Session TC4-3

DEVELOPMENT OF MINIATURE Li-Ion BATTERY FOR MULTI-SENSOR CHIP

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Abstract

Li-ion battery is the most sought out battery in the present world because of the ease in making it into desired shape and size and due to its light weight. It is also most efficient in its miniature size unlike other batteries, as it has most energy capacity and its I-V curve is almost flat as an ideal curve. From previous research papers we found V_2O_5 (Vanadium oxide) and $LiCoO_2$ (Lithium cobalt oxide) to be the best electrode materials that can be used in the Li-ion secondary battery. Li-ion batteries are two types: Li-ion and Li-ion polymer batteries. We have chosen LiPON (Lithium phosphorous oxynitride), which is a polymer (non-aqueous) for our electrolyte. The major advantage of a polymer electrolyte is, it can be made into a very thin membrane, flexible and can be sputtered on. For our case we are using the Li-ion secondary polymer battery for a multi-sensor chip. The chip is of dimensions 1cm × 1cm, therefore, there is a need for miniature battery on which the system can piggy back and get bonded. We selected Li-ion polymer battery to be miniaturized for the above said reasons. We are using RF sputtering process, hard bake and soft bake processes to produce the battery. The dimensions of the battery would be in the order of microns. There will be 6 layers in the battery: Si Chip layer, Bottom connection layer, Cathode layer, Electrolyte layer, Anode layer, Top connection layer and a bonding layer. We will be testing for the materials performance of the battery in various conditions and the recharge cycles and capacity of the battery. Our ultimate objective is to produce a miniature Li-ion secondary battery with good performance in all aspects when compared to the other secondary batteries in spite of its size. The procedure for fabricating this battery is presented in this paper.

Introduction

Modern trend towards the miniaturization of electronic (like cell phones) and mechanical devices (like Tesla cars) has increased the demand for smaller power sources such as rechargeable *secondary* Li-ion micro-batteries. Li-ion polymer and Li-ion batteries with features such as good thermal stability and relatively high safety characteristics have been selected for smart cards, RFID tags, remote sensors, semiconductor circuits and military gadgets. Primary Li-ion cells are used for biological applications where charging rates are higher and longer life time is needed and it has a reasonably high voltage. Li-ion micro batteries can vary in shape and size according to the customer's specifications, which is an important advantage. They also have low self-discharge rates of approximately 5% per month at maximum load. In our work for remote sensors with Li-ion power sources, we decided on testing the dry processed electrodes for Li-ion and Li-ion polymer batteries. The main components of the Li-ion battery are anode, cathode and an electrolyte. **Anode:** V_2O_5 anode material has the structure needed to retain large amounts of Li, and could be used as an anode material, but it does not easily form compounds with Li. This problem can be solved by complementary doping the cathode with Lithium ions and migrating them to the anode to achieve the higher battery capacity. We are sputtering V_2O_5 from the target to the patterned anode area. **Cathode:** $LiCoO_2$ is a suitable cathode material for sensor applications. $LiCoO_2$ as a lithium intercalation material has a layered rock-salt structure, and a high operating potential of ~4.0V and gives a theoretical capacity of $69Ah/cm^2/m$ over the range $0.5 \leq x \leq 1$ inLi_xCoO_2 is a suitable cathode material. With fabrication of micro-batteries, processes such as RF magnetron sputtering, ion-beam directed assembly, a sol–gel process and laser ablation techniques are widely used. For our purpose we are employing a R.F magnetron sputtering system to form a thin (less than 5000Å) layer of $LiCoO_2$ as it has better uniformity. **Electrolyte:** An electrolyte can be an aqueous or non-aqueous substance which acts a medium to conduct electricity. Good electrolyte should have the properties like: Good mechanical properties, high ionic conductivity, high lithium ion transport, wide electrochemical stability, low cost, benign chemical composition. Lithium batteries use a special gel type organic electrolyte which works at much lower temperatures than more traditional water-based electrolytes because of its freezing characteristics. The electrolytes which can be used in Li-ion battery are LiPON (Lithium phosphorous oxynitride) or $LiPF_6$ (Lithium floro phosphate). However, after comparing the charge transfer efficiency of $LiPF_6$ to LiPON we chose LIPON is more suitable electrolyte. (*Electrolyte Properties Experience to-date suggests that the present polymer electrolytes can be formed into thin, continuous films (i.e., films substantially free of chemical boundaries and thicknesses from 25 to about 2000 microns). Additionally, these electrolyte films have good specific conductivity (i.e., about 10^{-5} S/cm or smaller, as determined by low voltage measurements at temperatures ranging from about 20°C. to about 100° C.).*

