Templated Synthesis of Nanomaterials for Ultracapacitors

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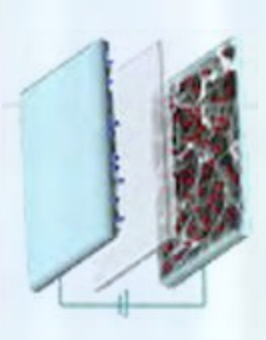
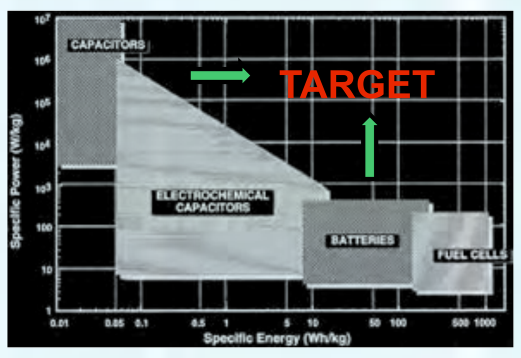
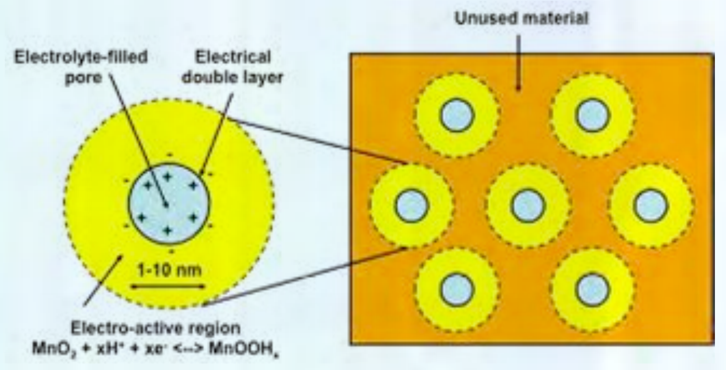
Problem

Ultracapacitors: energy-storage devices that are hybrids between batteries and capacitors.

Goal: Explore simple, inexpensive solution-based self-assembly processes to maximize power and energy densities of ultracapacitors by organizing electroactive materials into nano-architectures.





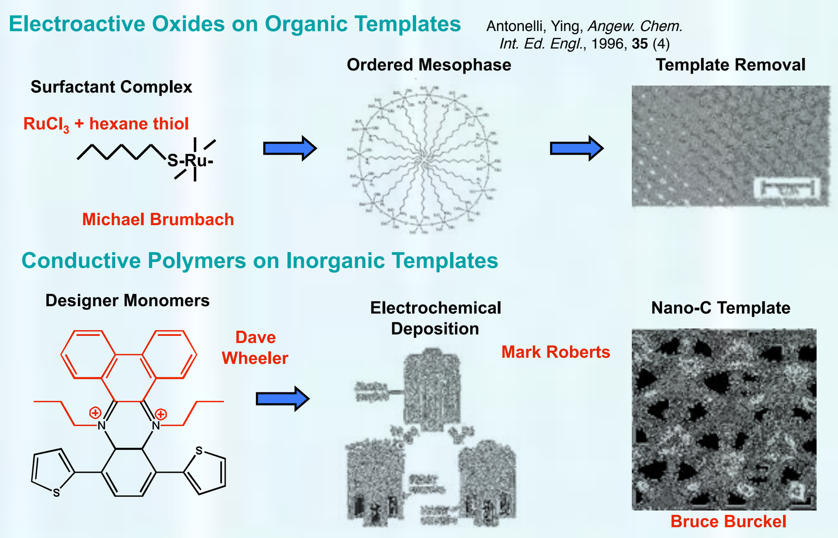


Batteries: High energy density, low power density.
Capacitors: High power density, low energy density.
Ultracapacitors: High power and energy densities.

Nano-architectures are desired that:
- Maximize electrode:electrolyte contact.
- Utilize all active material.
- Mix inorganic, organic components.

