Integrated Micro/Nano Systems for Power Conversion, Energy Storage and Sensor Applications

Reza Ghodssi, Herbert Rabin Distinguished Professor of Electrical and Computer Engineering and ISR Director

Affiliated with Bioengineering, Materials Science and Engineering, UMERC, and Maryland Nanocenter

Collaborators: James Culver (IBBR, UMD), Chris Cadou (AERO, UMD), Chunsheng Wang (ChBE, UMD), Xiaobo Tan (ECE, MSU)

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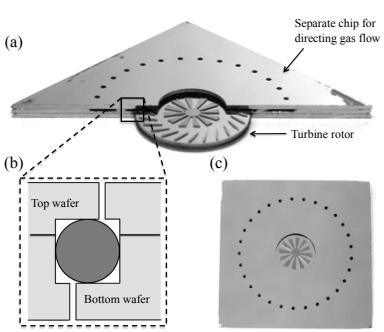
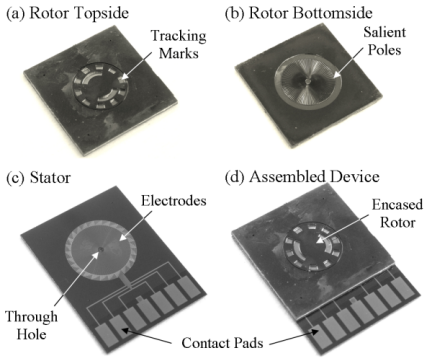
Ball Bearing Supported Micro-Turbo-Machinery for Micro-Scale Power Conversion

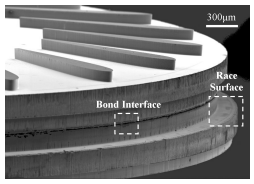
- Microball bearings offer many advantages for the realization of high-performance dynamic MEMS devices such as;
  - reliable and robust support mechanism along with low friction and wear due to the rolling motion
  - stability to achieve speeds up to 100krpm with simple fabrication and integration
- Encapsulated microball bearings have been demonstrated in a silicon microturbine actuated by pressurized gas flow
  - Ball encapsulation is achieved by bonding two silicon wafers with etched raceways and stainless steel microballs in between
- A micro-turbo-pump that utilized the microturbine structure has been developed with a maximum speed of 87krpm
- A ball-bearing-supported electrostatic actuator has been designed for rotary positioning and operated at 0-2000rpm
- Wear and long term reliability of the encapsulated microball bearings is under investigation
  - Negligible performance degradation after 1 week of operation (100 million revolutions)



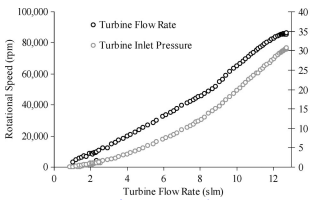
(a) Cut-away view of the fabricated microturbine, (b) Schematic of the encapsulated ball bearings Ø=285μm, (c) Top view of the device



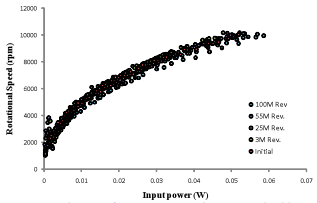
Photographs of the electrostatic actuator showing salient poles on the encapsulated microball bearing supported rotor and discrete electrodes on the stator



SEM image of the rotor periphery identifying the race surface and the sidewall bond interface locations exhibiting wear.



Micropump performance curve demonstrating a maximum speed of 87krpm

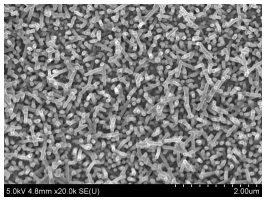


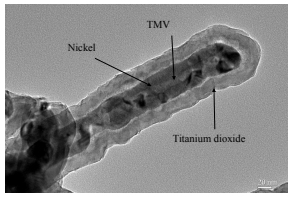
Microturbine performance curve showing negligible drift after one week of operation at 10krpm (100M rev.)