The picture of how the ions in a Li-ion battery move during a charge and discharge cycles is given below:

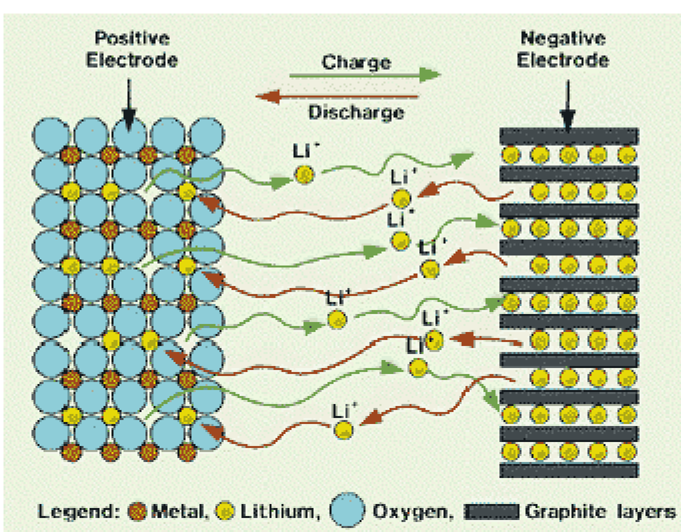

Fig 1: The movement of ions in Li-ion battery during charge/discharge cycles.

During a discharge cycle the ions from the negative electrode (Cathode, which is $LiCoO_2$) moves towards positive electrode (Anode, which is V_2O_5) giving the charge out. During the charging cycle the process is reversed, i.e. The Li ions move from Anode to the Cathode.

Battery Structure and Fabrication

The placement of the battery in the multi-sensor chip structure is as follows.

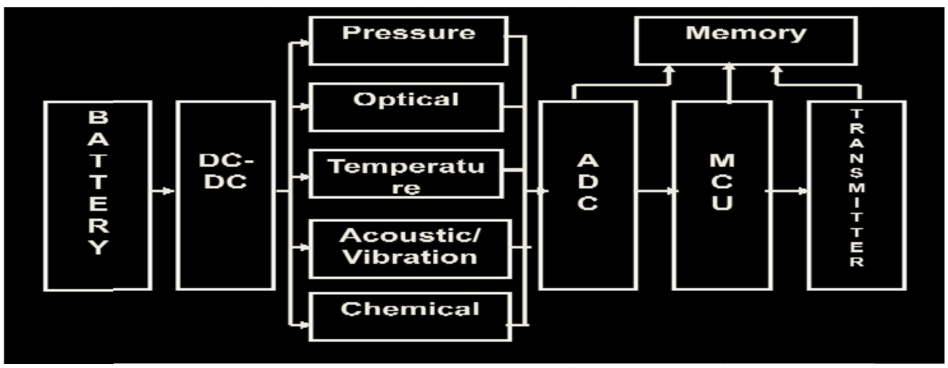

Fig 2: The Multi-sensor chip structure.

We are dealing with a battery to be placed on a micro dimensioned multi-sensor chip as pictured above. Although we are in the process of constructing the secondary Li-ion battery, it is our primary goal to build a miniature Li-ion battery that is to be piggy-backed on the sensor chip. Therefore, the battery dimensions are in the order of 42x26 microns.

