Nanostructured Electrodes for Lithium Ion Batteries Using Biological and Chemical Scaffolds

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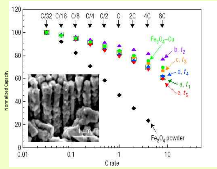
Abstract

Development of materials that deliver more energy at high rates is important for high power applications including portable electronic devices and hybrid electric vehicles. For lithium ion batteries, reducing materials dimensions can boost Li^+ ion and electron transfer in nanostructured electrodes. Therefore, there is a growing need for nanostructured electrodes for lithium ion batteries to boost electron transfer for high power applications. There have been efforts to electrically address electrode materials with poor electronic conductivity through nanoscale wiring of active materials. However, the wiring tools used so far were functionalized for a single component, either active materials or conducting materials. The wiring did not completely exploit specificity but depended on random occurrence of contacts between either conducting networks or active materials. Here, we present two research directions that utilized biological and chemical template for achieving intimate nanoscale electrical wiring to active material.

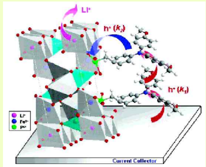
Importance of Nanostructured Electrodes for Intimate Electrical Wiring to Active Materials

Nanostructured Electrode: Fe_3O_4 deposits on Cu nanostructured electrodes



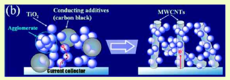
Tarascon, J-M. 2006, Nat. Mater.

Molecular Wiring: molecular charge transport layers



Grätzel, M., 2007, JACS

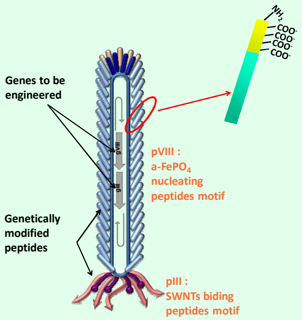
MWCNT Networks

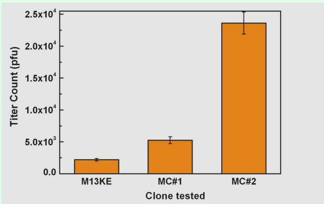


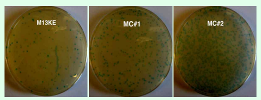
Kim, 2008, Crystal Growth & Design

To electrochemically address active electrodes materials and enhance high power performance : Intimate electrical wiring to active materials is becoming a key process for electrodes fabrication

Biological Toolkits: Genetic Engineering for Multifunctional Virus







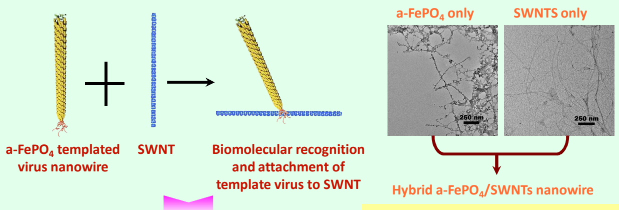
Genetic Engineering for multifunctional biological platform : two gene engineering for hetero-functionality (two-gene system)

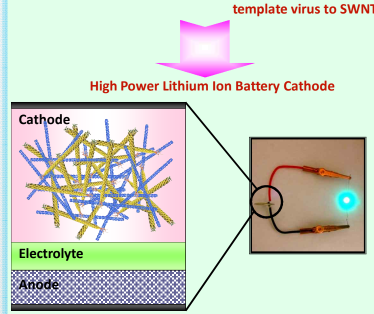
- EC#1 (pVIII, E4 + pIII, MC#1)
- EC#2 (pVIII, E4 + pIII, MC#2)

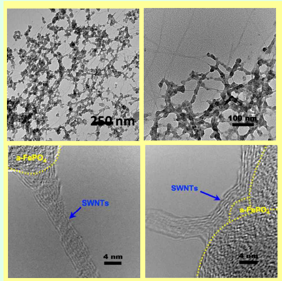
Phage display with pIII library against single-wall carbon nanotubes (SWNTs)

