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Graphene Based Supercapacitors For Advanced Electronic Devices

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ABSTRACT: The Graphene based materials are promising for applications in super-capacitors and other energy storage devices due to the intriguing properties, i.e., highly tuneable surface area, outstanding electrical conductivity, good chemical stability and excellent mechanical behaviour. This review summarizes recent development on graphene based materials for super capacitor electrodes, based on their macro structural complexity, i.e., zero-dimensional (0D) (e.g. free-standing graphene dots and particles), one-dimensional (1D) (e.g. fiber type and yarn-type structures), two-dimensional (2D) (e.g. graphenes and graphene based nano composite films), and three-dimensional (3D) (e.g. graphene foam and hydrogel- based nano composites). There are extensive and on-going researches on the rationalization of their structures at varying scales and dimensions, development of effective and low cost synthesis techniques, design and architecting of graphene based materials, as well as clarification of their electrochemical performance.

KEYWORDS: Graphene, Supercapacitors, Energy Density, Storage capacity.

I. INTRODUCTION

Supercapacitors or ultra-capacitors have attracted considerable recent attentions due to their high power density, high charge/discharge rates, and long cycle life performance. They are considered as one of the most promising electrochemical energy storage devices, having a potential to complement or eventually replace the batteries for energy storage applications, i.e., those for wearable and portable electronics, electrical and hybrid vehicles. Based on the energy storage mechanisms, supercapacitors can be classified into two main categories, i.e., electric double layer capacitors (EDLCs) and pseudo-capacitors. For EDLCs, the capacitance is originated from the accumulation of charges at the electrode-electrolyte interfaces. Therefore, controlling the specific surface area and pore size and enhancing electrical conductivity are the effective ways to achieve a high storage capacity. Also, the energy storage of pseudo capacitance is realized through transferring the faradic charges between electrolyte and electrode due to the reversible multi-electron redox faradaic reactions, which generally exhibits higher specific capacitance and energy density, compared to EDLCs. However, the poor electrical conductivity in the commonly known pseudocapacitive electrodes can restrict the Faradic reactions, therefore leading to unsatisfactory electrochemical performance and life cycles.

II. RELATED WORK

The ongoing development of lithium-ion batteries (LIBs) has resulted in remarkable improvements in various aspects of their operation, including energy density, power density, cycle life, and safety. At present, mobile

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IT devices account for a significant portion of LIB applications, where the operating specifications of current state-of-the-art LIBs are mostly satisfactory. However, as electric vehicles (EVs) have penetrated LIB markets, key electrochemical properties have imposed more challenging standards; while higher energy densities are desired for increased driving mileage, enhanced reaction kinetics are demanded for fast charging and high rate operations. Safety is also definitely a critical factor for EV applications. A formidable challenge lies in overcoming the trade-off relation among these key properties; it is usually nontrivial to improve one property without sacrificing others.

III. GRAPHENE SUPERCAPACITOR

Capacitors, are able to be charged and release energy very quickly, but can hold much less energy than a battery. Graphene application developments have led to new possibilities for energy storage, with high charge and discharge rates, which can be made cheaply. But before we go into specific details, it would be sensible to first outline basics of energy storage and the potential goals of developing graphene as supercapacitors.

A capacitor is an energy storage medium similar to an electrochemical battery. Most batteries, while able to store a large amount of energy are relatively inefficient in comparison to other energy solutions such as fossil fuels. It is often said that a 1kg electrochemical battery is able to produce much less energy than 1 litre of gasoline; but this kind of comparison is extremely vague, and should be ignored. In fact, some electrochemical batteries can be relatively efficient, but that doesn't get around the primary limiting factor in batteries replacing fossil fuels.

High capacity batteries take a long time to charge. This is why electrically powered vehicles have not taken-off as well as we expected twenty or thirty years ago. While you are now able to travel 250 miles or more on one single charge in a car such as the Tesla Model S, it could take you over 43 hours to charge the vehicle using a standard 120v wall socket in order to drive back home. This is not acceptable for many car users. Capacitors, on the other hand, are able to be charged at a much higher rate, but store somewhat less energy. After applying all these 4 steps, we get a filtered image that contains only text regions.