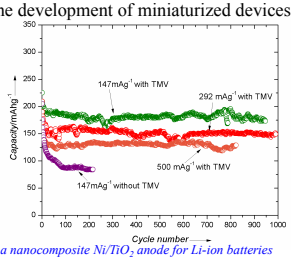
- A ***micro-turbo-generator*** is currently being designed exploiting the advantages of encapsulated microball bearings,
  - Permanent magnets are integrated into the microturbine along with low resistance stator coils for electromagnetic induction
- The microgenerator will be integrated with a miniature/micro-scale heat engine to utilize hydrocarbon fuels that possess energy densities up to 50MJ/kg, and to convert the chemical energy into electrical power for portable systems
- This ***high-energy-density*** and ***low-weight*** power system will be used for applications such as micro flying vehicles where hydrocarbon fuel is readily available, and is expected to improve the performance and operation time of the overall system

Nanomanufacturing Using Viral Nanotemplates For Energy Storage and Sensor Applications

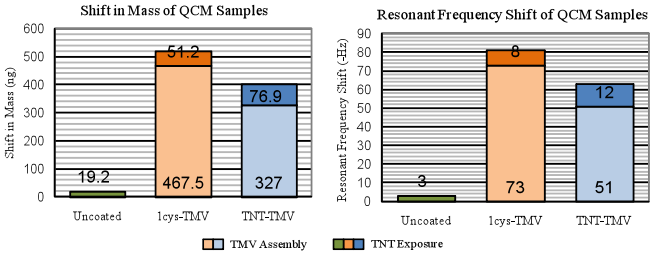
- The *Tobacco mosaic virus* (TMV) is used as a template for the synthesis of composite nanostructured materials
- Genetic modifications allow incorporation of functional groups with enhanced metal binding properties that enable self-assembly onto gold substrates and electroless coating (TMV1cys particle); alternatively, peptides with specific binding affinity to explosive molecules such as TNT can be fused to the TMV (TNT-TMV)
- These modified nanoparticles can be used as active materials for microbatteries or explosive detection sensors and improve energy density and selectivity/sensitivity respectively
- This "toolbox" of materials/processes is integrated with microfabrication for the development of miniaturized devices



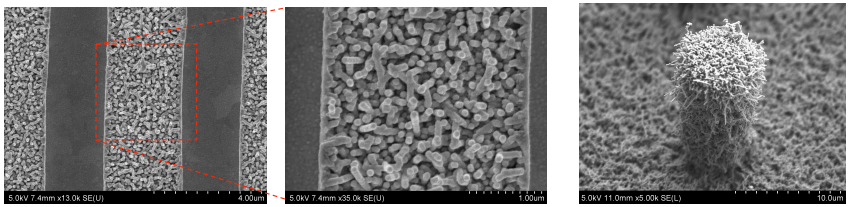




SEM image of nickel-coated TMV vertically aligned on a gold substrate (left), cross-section TEM images of a nanocomposite Ni/TiO_2 anode for Li-ion batteries where active material is deposited on the template usine ALD (middle) and cross-section TEM of nickel-coated TMV on a gold substrate (right)



Characterization of Quartz Crystal Microbalance (QCM) sensors for the attachment of TNT molecules. Uncoated, TMV1cys-coated and TNT-TMV coated devices were used. The TNT-TMV modified QCMs showed the higher increase in resonant frequency mass even though the mass of the virus was less compared to the 1cys-TMV case, indicating the significant increase in sensitivity.



SEM image of nickel coated TMV arrays patterned on a silicon wafer using lift off (left, middle) and SEM image of a polymer micropillar uniformly textured with nanostructured materials; these processes show the feasibility of selectively patterning TMV materials in microfabricated devices and complex 3D geomtries

- In current work, the TMV nanostructured materials are integrated with the biofabrication processes for the development of microbatteries with 3D hierarchical electrodes (micro+nano components) and optical nanosensors for explosive sensing
- Overall, this interdisciplinary research bridges the worlds of biology/protein engineering and micro/nano fabrication through the combination of bottom-up self-assembly and top-down micromachining
- The approach is simple, batch-manufacturing compatible and versatile as it can be used in a large range of technological and scientific applications