- N'-HGHPYQHLLRVL-C', named as MC#1 with relatively moderate affinity(X2.5)
- N'-DMPRTTMSPPPR-C', named as MC#2 with strongest affinity(X10)

Fabricating Genetically Engineered High Power Batteries





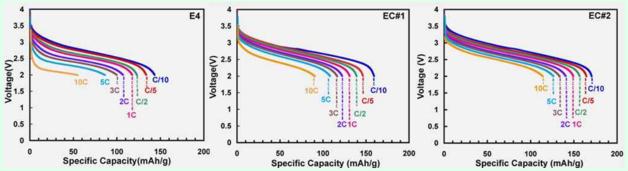


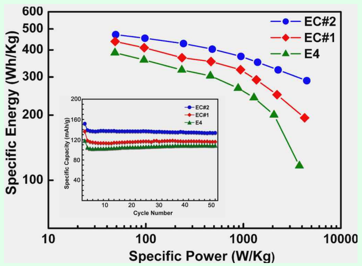
Schematic diagram of fabricating genetically engineered high power lithium ion battery cathodes using multifunctional viruses (two-gene system) and a photograph of actual battery used to power a green light-emitting diode (LED)

The biomolecular recognition and attachment to conducting SWNT networks make efficient electrical nanoscale wiring to active materials

Multifunctional biological platform has been developed!!

Electrochemical Performance of Hybrid a-FePO4/SWNTs Cathodes



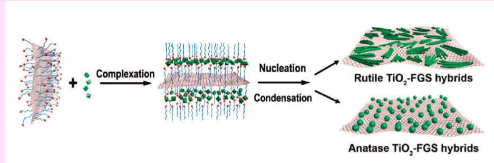


Electrochemical performance scales with the binding affinity to SWNTs.

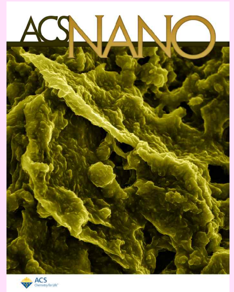
High power performance comparable to state-of-the art crytalline-$LiFePO_4$.

True nanoscale electrical wiring for high power lithium ion batteries using basic biological principles has been realized!!

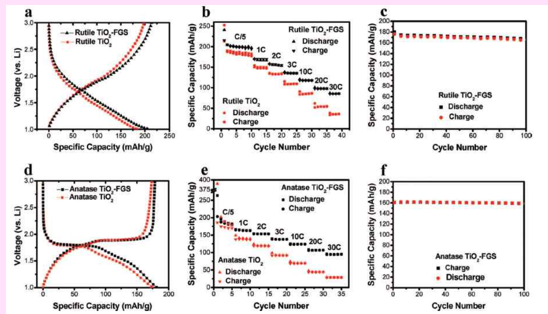
Future Direction at PNNL: Integrating Bioinspired Strategy with Synthetic Materials for Energy Storage



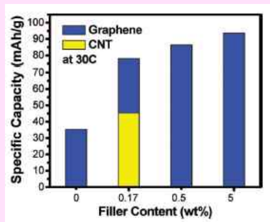
Self-Assembled Hybrid Nanostructures using Graphene and Chemical Template



Example from PNNL work: self-assembled TiO_2 graphene nanocomposites showed greatly improved stability and high rate capacity due to improved conductivity. . Courtesy of Dr. Jun Liu and Dr. Donghai Wang from PNNL,.



The nanostructured TiO_2 graphene hybrid materials show enhance Li-ion insertion/extraction kinetics in TiO_2, especially at high charge/discharge rates



Besides advantages in manufacturing cost, graphene showed better performances than CNT as a template for hybrid materials

Percolating graphene networks provide efficient pathway for electrode kinetics mediated by anionic surfactant as chemical templates

Acknowledgement: Work at MIT was supported by the Institute for Collaborative Biotechnologies through contract no. W911NF-09-D-0001 from the U.S. Army Research Office. Work at PNNL is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award KC020105-FWP12152. PNNL is operated by Battelle for the U.S. Department of Energy under Contract DE-AC05-76RL01830. I would like to thank Professor Angela Belcher and Dr. Jun Liu for supervising the research at MIT and PNNL respectively.