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CRADA Final Report
for CRADA Number ORNL/94-0264

Development of Thin-Film Battery Powered Transdermal Medical Devices

J. B. Bates
(Principal Investigator)
Oak Ridge National Laboratory

T. Sein
Teledyne Electronic Technologies

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C/ORNL/94-0264

CRADA Final Report
for
CRADA Number 94-0264
with
Teledyne Microelectronics

DEVELOPMENT OF THIN-FILM BATTERY POWERED TRANSDERMAL MEDICAL DEVICES

J. B. Bates
Oak Ridge National Laboratory

TELEDYNE
ELECTRONIC TECHNOLOGIES
Medical Devices
A Allegheny Teledyne Company

12964 Panama Street
Los Angeles, CA 90066-6534
Phone: 310.822.8229
Fax: 310.577.3805

7/6/99

IN REPLY REFER TO:
5153/PMO: 07-099-001

Dr. John Bates
Solid State Division
Oak Ridge National Laboratory
P.O. Box 2008, MS-6030
Oak Ridge, Tennessee 37831-6030

Subject: CRADA No. ORNL 94-0264

Dear John,

Teledyne has reviewed the CRADA number ORNL 94-0264 (Development of Thin Film Battery Powered Transdermal Medical Devices with Teledyne - Final Report) and ascertain that it does not contain protected information and can be released.

Sincerely yours,

TELEDYNE ELECTRONIC TECHNOLOGIES

Tin Sein
Program Manager
Medical Devices SBU

CRADA No. ORNL 94-0264
with
Teledyne Microelectronics
for
Development of Thin-Film Battery Powered Transdermal Medical Devices
Final Report

J. B. Bates

Oak Ridge National Laboratory

Abstract

Research carried out at ORNL has led to the development of solid state thin-film rechargeable lithium and lithium-ion batteries. These unique devices can be fabricated in a variety of shapes and to any required size, large or small, on virtually any type of substrate. Because they have high energies per unit of volume and mass and because they are rechargeable, thin-film lithium batteries have potentially many applications as small power supplies in consumer and medical electronic products. Initially, the objective of this project was to develop thin-film battery powered transdermal electrodes for recording electrocardiograms and electroencephalograms. These "active" electrodes would eliminate the effect of interference and improve the reliability in diagnosing heart or brain malfunctions. Work in the second phase of this project was directed at the development of thin-film battery powered implantable defibrillators.

Objectives

The objectives of this project were the development of transdermal and implantable medical devices that could be powered by the thin-film batteries developed at the Oak Ridge National Laboratory.

Benefits to DOE Missions

The work carried out in this project was part of a larger program in the Solid State Division of ORNL aimed at developing new thin-film materials for lithium and lithium-ion batteries. Therefore, this project supported ORNL's core competencies in Advanced Materials, Synthesis and Processing, Energy Production, and End Use Technology. This project also significantly enhanced the prospects for commercialization of thin-film batteries.

Work Performed

Phase 1

Heart and brain activity are monitored by measuring microvolt signals developed on the surface of the skin. Existing electrocardiogram (EKG) and electroencephalogram (ECG) recording units measure these small signals using electrodes attached to the skin. The long cables attached to the electrodes act as antennas, so the EKG or ECG signals often are corrupted from pickup from fluorescent lights and other sources of spurious AC signals. Through their work for NASA, Teledyne Electronic Technologies has developed specialized equipment for measuring the EKGs and ECGs of astronauts in space. The present CRADA originated from their idea to incorporate a thin-film battery powered preamplifier into the transdermal electrodes for commercial units so that the small EKG and ECG signals could be amplified before transmission to the recording unit. By incorporating thin-film batteries into the circuit to power the amplifiers, no

