Micro-Power Sources Enabling Robotic Outpost Based Deep Space Exploration : W. C. West[1], J. F. Whitacre[1], B. V. Ratnakumar[1], E. J Brandon[1], and G. Studor[2], [1]Jet Propulsion Laboratory (4800 Oak Grove Drive, Pasadena, CA 91109), [2]Johnson Space Center, (2101 NASA Road 1 Houston, TX 77058).

Introduction: Robotic outpost based exploration represents a fundamental shift in mission design from conventional, single spacecraft missions towards a distributed risk approach with many miniaturized semi -autonomous robots and sensors. This approach can facilitate wide-area sampling and exploration, and may consist of a web of orbiters, landers, or penetrators. To meet the mass and volume constraints of deep space missions such as the Europa Ocean Science Station, the distributed units must be fully miniaturized to fully leverage the wide-area exploration approach. However, presently there is a dearth of available options for powering these miniaturized sensors and robots. This group is currently examining miniaturized, solid state batteries as candidates to meet the demand of applications requiring low power, mass, and volume micro-power sources. These applications may include powering microsensors, battery-backing rad-hard CMOS memory and providing momentary chip back-up power.

Technical Approach: The requirements of micro-power sources for robotic outpost applications are high specific energy, high energy density, robustness to temperature extremes and mechanical shock, long cycle life and long storage lifetime. Furthermore, the system should be capable of being integrated directly on an integrated circuit for low noise on-chip power, voltage leveling and voltage referencing. The solid state lithium battery system most fully meets these requirements. This battery design consists of thin films of a $LiCoO_2$ cathode, lithium phosphorous oxynitride (LIPON) solid electrolyte, and a lithium anode. The process of RF sputtering and thermally evaporating these layers to fabricate a thin film solid state battery was first developed at Oak Ridge National Laboratories.[1] However, the ORNL process requires the thin film battery cathode to be annealed at 700°C to achieve desired crystallinity and high capacity. This high temperature processing step precludes on-chip integration of the battery, or use of heat sensitive substrates. A process has been developed in our laboratories to achieve high capacity cathode performance with a 300°C anneal, which is much more compatible with back-end IC processing. [2]

Results: The thin film batteries have many attractive features such as high voltage (3.9V/cell), high capacity (65 μA-hr/μm-cm^2) and excellent cycle life (>7000 cycles) as shown in Fig. 1. As a means of comparison, thin film batteries with footprints of approximately 1 cm^2 can power devices such as electronic thermometers for several hours on a single discharge cycle.

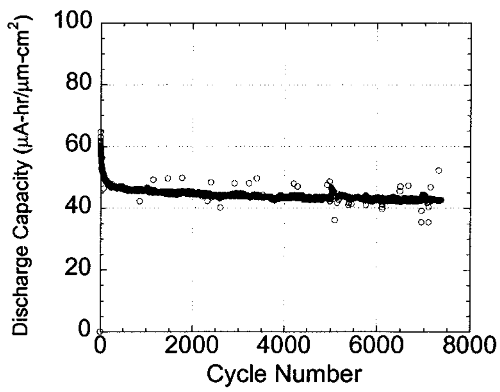

Fig. 1. Discharge capacity as a function of cycle number. This cell was cycled continuously for approximately three months.

The thin film battery fabrication process has recently been modified to yield cells with active area on the order of tens of microns on a side, as shown in Fig. 2. Using conventional microelectronic fabrication techniques such as photolithography, wet etching, and ion milling, the cells can be prepared in both parallel and serial arrangements, yielding a suite of available voltages and capacities.

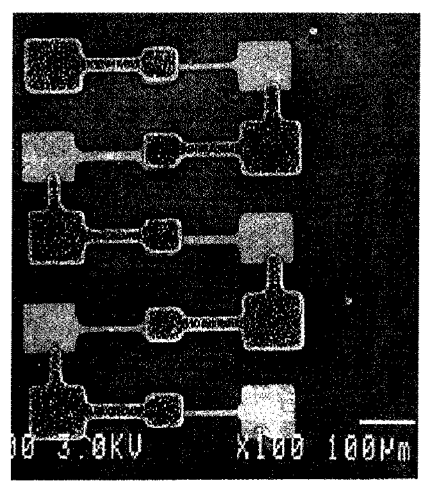

Fig. 2. Array of micro batteries fabricated on a Si substrate.

References: [1] See for example: B. Wang, J. B. Bates, F. X. Hart, B. C. Sales, R. A. Zuhr, and J. D. Robertson, *J. Electrochem. Soc.*, **143**, 3203 (1996). [2] J. F. Whitacre, W. C. West, B. V. Ratnakumar, and E. J. Brandon, submitted to *J. Electrochem. Soc.* (2001).