

Introduction

Micro-electromechanical systems (MEMS) and their proposed smaller counterparts, nano-electromechanical systems (NEMS), have great potential commercial importance in micro and nanoscale motors, pumps, relays and other components. However, for these minute systems to be fully-utilized, autonomous devices they need self-contained miniaturized power sources. One potential source of energy that has received relatively little study at the nanoscale is the common battery discovered by Volta in the 1800s. Previous studies in the literature referring to nano or microbatteries have dealt almost exclusively with thin film work. For instance, Bates et al. have made thin-film microbatteries by a deposition technique using a metallic lithium electrode layer with a solid Li_3PO_4 electrolyte [1]. However, these batteries have lateral dimensions greater than a centimeter which would restrict their use in many micro and nanoscale applications. Reducing the size of the electrodes would thus increase their utility.

Reducing the size of battery electrodes to the nanoscale not only allows their use in autonomous nanodevices, but also has potential performance advantages as well. Martin and his group have shown that nanoscale electrode materials typically show higher capacities, lower resistance, and lower susceptibility to slow electron-transfer kinetics than standard electrode configurations [2-5].

This work involves the fabrication of and characterization of microbattery and nanobattery systems that have electrode dimensions from around one μm down to the nm regime. The work described combines some of the aspects of nanoporous template technology combined with porous membrane electrolyte materials. We have used this combination of techniques to develop complete nanobattery systems that can be characterized and modeled.

Results

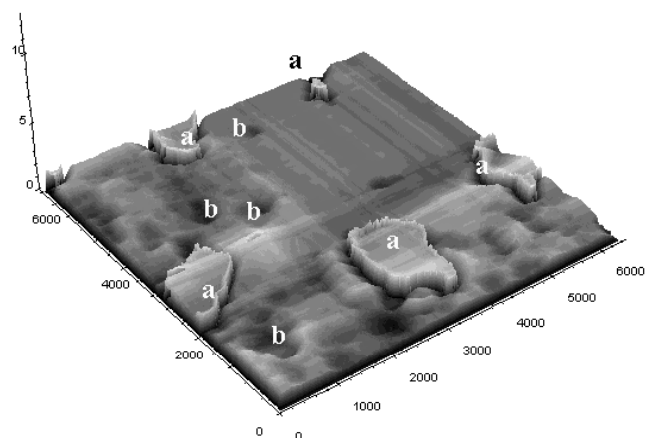
The body of the micro and nanobatteries where the electrolyte is contained, was made using commercial filtration membranes that have pores from one μm to 20 nm in diameter. We have successfully filled membranes (60 to 6 μm thick) having pores ranging from 200 nm to 20 nm, with poly(ethylene oxide), PEO, polymer electrolyte materials. This was done either by extrusion of the molten polymer through the membrane, by using capillary forces to "pull" the liquid molten polymer through the pores, or solvent casting. Interestingly, our preliminary work has shown that polymer electrolytes confined in these tiny pores have higher ion conductivities than pure films of the same electrolyte material. Since there is a constant search for polymer electrolyte materials with high ionic conductivities for use in battery systems, this discovery is very intriguing and another apparent advantage to these nanostructured power sources.

The next step in the process of forming the

batteries is "capping" the electrolyte-filled pores with the appropriate electrode materials. Several materials have been used, including microparticles and nanoparticles of graphite and polyacetylene for the anode and sol-gels of V_2O_5 for the cathode.

In one technique we have used a liquid suspension of polyacetylene particles having a particle size that will just cover the membrane pores, which allows the formation of anodes for the nanobattery systems. Some of our initial work has been to place the particles over 200-500 nm sized pores in a polycarbonate membrane. These polymer electrode particles were placed over the pores by pouring a suspension of the particles on the membrane, thereby allowing the solvent to enter and exit the pores while the particles cannot go through the pores and are trapped in the correct position for the electrode arrangement. The result of this experiment is shown in the 6 μm by 6 μm AFM image below where the pores are labeled with "b" and the polyacetylene particles with an "a." By similar procedures or by a nanocoating technique, other electrode materials can be placed over both ends of the electrolyte-filled pores making complete nanobatteries.

In order to study the batteries, gold coated AFM tips are used to make electrical contact with the electrode surfaces. Using the AFM in this manner in combination



with specially developed instrumentation, we have been able to conduct charge/discharge studies as part of our initial characterization of the micro and nanobatteries.

The procedures and materials used for fabrication, the electrochemical techniques used for characterization, and the performance of the micro and nanobatteries will be discussed in detail and be related to our previous work in this area [6].

References

1. Bates, G. R. Gruzalski, M. J. Dudney, C. F. Lick, H.-h. Yu, and s. D. Jones, *Solid State Tehcnology*, **36**, No 7, 59 (1993).
2. N. C. Li, C. J. Patrissi, G. G. Che, and C. R. Martin, *J. Electrochem. Soc.*, **147**, 2044 (2000).
3. N. C. Li, C. R. Martin, and B. Scrosati, *Electrochem. And Solid State Lett.*, **3**, 316 (2000).
4. V. M. Cepad, J. C. Hulteen, G. Che, K. B. Jirage, B. B. Lakshmi, E. R. Fisher, and C. R. Martin, *Chem. Mater.*, **9**, 1065 (1997).
5. C. J. Patrissi and C. R. Martin, *J. Electrochem. Soc.*, **146**, 3176 (1999).
6. C. Dewan and D. Teeters, *J. Power Sources*, in press.