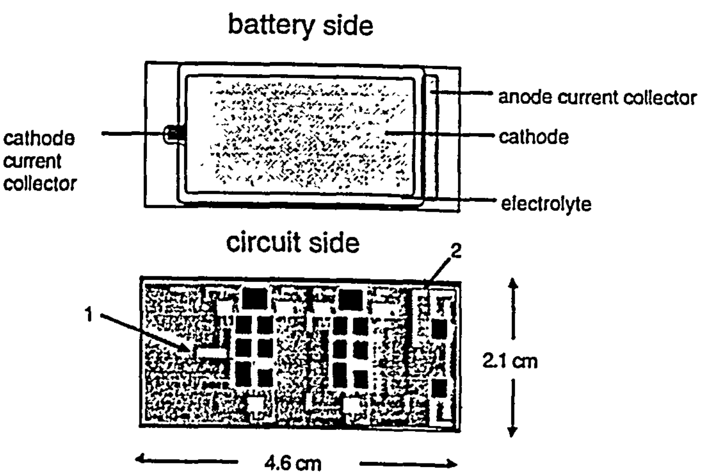

Fig. 1. Layout of the thin-film battery fabricated on the backside of the multichip module package. Connection of the battery to the circuit on the front side was made with Au plated through holes which contacted the traces 1 and 2 indicated by the arrows.

change to existing EKG or ECG recording equipment or increase in the size of the electrodes is required.

The work carried out in Phase 1 was directed toward the fabrication of thin-film batteries on the reverse side of ceramic packages for multichip modules which were prototypes of the transdermal amplifier. A schematic drawing of the front and backside of the device is shown in Fig. 1. At ORNL, research on laboratory-sized thin-film Li-$LiMn_2O_4$ and Li-$LiCoO_2$ batteries was carried out to establish their performance characteristics under the conditions that simulated Teledyne's requirements. Details regarding the fabrication of the batteries have been given elsewhere [1,2]. In particular, the investigations included a determination of capacity decrease on cycling using the discharge and charge current densities appropriate to Teledyne's device. The data obtained from these investigations provided the basis for designing prototype batteries having the desired properties. To operate their device, Teledyne requested a battery that could supply 160 μAh above 3.4 V for 500 cycles at a discharge current of 20 μA. The battery was to be charged at the short circuit rate. A Li-$LiCoO_2$ cell with a 0.6 μm thick cathode fabricated on the backside of a multichip module package could supply more than 190 μAh at a current of 20 μA and a minimum potential of 3.8 V (Fig. 2). If the cathode thickness should be increased to 2.5 μm as typical of our present Li-$LiCoO_2$ cells, the capacity of a battery with the same active area would be 840 μAh. On cycling between 4.2 V and 3 V, the capacity loss was negligible, and so cell retained its capacity of 190 μAh after 500 cycles.

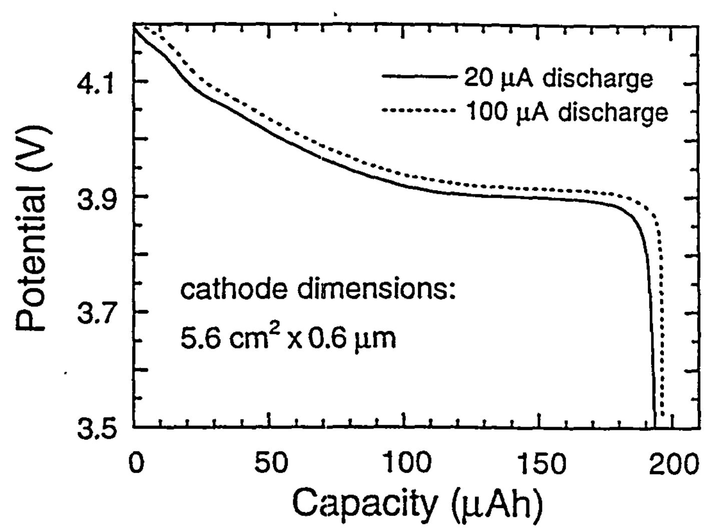

Fig. 2. Charge and discharge curves of a Li-$LiCoO_2$ battery fabricated on the backside of a multichip module.

Phase 2

Two of the important features of thin-film lithium batteries are their very high energy and power densities. In a joint project with Angieon Corporation and Teledyne, research in the second phase of this project sought to utilize these properties in the development of an implantable defibrillator powered by a thin-film rechargeable lithium battery. Based on laboratory experiments with 1 cm^2 cells, it was apparent that the size of implantable defibrillators could be reduced significantly if the existing primary battery could be replaced with a multicell thin-film battery. In addition, the thin-film battery could be recharged by inductive coupling through the skin and thus should never need to be replaced. The battery was required to produce on a single charge a minimum of five pulses every two seconds each with a minimum energy of 27 J. For the Li-$LiCoO_2$ battery, this translates to 1.5 A pulses of 8.5 s duration having a minimum potential of 2.7 V. Experiments showed that 1 cm^2 thin-film lithium batteries with crystalline $LiCoO_2$ cathodes could deliver on a single charge up to 20 pulses of the required duty cycle and potential with an amplitude of 2.5 mA. For a defibrillator, a thin-film battery therefore would need a total active area of about 600 cm^2.

