for Nb_2O_5 nanoparticles. The amorphous as-deposited Nb_2O_5 particles were converted to the orthorhombic structure by a post-synthesis heat treatment.

Further reading

[1] Y. Gogotsi, J. Phys. Chem. Lett. 2 (2011) 2509–2510.
[2] Z.-S. Wu, et al. Nano Energy 1 (2012) 107–131.
[3] P. Simon, Y. Gogotsi, Acc. Chem. Res. 46 (2012) 1094–1103.
[4] V. Augustyn, et al. Nat. Mater. 12 (2013) 518–522.