Microbatteries and Advanced Thermoelectrics

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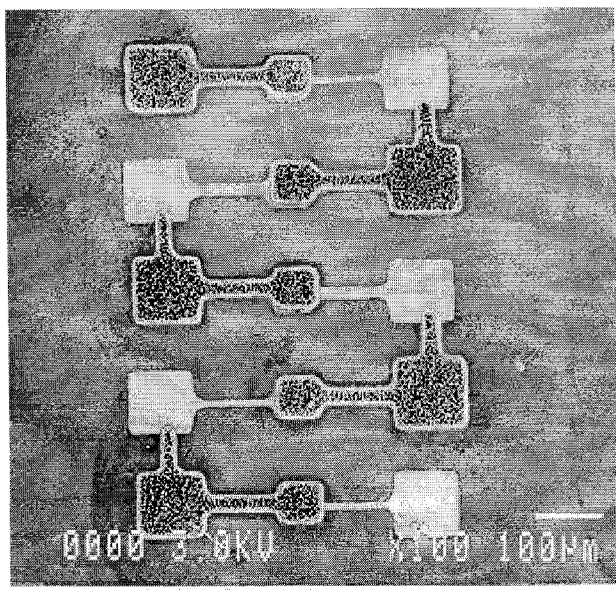
Thin Film/Micro Battery Development

Development effort:

Thin solid state Li batteries (<10 μm) with footprint determined by power demand:

- Thin film battery: (0.1 - 5 cm)^2
- Micro battery: (1 - 100 μm)^2
- Provides continuum of programmable voltages (≥4V) and currents (1 nA - 10 mA)

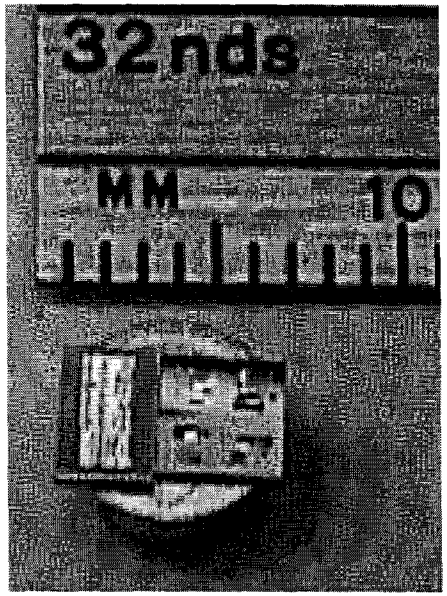


Advantages of Materials System:

- Leak-proof, safe
- Robust to temperature extremes, shock
- Outstanding cycle life
- High voltage (4V/cell)

Motivation

- Currently, there is a dearth of options for low mass, low volume ***integrated*** power sources for micro/nanospacecraft (e.g. coin cell powered MEMS device at right).
- S.O.A. Li batteries are not solid state, are sensitive to temperature extremes, and cannot be integrated directly on-chip.
- Thin film/micro batteries may provide power for:
  * Rad-hard battery-backed SRAM non-volatile memory
  * Distributed micro-sensors
  * MEMS devices
  * Ultra-low noise voltage leveling/reference for sensitive analog sensors
- Ongoing efforts include studies of alternate deposition techniques for large (several orders of magnitude) improvement in capacity

