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Quantum materials for energy storage and conversion: graphene-based multifunctional hybrids

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Host: Yong Chen

Intense research in sustainable alternative energy is stimulated by global demand for electric energy. Electrochemical energy systems (EES) represent some of the most efficient and environmentally benign technologies. Moreover, engineered electrodes are enabling emergent next-generation electrochemical devices approaching the practically useful limit of specific energy and power densities and delivering electrical power rapidly and efficiently. Among carbon-based nanomaterials, two-dimensional ((2D) graphene and its variants continue to stimulate extensive research and development interests since its inception due to its extraordinary physical-chemical properties. This presentation will focus on graphene-based hybrid quantum materials as potential game changing multifunctional materials giving rise to high-performance when combined with other nanomaterials such as transition metal oxides, conducting polymers, carbon nanotubes and transition metal dichalcogenides.

In the first part, I will discuss synthetic approaches for strategic materials design to promote chemical and molecular bridging of the graphene layer to nanotubes and transition metal oxides via electrostatic layer-by-layer assembly and electrodeposition and interconnecting graphene to carbon nanotubes topologically by hydro-solvothermal method followed by freeze-dry to form aerogel monoliths. Experimental studies showed significant enhancement toward gravimetric capacitance, interfacial capacitance, charging-discharging rate, specific energy and power densities, and cyclability attributed to combined super capacitive (charge induction at non-Faradaic electric double-layer) and Faradaic pseudocapacitive (charge transfer) mechanisms, increased electrical conductivity and surface area due to open network yielding ultralow densities and tunable mesoscopic pore sizes. All these properties are also useful for enhanced electro-sorption, charge transfer and rapid transportation of ions in pseudo capacitors and efficient thermo-electrochemical energy harvesting.

In the second part, advanced characterization gaining fundamental insights into the redox mechanisms and ion transportation at the electrode-electrolyte interface during energy storage and low-grade thermal energy harvesting applications will be presented. The scanning electrochemical microscopy (SECM), a powerful analytical and imaging tool, that uses microelectrode to probe dynamic physical-chemical reaction processes occurring at the working electrode surface / interfaces with high spatial resolution will be highlighted. Analysis of small capacitive currents that reinforces the effective electron density overlap between electrode and electrolyte during redox reactions determines heterogeneous electron transfer rate and diffusion coefficient and visualizes distribution of highly electroactive sites in-situ over larger sample areas. These findings are complemented with theoretical calculations that reinforce the available density of states in the vicinity of Fermi level contributing to higher electrochemical activity. Finally, this research opened up new innovations for graphene related quantum materials with significant value propositions in hybrid supercapacitors, batteries, hydrogen generation, electrocatalysis, and biosensing for both academe and industrialist alike.

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