Design, Fabrication and Integration of a Multi Sensor Chip

Joseph Boone Jr., Dr. Pradeep Bhattacharya, Dr. Fred Lacy, Dr. Ernest L. Walker and Dr. Zhengmao Ye

Electrical Engineering Department
Southern University, Baton Rouge, LA 70813
Email: josephboone@engr.subr.edu
Phone: (337) 296-5067

Abstract

Modern sensors are being developed as a tool for homeland security using wireless communications. The design, fabrication, and integration of these modern sensors allow them to react in many different physical and chemical variables simultaneously on a single chip. The Multi Sensor Chip (MSC) is the primary source for the pressure, temperature, chemical, biological and acoustic/vibration sensors. The Multi Sensor Chip is being created through the intent of each sensor being complex in memory, but micro in size to be able to fit onto the single chip. Through the process of sputtering, in which atoms are ejected into a gas phase, the pressure sensor will utilize the properties of Lead zirconate titanate. Lead zirconium titanate (PZT), is a ceramic perovskite material that shows a marked piezoelectric effect - that is, it develops a voltage difference across two of its faces when compressed. It also features an extremely large dielectric constant. These properties make it one of the most prominent and useful electroceramics. It is used to make ultrasound transducers and other sensors and actuators, as well as high-value ceramic capacitors. To detect the temperature the temperature sensor will employ a Platinum resistance thermometer as a thermo resistive device (RTD). A resistance temperature detector measures the relationship between electrical resistance and temperature. As they are robust and have wide ranging temperature linearity they are made of platinum, and they are often called PRTs (platinum resistance thermometers). Through acoustics and vibration modes, these sensors also will go through a fabrication process with PZT as the main element. Thus, a thin bottom acoustic sensor will be used as a vibration sensor to detect high frequency vibrations. The construction of the MSC consists of three subsystems. Forms of this research are suitable in developing miniaturized Li-Ion battery. Lithium-ion batteries pack in a higher power density than Nickel-based batteries. This gives you a longer battery life in a lighter package, as Lithium is the lightest metal. You can also recharge a Lithium-ion battery whenever convenient, without the full charge or discharge cycle necessary to keep Nickel-based batteries at peak performance. (Over time, crystals build up in Nickel-based batteries and prevent you from charging them completely, necessitating an inconvenient full discharge). The power supply contains a rechargeable Lithium Ion Battery and a dc-dc converter. The MSC also involves a sensing subsystem, which connects the node to the physical aspects, an analog to digital converter (ADC), with a computer microcontroller unit. The ADC and microcontroller units will be used as smart interfaces, which will

concentrate on the marriage of laboratory-on-a-chip (LOC) and system-on-a-chip (SOC) techniques.

Introduction

The rapid growth of information, communication, and fabrication technologies is driving the semiconductor industry to extreme altitudes, by emerging portable micro-power applications such as sensors that continue to push technology to cater to small, long lasting, low cost, and fully integrated solutions, fueling the demand for system-on-chip (SoC). Through increasing the efficient density the semiconductor industry is devoting its time to integrate most of the microelectronics necessary to support a system into a single chip. Through design and fabrication, the multi sensor chip will result in several sensors being obtained on a single chip powered by micro Li-Ion batteries. Along with two electrolytes, a two millimeter sized Li-Ion batteries provides 3.7V of output, which are connected in series. The Li-Ion battery is hybridized during the fabrication process of depositing and steam oxidation bonding. Their ability to be fabricated in thin sheets combined with the increasing capabilities of packaging technologies promises to solve some of the chip-integration issues of the self-powered chip paradigm. These batteries can handle the "burst" power load demands that micro-fuel cells are incapable of satisfying. For many years, the Nickel Cadmium (NiCd) was the only suitable battery for portable applications such as wireless communications. In 1990, the Nickel Metal Hydride (NiMH) and Lithium Ion (Li-ion) emerged, offering higher capacities. The Li-ion is a low maintenance battery, which is an advantage that no other chemistry can claim. There is no memory and no scheduled cycling required, thus, prolonging the battery's life. In addition to high energy density and lightweight, the self-discharge is less than half compared to the NiCd and NiMH, making the Li-ion well suited for modern wireless applications. To power the sensors Li-ion nanobatteries are going to be used.