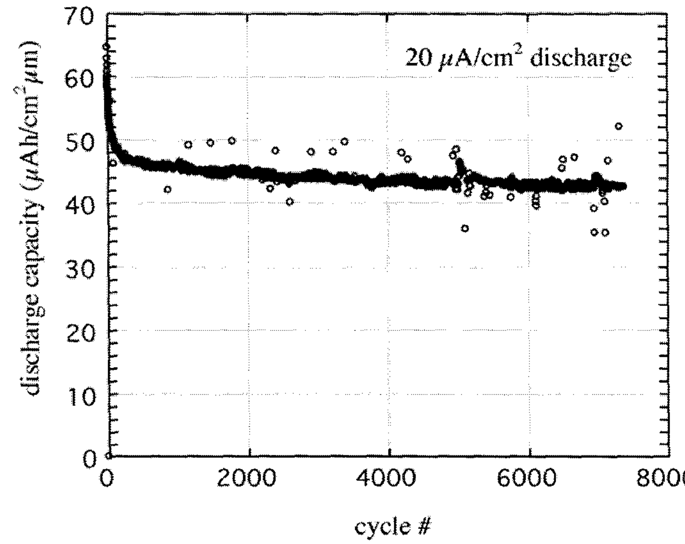


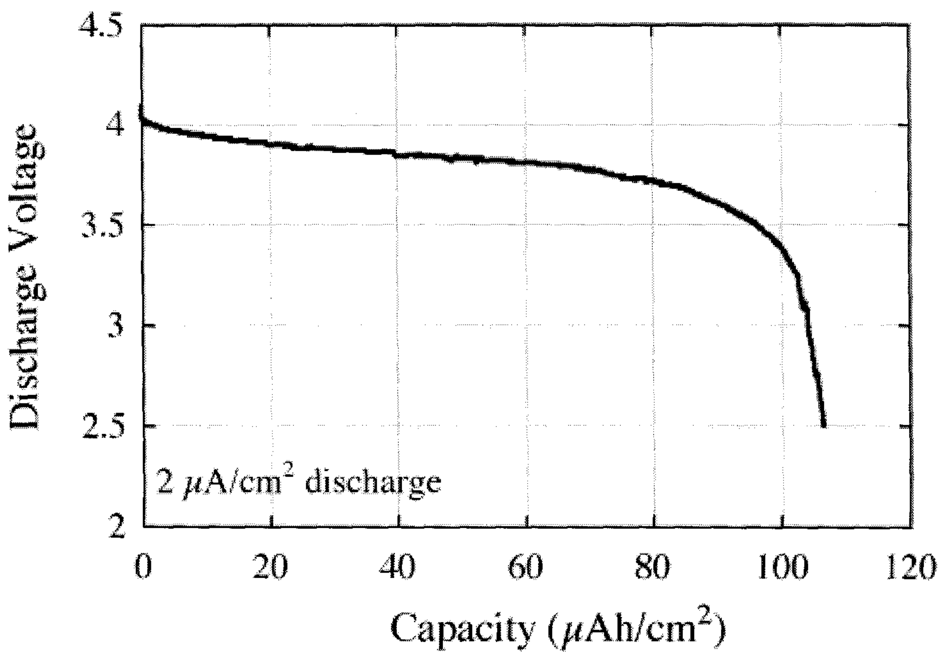
UC Berkeley optical transmitter on a coin cell
(http://robotics.eecs.berkeley.edu/%7Epister/SmartDust/)

Technology Products

Thin film batteries:

•Prepared on variety of substrates: (e.g. Si, silica, Kapton)
•Capacity scales with area, thickness
  °typical: 100 uA-hr at 3.8V for 1 cm^2 cell
•Hermetically sealed with Parylene films





Micro batteries:

•Prepared on Si substrates
•Fabricated in lots of 20,000/ 4" substrate
•Easily fabricated in parallel or series arrangement
•Capacity scales with area, thickness
  °typical: 1 nA-hr at 3.8 V for (100 μm)^2 cell
•Hermetically sealed with Parylene films

Team Skills and Laboratory Capabilities

Team skills:

- Microdevice fabrication
- Thin film deposition:
  - °RF/DC sputtering
  - °thermal evaporation
  - °spray deposition
  - °CVD
  - °electrodeposition
  - °sol-gel
  - °solvent/spin casting
  - °electrophoretic deposition
- Solid state electrochemistry
- Flight battery design and testing
- Novel battery development

Laboratory Processing Tools:

- Photolithography equipment:
  - °Photomask aligners
  - °Photoresist spinners
  - °Photoresist processing labs
- RF/DC sputter chamber
- Parylene CVD chamber
- Thermal evaporator (in dry room for Li metal or other H_2O reactive films)
- Ar glove boxes
- Electrochemical equipment:
  - °Automatic battery cyclers
  - °Potentiostats/galvanostats
  - °Frequency response analyzers

Ongoing Collaborations

Materials Development:

- Caltech: XRD, EELS, XPS, ICP-MS, SEM, TEM characterization of materials
- Stanford Synchrotron Radiation Laboratory: Synchrotron radiation studies of cell components
- Chemat Technology: Industrial partner developing novel solid electrolytes/ thin film supercapacitors

Charge Electronics Design and Implementation:

- University of Idaho
- Mississippi State University

Technology Insertion:

- NASA Johnson Space Center: Micro-Wireless Instrumentation System (μ-WIS) integration
- NASA Goddard Space Flight Center: Micro-power source testing