Approach

Solution Synthesis on Organic and Inorganic Templates



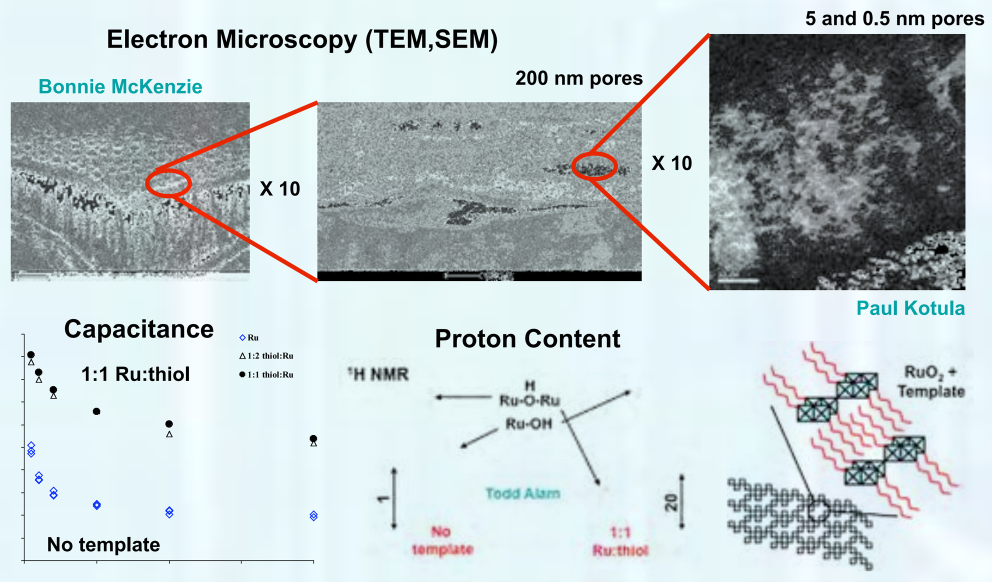
Templates organize electroactive materials at the nano-scale.

Solution-based processing methods are being used to deposit: 1) electro-active oxides on organic templates, 2) conductive polymers on inorganic hosts, and 3) nano-architectures containing intermingled phases such as proton and electron conductors. Examples illustrating each approach are shown (left).

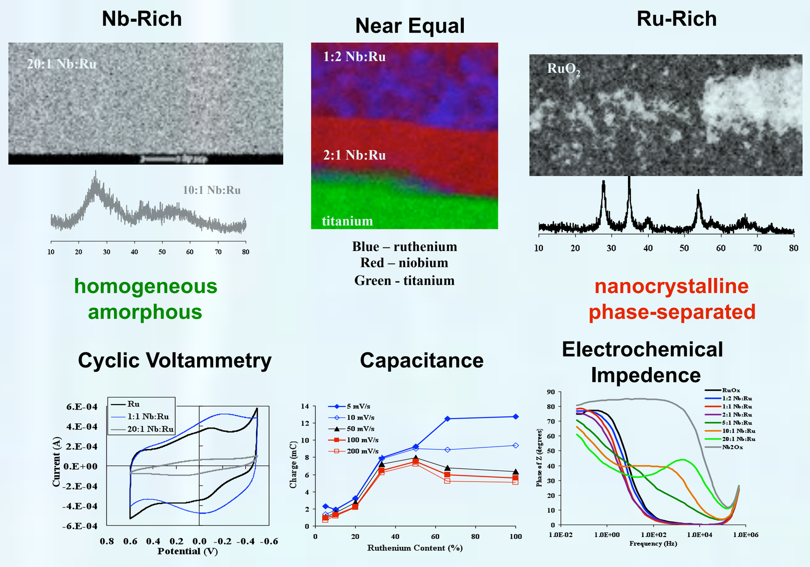
Results

RuO_2 on Surfactant Templates

The hexane thiol template:
1) complexes with dissolved ruthenium species for deposition,
2) generates hierarchical porosity during thermal processing, facilitating access to electrolyte solutions, and 3) sterically inhibits oxide polymerization, leading to a nano-architecture containing molecular clusters with high hydroxyl concentrations, proton conduction, and enhanced capacitance.