Scientists looking at using graphene instead of the currently more popular activated carbon? Well, graphene is essentially a form of carbon, and while activated carbon has an extremely high relative surface area, graphene has substantially more. As we have already highlighted, one of the limitations to the capacitance of ultra-capacitors is the surface area of the conductors. If one conductive material in a supercapacitor has a higher relative surface area than another, it will be better at storing electrostatic charge.

IV. GRAPHENE SUPERCAPACITOR PROPERTIES

Graphene is very porous. The extreme capacitance value comes from graphene's high internal surface area, which is also known as Brunauer-Emmett-Teller surface area. One gram of graphene has an equivalent surface area of approximately 1600 m^2 , which is equivalent to 17200 square feet! This means that 5 grams of graphene have an internal surface area equivalent to the area of an entire soccer field.

V. THE CYCLE-LIFE OF A GRAPHENE SUPERCAPACITOR

Graphene Supercapacitors beat batteries in one more field: cycle life. Cycle life basically defines how many times a battery or a supercapacitor can be fully discharged and then fully charged again. Batteries can only last for about 500-1000 full charges. You might have noticed this effect yourself. If you use your laptop or cell phone every day, you'll notice that its battery life reduces with age. This is actually because the battery approaches its cycle life after many charge/discharge cycles. As this happens, the maximum capacity of a battery degrades. On the other hand, graphene supercapacitors still retain 94% of their nominal charge after 3000 complete charge/discharge cycles. The typical cycle life of a graphene supercapacitor can be up to 1 million cycles.

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VI. FUTURE OF GRAPHENE SUPERCAPACITOR

Vehicles that utilize supercapacitors are already prevalent in our society. One Chinese company is currently manufacturing buses that incorporate supercapacitor energy recovery systems, such as those used on Formula 1 cars, to store energy when braking and then converting that energy to power the vehicle until the next stop.

Additionally, we will at some point in the next few years begin to see mobile telephones and other mobile electronic devices being powered by supercapacitors as not only can they be charged at a much higher rate than current lithium-ion batteries, but they also have the potential to last for a vastly greater length of time.

To develop the graphene-based materials as supercapacitor electrodes and broaden their applications into other energy storage devices, the following future aspects should be considered:

- (i) Graphene-based electrode materials with different architectures exhibit varying physical, mechanical and chemical behaviors, therefore affecting their performance in energy storage. Compared to the 0D, 1D and 2D structures, more attention should be paid to further exploring the tuneable 3D graphene networks with interconnected porous structure, which can be manipulated for large internal surface area, ion/charge pathways, and avoiding the dead volume and collapse of the overall structures.
- (ii) The nanocomposites consisting of graphene-based and pseudocapacitive materials, *i.e.*, those graphene/conductive polymers, graphene/metal oxides or hydroxides, are promising for achieving the long awaited requirement of both power density and high energy density. Therefore, there is a need to future explore efforts on the clarification of the nano hybrid structures and the control of the interfacial interaction between graphene and pseudocapacitive materials in order to improve the overall Faradic processes across the interface.
- (iii) The rapid development of flexible electronics requires flexible and deformable energy storage devices. Therefore, future studies focus on the development of mechanical flexibility of graphene-based materials for supercapacitors and other energy storage devices.
- (iv) The multifunctional or self-powered hybrid systems will be of considerable interests for future development. Recent pioneer work on the combination of flexible supercapacitors with other electronic and energy devices (*i.e.*, solar cells, Li-ion batteries, electrochromic devices and nano-generators) were reported. Therefore, the integration of graphene-based supercapacitors with these devices will be of considerable values and a challenge as well.

VII. CONCLUSION

Graphene has rapidly changed its status from being an unexpected and sometimes unwelcome newcomer to a rising star and to a reigning champion. The professional scepticism that initially dominated the attitude of many researchers (including myself) with respect to graphene applications is gradually evaporating under the pressure of recent Developments. Still, it is the wealth of new physics – observed, expected and hoped for – which is driving the area form the moment.

Research on graphene's electronic properties is now matured but is unlikely to start fading any time soon, especially because of the virtually unexplored opportunity to control quantum transport by strain engineering and various structural modifications. Even after that, graphene will continue to stand out as a truly unique item in them arsenal of condensed matter physics. Research on graphene's non-electronic properties is just gearing up, and this should bring up new phenomena that can hopefully prove equally fascinating and sustain, if not expand, the graphene boom.

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