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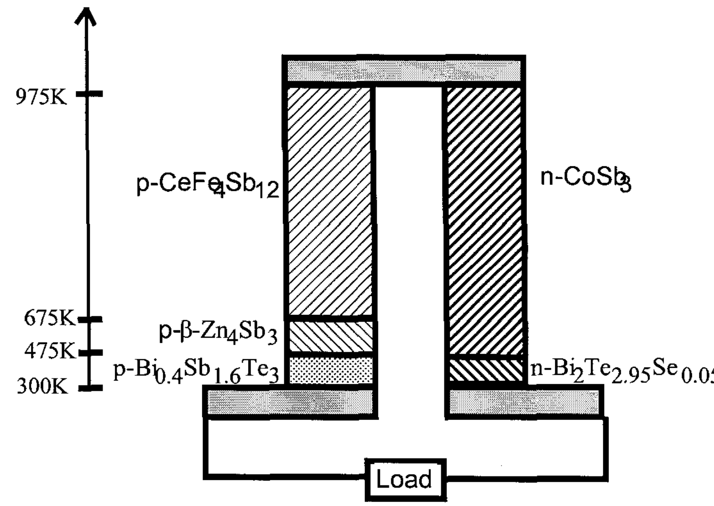
Segmented Thermoelectric Generator

- A segmented thermoelectric unicouple incorporating advanced thermoelectric materials with superior thermoelectric figures of merit has been fabricated and tested at JPL.
- These measured power conversion efficiencies are approximately double those of traditional thermoelectric unicouples.
  - These unicouples would significantly reduce the mass of thermoelectric power conversion systems for deep space missions.

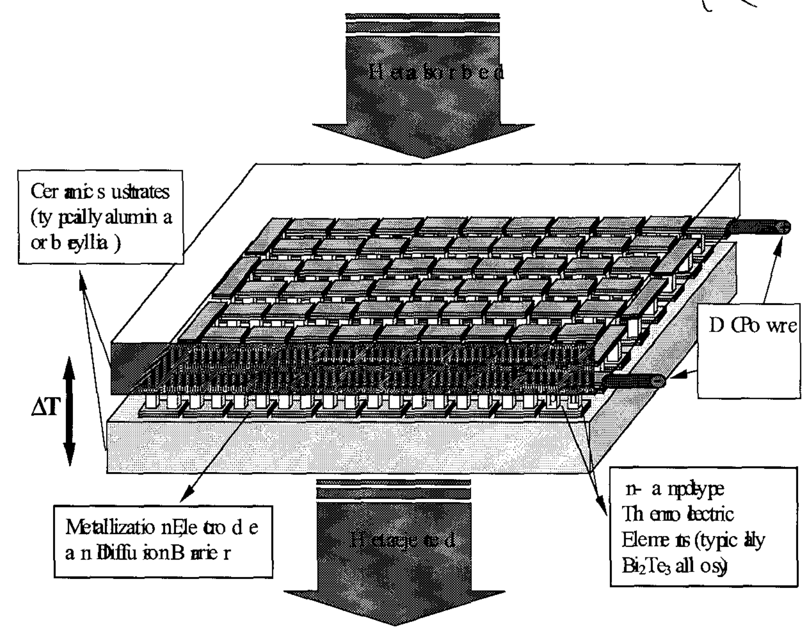


•A conversion efficiency of about 10% has been experimentally determined for this unicouple operating at a hot-side temperature of about 600°C and a cold side temperature around room temperature.

Thermoelectric Microcoolers

Pat. # 09-017,211
NTR 20472

- Electrochemical deposition of Bi_2Te_3, $Bi_{2-x}Sb_xTe_3$ and electrochemical co-deposition of Co/Sb films has been done successfully from novel pH 7 (neutral) solutions
  - The use of neutral, rather than conventional strongly acidic solutions, makes it possible to deposit thermoelectric compounds on a wide variety of substrates and templates, near room temperature and at a high rate.
- These thin film materials are being incorporated into thermoelectric microcoolers which are expected to be capable of cooling power densities up to two orders of magnitude better than state of the art.



Thermoelectric Nanowires

- Bi_2Te_3 thermoelectric nanowires & nanostructures have recently been successfully electrodeposited from aqueous solutions using nanoporous templates and nanotubes obtained from various JPL partners.
- These thermoelectric nanowires will use quantum effects to substantially increase figures of merit for thermal-to-electric micropower and nanopower generation.