Mixed RuO_2:Nb_2O_5 Nanocomposites

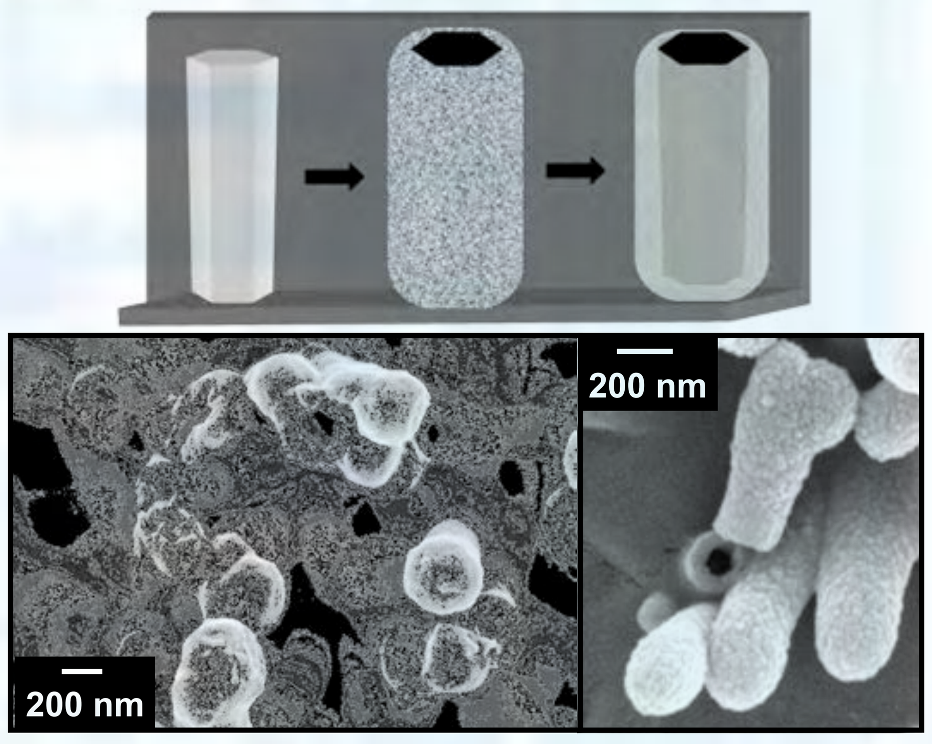


Transition in phase behavior seen near Nb:Ru = 1.

Nano-architectures containing both RuO_2 and Nb_2O_5 have been created by coating substrates with soluble precursors of both constituents. Electrochemical measurements show that the performance of electro-active RuO_2 is boosted due to enhanced proton conductivity associated with the Nb_2O_5 phase.

Results (cont.)

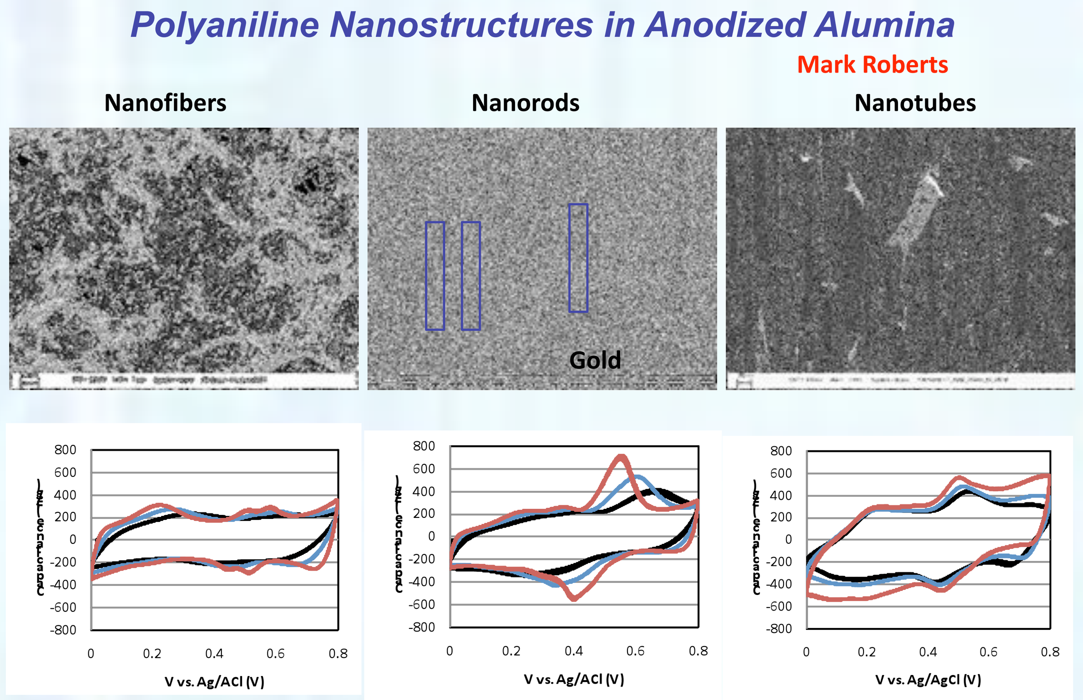
RuO_2 on Inorganic Templates



Hollow nanorods of a mixed RuO_2-Nb_2O_5 material were produced by exposing ZnO nanorod arrays to acidic solutions containing both Ru- and Nb-precursors. The precursors quickly deposit on the rods, followed by dissolution of the ZnO to leave behind arrays of hollow rods of electroactive material that are ideal for promoting electrolyte access.