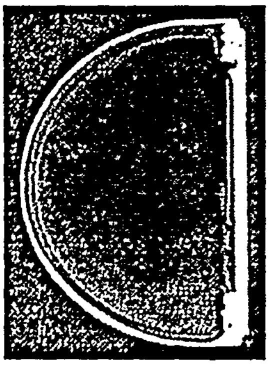

Fig. 3. Thin-film Li-$LiCoO_2$ "D" cell.

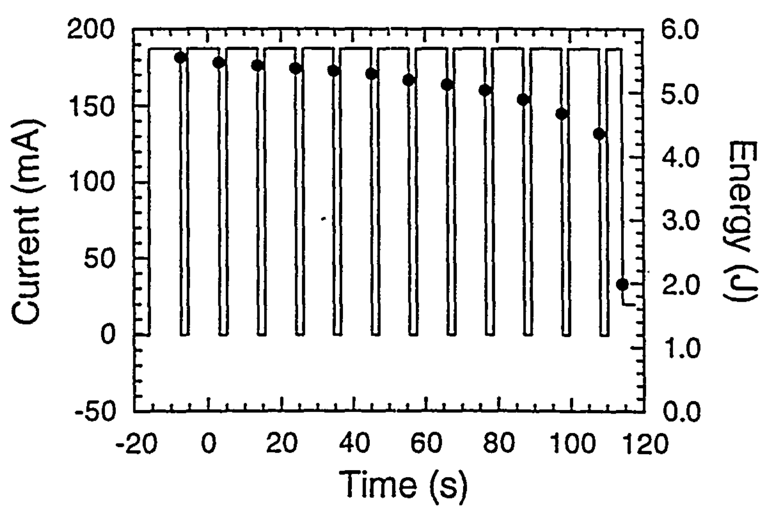

Fig. 4. Pulse testing of a Li-$LiCoO_2$ battery consisting of a parallel connection of ten, 7.5 cm^2 "D" cells. The solid points are the energies at the delivered by each pulse.

"D"-shaped cells (Fig. 3) with active areas of 7.5 cm^2 suitable for an implantable defibrillator were fabricated at Teledyne and ORNL. The current collectors, cathode, and electrolyte were deposited at Teledyne, and the lithium anode and protective coating were deposited at ORNL. Tests were conducted on single cells and on batteries consisting of up to ten cells connected in parallel. A test result for a ten-cell battery with a total active area of 75 cm^2 is shown in Fig. 4. To meet the device specifications scaled to an active area of 75 cm^2, the battery was required to deliver 187.5 mA pulses of the required shape with a minimum energy of 3.4 J per pulse. The results in Fig. 4 show that the battery could deliver twelve of the required pulses before recharge. As expected, these experiments demonstrated that the properties observed for 1 cm^2 cells scaled with increasing area. More importantly, the results of this study showed that thin film batteries could be used in implantable defibrillators resulting in a significant reduction in device size and an improvement in reliability.

Inventions

No inventions originated from this project. The core thin-film battery technology was patented earlier.

Commercialization Possibilties

The work performed in this project demonstrated the applicability of thin-film rechargeable lithium batteries to medical devices. As of this writing, three licenses have been issued, and an additional three are expected to be signed shortly. Pilot production lines are nearing completion at two of the licensees' facilities, and it is anticipated that thin film batteries will be commercially available in 2000. The broad commercial interest in ORNL's thin-film battery technology for application in consumer and medical electronics is partly due to the success in this project.

Plans for Future Collaboration

There are no plans for future collaboration with Teledyne Electronic Technologies.

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DISTRIBUTION

1. J. B. Bates, Excellatron Corporation, Suite J, 1640 Roswell Street, Smyrna, GA 30080
2. T. Sein, Teledyne Electronic Technologies, 12964 Panama Street, Los Angeles, CA 90066-6534
3. N. J. Dudney, Bldg. 3025, MS 6030
4. P. L. Gorman, Bldg. 4500N, MS 6269
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