Sensor Structure and Fabrication

MEMS devices refer to mechanical components on the micrometer size and include 3D lithographic features of various geometries. They are typically manufactured using planar processing similar to semi-conductor processes such as surface micro-machining and/or bulk micro-machining. These devices generally range in size from a micrometer to a millimeter. The multi-sensor contains several structures that contain and conform to micro-electro-mechanical systems. The pressure sensor construction involves the process of utilizing a pressure-sensing element that will satisfy its characterization of large pressure changes in the vicinity of the multi-chip. It was determined that lead zirconate titanate (PZT) would be the perfect match for the pressure sensor. This particular sensor is developed through a method known as sol-gel preparation. The sol-gel process is a resourceful solution process for making ceramic and glass materials. In general, the sol-gel process involves the transition of a system from a liquid "sol" (mostly colloidal) into a solid "gel" phase. Applying the sol-gel process, it is possible to fabricate ceramic or glass materials in a form of thin film coatings. The initial materials used in the preparation of the "sol" will be metal alkoxides. In a typical sol-gel process, the precursor is subjected to a series of hydrolysis and polymeration reactions to form a colloidal suspension, or a "sol". Further processing of the "sol" enables one to make a ‘gel’ in the form of a solid ceramic material in different forms. Thin films can be produced on a piece of substrate by spin-coating or dip-coating. When the "sol" is cast into a mold, a wet "gel" will form. With further drying and heat-treatment, the "gel" is converted into dense ceramic or glassy articles. This method is demonstrated in Figure 1.

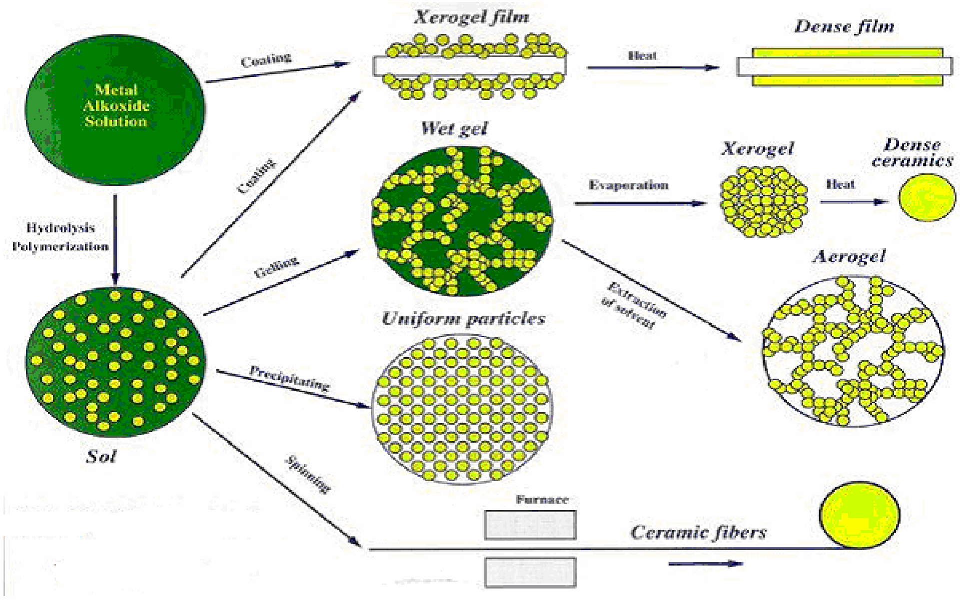

Fig. 1 Sol-Gel Technologies and Their Products

Once the sol-gel method is performed the PZT undergoes a nine-step design and fabrication procedure. These steps range from growing thermal SiO_2 on silicon and depositing the bottom electrode of titanium and platinum, to depositing and etching gold bonding pads.

A thermo-resistive device measures the relationship between electrical resistance and temperature of a thin film. As they are almost invariably made of platinum they are often called PRTs (platinum resistance thermometers). The temperature sensor involves platinum resistance thermometers as its thermo resistive device. Platinum is used because it has excellent high and low temperature characteristics, and stable electrical properties. The platinum will undergo a brief design and fabrication process. This will involve sputtering it into a tiny spiral located on the oxidized silicon. With the spacing of the electrodes being 25µm this is displayed in Figure 2.

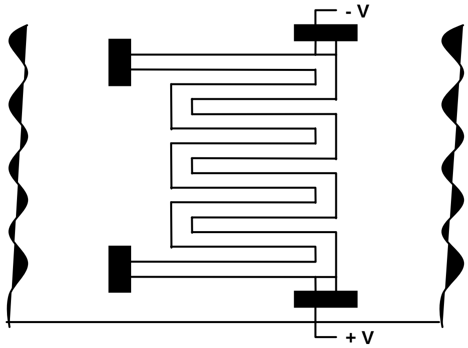

Fig. 2 Spacing of Electrodes 25 μm apart

The PZT material is also used to develop the acoustic sensor. Lithography is used as a method for printing on a smooth surface. X-ray lithography can also be used. It can also refer to a method of manufacturing semiconductor and microelectromechanical (MEMS) systems and devices. As shown in Figure 3 its fabrication process involves the method of lithography to form a window on the back of the silicon substrate. Then the resist is stripped and the oxide layer is etched. Last the PZT films are deposited accordingly. The acoustic sensor can also be used as a vibration sensor to detect high and low amplitude frequency vibrations yielding a piezoelectric signal. All these sensors give analog signals, which are converted to digital pulses and sent through a microcontroller to a transmitter.

