Nanofabrication Using Viral Biotemplates for MEMS Applications
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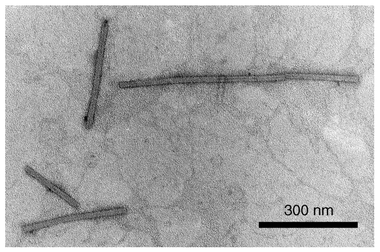
Introduction

The objective of this work is to develop a nanostructured scaffolding using biological materials for the enhancement of microsystems. The nanostructures are used to increase the surface area and binding density of microdevices.

- The Tobacco *mosaic virus* (TMV) was used as template for the fabrication of monodisperse nanorods
- The TMV self-assembly and metallization were used to fabricate a 1st generation nickel-zinc microbattery
- The TMV coat protein was mutated for specific binding of trinitrotoluene (TNT) molecules used in the 1st generation TNT vapor sensor
- Novel core/shell nanocomposite materials with excellent cyclic stability and high capacity were developed and will be integrated in 3D geometries

Tobacco mosaic virus

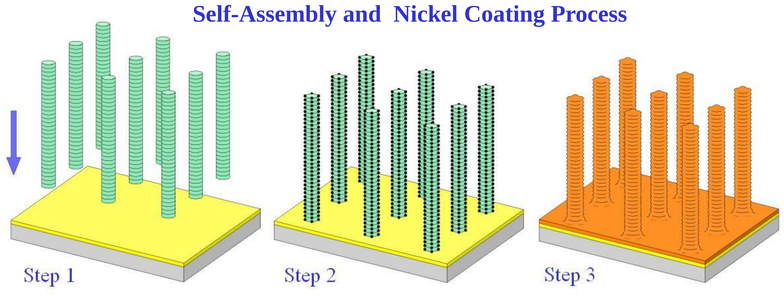
The Tobacco *mosaic virus* is a high aspect ratio nanostructure and a robust biological platform, showing stability in a range of temperatures (up to 60°C) and pH values (2-10). It is renewable in large quantities and has well defined assembly features.



TEM image of wild-type viruses

- The TMV is made useful for the fabrication of high surface area electrodes by genetic modifications of its coat proteins.
- By introducing a cysteine residue in each of the coat proteins the virus can self-assemble onto metallic surfaces through thiol-gold interactions (*TMV-1cys*).
- The surface exposed cysteines allow for electroless nickel deposition.
- Sequence specific peptides can be introduced in the coat protein for specific sensing purposes.

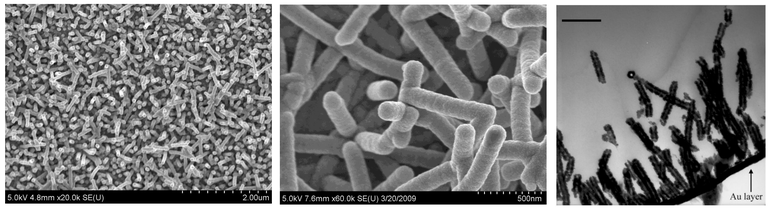
Self-Assembly and Nickel Coating Process



A gold surface is immersed in a TMV solution and allowed to incubate overnight – the viruses self assemble from the bottom end.

The surface of the virus is activated with a palladium catalyst.

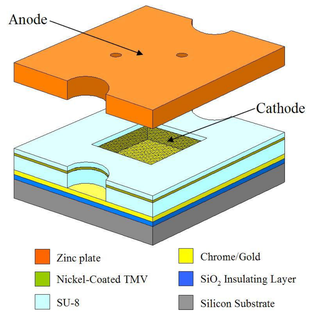
The chip is immersed in a nickel electroless solution and nickel is reduced onto the palladium catalyzed sites.



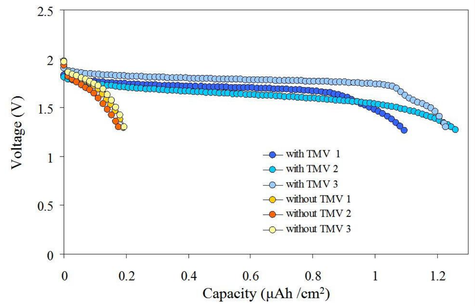
SEM image of nickel-coated TMV vertically aligned on a gold substrate (left), high magnification of metalized viruses showing uniform coating (middle) and cross-section TEM of nickel-coated TMV on a gold substrate (right)

1st Generation Microbatteries

- The cathode consists of nickel-coated TMV nanostructures, the anode is a machined zinc plate, and one molar potassium hydroxide (KOH) is used as the electrolyte.
- The overall device dimensions are 20 mm x20 mm, with active areas of 36 mm2, 64 mm2 and 1 cm2 and electrode spacings of 65 µm and 110 µm.
- A six-fold increase in capacity was measured for devices with TMV-modified electrodes compared to planar nickel cathodes



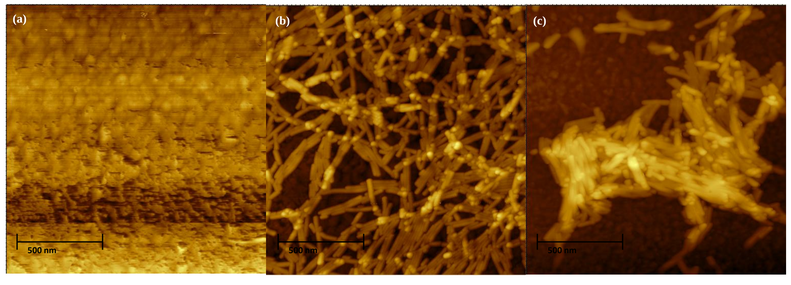
Three-dimensional view of the microbattery layers