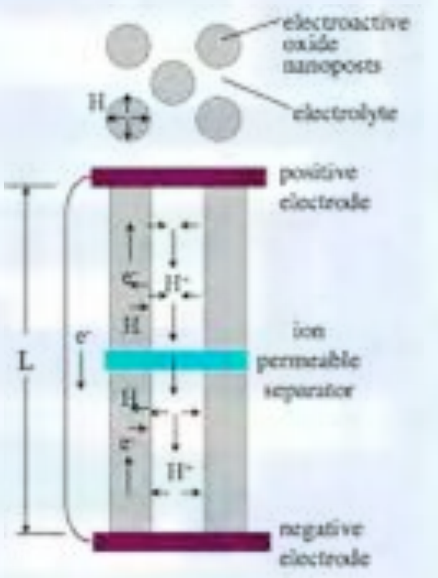
Conductive Polymers on Anodized Alumina

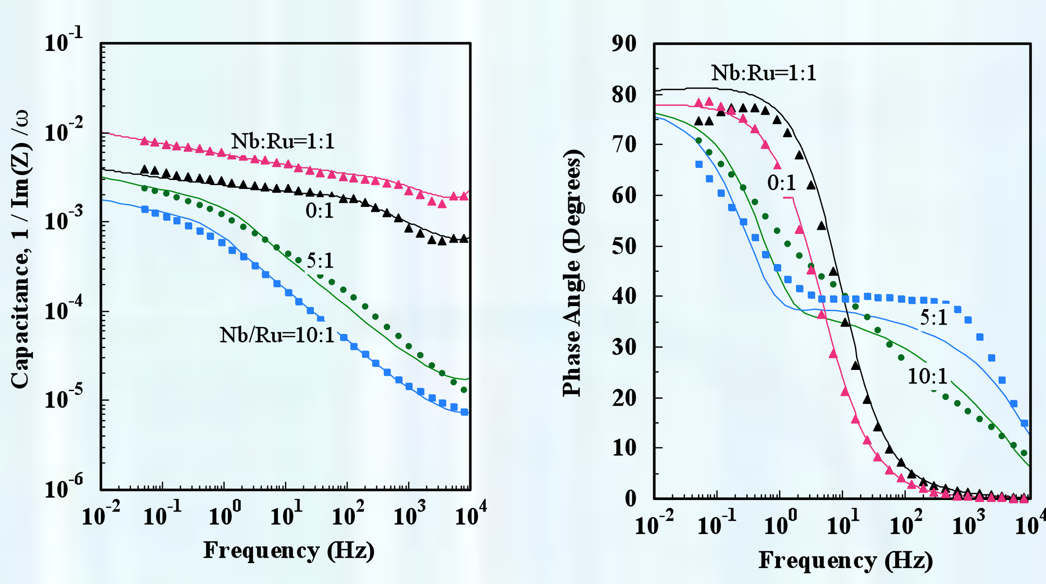
Conductive polymers such as polyaniline have been electrochemically deposited into the nano-pore arrays defined by anodized alumina substrates. Performance testing shows that the architecture can be tuned to orient molecular units, redox activity, and the net capacitance per unit polymer.



Electrical characteristics strongly depend on the nanostructure of the conducting polymer.

Performance Modeling





Mathematical models have been used to analyze performance data and extract information concerning rate limiting parameters such as electron, proton, and electrolyte transport. Conversely, once performance parameters are known, the models have been used to predict nano-architectures that maximize performance.

Significance

The primary advantage of ultracapacitors relative to batteries is the speed at which charge can be stored and released, which translates into higher power.

This study demonstrates that relatively inexpensive solution processing routes can be used to create nano-architectures that boost power by:
1) Minimizing distances required to electron and ion transport within electroactive materials.
2) Maximizing electrolyte access while assuring that ion transport and depletion are not rate limiting.
3) Maximizing the volume occupied by active material to preserve energy density.
4) Mixing active materials at the nano-scale to allow components having different functionalities to work in concert.

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