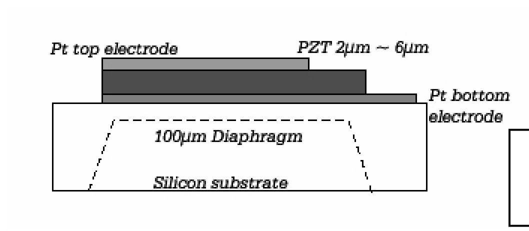

Fig. 3 Acoustic Sensor Fabrication Process

Battery Structure and Fabrication

During structure and fabrication Li-ion cells are typically composed of three major components: cathode, anode, and electrolyte. In the case of the Lithium-ion battery power source the cathode should have adaptation ability and also be a budget saver. The cathode is generally comprised of Lithium-Metal- Oxide, which in this case is $LiMn_2O_4$ spinel. The anode mostly contains a carbon material in the form of carbon nanotubes capable of intercalation and release of lithium ions from and to the cathode. The material carbon is used as the anode, which maintains a high surface area, high cycling capacity, and excellent stability over extended cycling. The electrolyte is lithium phosphor fluoride ($LiPF_6$), which serves as a conductive buffer medium through which lithium ions can be transported to and from the electrodes. As shown in figures 4 and 5 these elements formulate the cell structure of a typical lithium ion battery, and also manipulate the operating mechanism for the Li-Ion batteries.

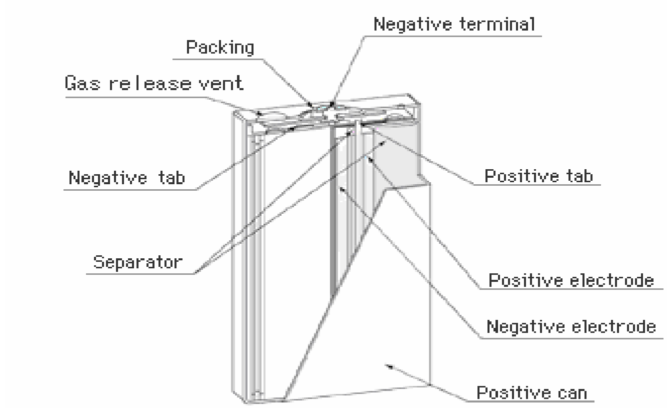

Fig.4 Cell Structure of Typical Li-ion Battery

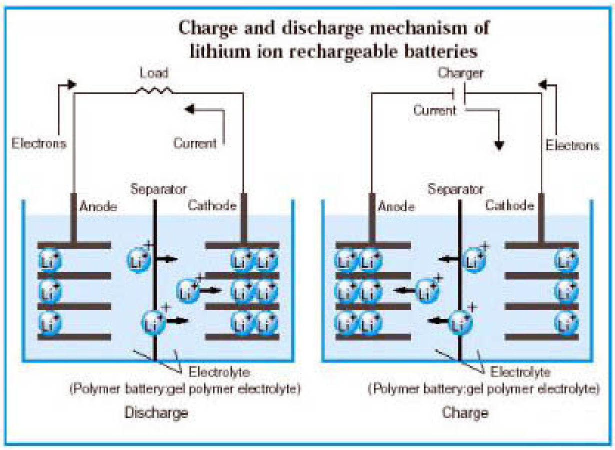

Fig.5 Operating Mechanism of Li-Ion Battery

The batteries dimensions are very important when constructing the Multi Sensor Chip. Since the chip will be micrometer in size it is only appropriate for the batteries to be also. With two millimeter sized batteries this allows lightweight flexibility during the assembling of the Micro Sensor Chip. The lithium-ion battery will deliver and maintain a stable operating voltage of over 3.7V until final discharge — three times as much longer battery voltage as a Ni-Cd or Ni-MH battery provides. The Lithium-ion batteries will provide stable discharge within a wide range of temperatures, from –20°C to 60°C. The batteries will not suffer from "memory effect" that may reduce discharge capacity, when Ni-Cd and Ni-MH batteries are repeatedly recharged without being fully discharged. This eliminates the need to energize or perform any other battery maintenance functions in the power supply. As shown in Figure 6 the packaging structure of the batteries begins with the fabrication process of depositing SiO_2 and tungsten on a silicon wafer. Finally, through the steam oxidation anodic bonding method at 900°C a tungsten metal case is attached to a silicon wafer, which encapsulates the battery.