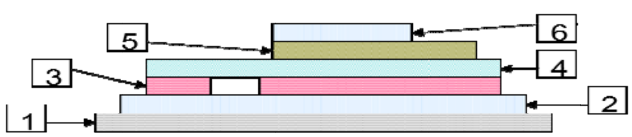

Fig 3: Cross Sectional structure of the Li-ion battery, 1) Si chip layer 2) Bottom connection layer 3) Cathode layer 4) Electrolyte layer 5) Anode layer and 6) Top connection layer

We will be using RF magnetron sputtering to build the battery on the silicon wafer. The wafer will be cleaned with IPA and DI water. Then starting from the bottom connection layer each layer will be sputtered on to the Si wafer using different masks designed to meet the requirements regarding the dimensions of the battery. In the process of building the battery we will use spin on glass techniques to coat each layer with the photo resist then, place the mask and sputter with respective layers using RF magnetron sputtering system and hard & soft bake processes with developers. Finally, when the sputtering of all the layers is done, the photo resist will be cleaned using acetone. The process will be repeated as we progress from bottom connection layer to the top connection layer. The top view of the battery is given in fig (4).

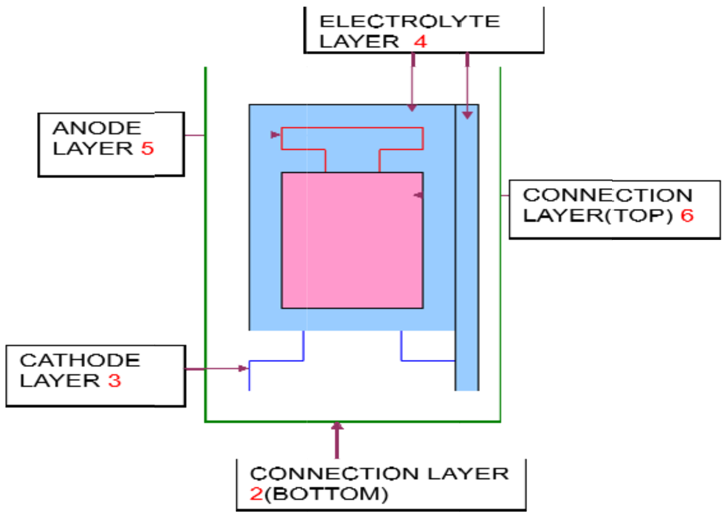

Fig 4: The top view of the Li-ion battery. Layer1 (not shown) is the Si chip layer mentioned in the cross sectional view.

Additives

Though Secondary Li-ion batteries have many advantages like: Higher energy density than most other types of rechargeable, for their size or weight being the lightest metal known they can store more energy than other rechargeable batteries, They operate at higher voltages typically about 3.7 volts, They also have a lower self discharge rates, They will retain most of their charge even after months of storage, etc… There are also some disadvantages like the explosion of the batteries due to heat accumulation with in the battery which is caused by the ion blocks in they electrolyte because of overcharging. This problem can be solved by adding *Additives*. Adding an additive enhances the performance of the battery and reduces the risk of thermal runaway, which results in explosion of the Li-ion batteries. The presence of additives reduces the risk of heat accumulation due to blocks and Joule heating (I^2R), and increases the efficiency of the battery. Through research we found that DMAC (dimethyl acetamide) and NMP (N-methyl pyrrolidinone) are the two additives that can be used in the secondary Li-ion batteries. When experimented with adding different compositions of DMAC and NMP to the electrolyte, it is found through research that the performance of the battery has increased drastically when 3% DMAC is added. The discharge rate of the battery is steadier than in any other case. Further experiments are being conducted to find the results of adding this additive to our battery.

Conclusion

From previous observation it is discovered that there is an ever increasing need for the smaller and smaller power sources for various application. Li-ion battery can provide the solution for the need of the miniature batteries. These can be molded in to any size and shape required for the particular application. We are concentrating on manufacturing the miniature Li-ion secondary battery for a multi-sensor chip with micrometer in size and working on eliminating the problem of thermal runaway using additives like DMAC. As it is already mentioned, the battery is not yet constructed. The material properties are being tested at present. The results will be presented after the construction of the battery is completed.

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