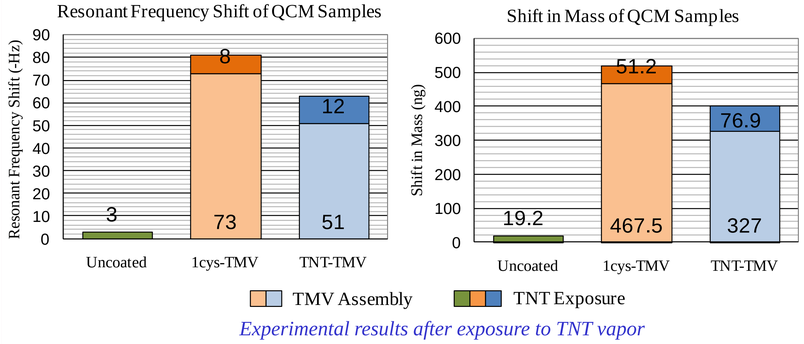
Initial discharges for microbatteries with and without TMV

1st Generation TNT Sensors

- Sequence specific peptide for specific binding to TNT was conjugated onto the surface of the TMV coat protein (*TMV-TNT*)
- Quartz crystal microbalance (QCM) were used to measure the change in mass due to TNT vapor binding
- The *TMV-TNT* showed a 300% and 50% increase in sensitivity were observed over uncoated and *TMV-1cys* coated QCMs
- TMV was used to as a self-assembling scaffolding that increased the sensitivity and selectivity of a TNT vapor sensor



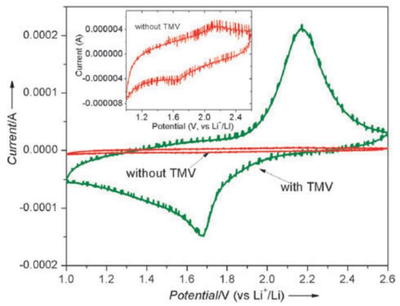
AFM images showing the surface morphology of (a) uncoated, (b) TMV-1cys coated and (c) TNT-TMV coated Quartz Crystal Microbalances (QCM)



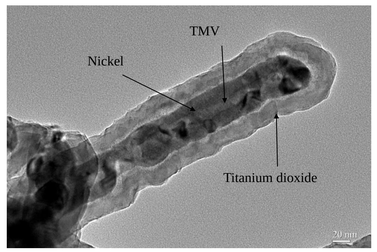
Experimental results after exposure to TNT vapor

Nanocomposite Electrodes with TMV

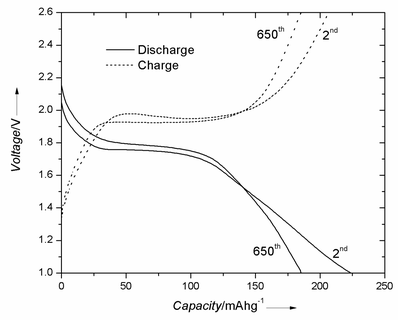
- The nickel-coated TMV can be used a "second" scaffold for the deposition of battery materials using ALD
- As a result, metal/metal oxide core/shell nanostructures can be synthesized; electrodes can be assembled directly onto current collectors without the use of binders and other additives.
- TiO_2-TMV-modified anodes were developed and compared with planar TiO_2 thin films. The nanostructured anodes demonstrate excellent cyclic stability up to 1,000 cycles, higher capacity than the planar films and higher rate capability.



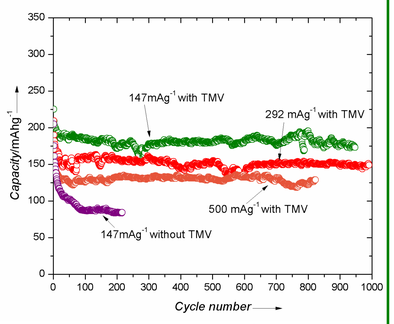
CV scans for electrodes with (green) and without (red) TMV at a rate of 0.5 mVs^{-1}; the inset is an exploded view of the planar sample



Core/shell Ni-TMV/TiO_2 electrode for Li-ion cells



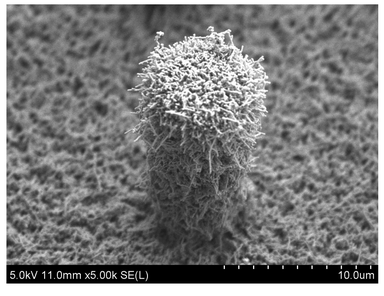
Charge/discharge curves for TMV modified electrodes



Capacity vs. cycle number for electrodes with and without TMV

Current and Future Work

- In current work, the core/shell TMV nanocomposites are assembled onto electroplated microposts to form hierarchical three-dimensional electrodes with micro and nano components.
- In future work, the main goals will be (a) Development of cathode electrodes and electrolytes onto the TMV template, (b) Combination of the process with TMV patterning for full three-dimensional microbatteries, and (c) to integrate TMV-TNT onto an optical resonator for TNT vapor sensing.



Capacity vs. cycle number for electrodes with and without TMV

Acknowledgements

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