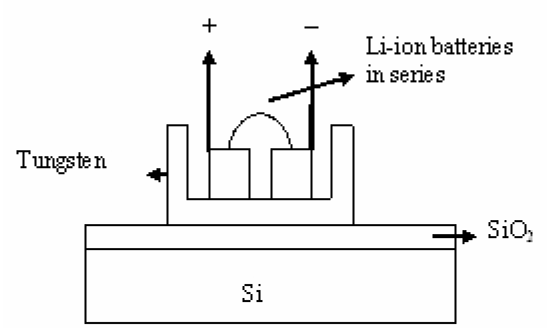

Fig. 6 Packaging Structure of Li-Ion Battery

Conclusion

As a result of the previous observations it was discovered that sensors are vital to the functionality, performance, and distinctiveness of an expanding array of established and emerging industries and applications. There is keen interest in using low-cost, fully integrated multi sensor chips in varied applications, therefore it is important to provide a sensor signal conditioning and calibration solution that addresses the accuracy, space, and cost requirements of a particular application and provides design flexibility with respect to the system designer's or customer's requirements. According to our design the fabrication of the sensor element should be compatible with the fabrication methods for the multi sensor chip. Integrating the signal processing and interfacing circuitry into the sensor chip may, in certain cases, engender sensor packaging, performance, and reliability issues. These will be tested and verified. Moreover, the materials used in the sensor element should be compatible with the integrated smart electronic circuitry for the future, lowering the costs involved in fabricating and manufacturing the sensor. When applying these sensors to the development of a multi-sensor chip it is important to maintain elements such as low-cost, extended life, and also fully integrated solutions. In order to provide these key elements the multi sensor chip must have a sturdy source that is the initial value of its operation. This source is the power supply, which is composed of Lithium Ion Batteries. These batteries contain the element lithium, which is the lightest of all metals, and it has the greatest electrochemical potential and provides the largest energy content. These rechargeable batteries use lithium metal as negative electrodes (anode), which are capable of providing both high voltage and excellent capacity, resulting in an extraordinary high energy density for the multi sensor chip.

References

1. Isidor Buchmann ,“Will Lithium-Ion batteries power the new millennium?” April 2001.http://www.buchmann.ca/Article5-Page1.asp
2. Lithium ion battery - Wikipedia, the free encyclopedia January 2006. http://en.wikipedia.org/wiki/Lithium_ion
3. Gabriel A. Rincón-Mora “Power Management DesignLine | Self-powered chips - The work of fiction.”April 28th 2005. www.powermanagementdesignline.com
4. P. Bhattacharya, Z. Ye, E. Walker, M. Banerjee “ Nano Scale Modeling for Miniature Power Source.” IEEE Symposium, pg.2, February 2006.

5. P. Bhattacharya, L. Dabbiru, M. Banerjee “Design Fabrication and Integration of a Multi Sensor Chip (MSC)” IEEE Symposium, pgs. 1-5, Fall 2003.

JOSEPH BOONE JR.

Joseph Boone Jr. is an Undergraduate Research Assistant in the Electrical Engineering Department at Southern University in Baton Rouge, Louisiana. His research interest includes advancement of nanotechnology, and spread spectrum communications. He is strongly in favor of the development of new ideas provided by the integration of modern communication.

PRADEEP K. BHATTACHARYA

Dr. Pradeep Bhattacharya serves as a Professor and Chair of Electrical Engineering at Southern University, Baton Rouge, Louisiana. His research interests include advanced electronic materials, nano- and bio-engineering. He is deeply interested in engineering education and management.

ZHENGMAO YE

Dr. Ye is currently serving as an Assistant Professor of Electrical Engineering at Southern University and A & M College. His research interests include Modeling, Control and Optimization of Automotive, Electrical, Mechanical and Biomedical Systems as well as Signal Processing and Image Processing. He is active in the fields of IEEE, ASME and SAE. He is the Founder of System and Control Laboratory at Electrical Engineering Department of Southern University and A & M College.

FRED LACY

Dr. Lacy’s research interests are in the areas of electronics and biosensors and the development of such devices for various applications (such as bacteria detection and oxygen free radical measurements). He develops these electronic sensors using IC (integrated circuit) technology and MEMS (Micro-Electro-Mechanical Systems) processing. Dr. Lacy’s teaching interests are in the areas of electronics, biosensors, solid state physics, electromagnetic field theory, and AC/DC circuits.

ERNEST L. WALKER

Dr. Walker's teaching and research interests are in the areas of telecommunications system design and stochastic modeling. Dr. Walker is a Registered Professional Engineer in the states of North Carolina and West Virginia.