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Smart Polymeric Temperature Sensors for Biological Systems

Article by: - Greenee AnilKumar Sinha
BSc (Physics), MS in Materials Science and Engineering

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1. Introduction

Many great activities are linked to the brain and temperature. While brain temperature is largely dependent on the metabolic activity of brain tissue, the regulation of these two parameters is complex. Observational data has shown that the core body temperature and brain temperature can differ significantly. During injuries and infections in the patients, the temperature gradient between brain and the core is nearly ranging from +0.3 to +2°C. Prior to patient's death it was noticed that the body core temperature had exceeded the brain temperature. As an injured brain is extremely receptive and vulnerable to minuscule temperature variation. Therefore, an accurate and stable method to monitor the temperature change in brain is developed. Measuring the core body temperature only is not enough to monitor the cerebral status of TBI patients. External ventricular drain (EVD) are used in the treatments of patients with TBI or a hemorrhage.

The current approaches are susceptible from low temporal and spatial resolution, EVD related bacterial infections. Using the new approach of micro-electro-mechanical systems (MEMS) based fabrication technology allows association of multiple micro-sensors on both inside and outside of the flexible polymer tube while dodging wiring and assembling problems associated with previous methods. Recent growth in MEMS and nanotechnology permits the development of highly functional probes for diagnosis and treatment of brain diseases and injuries. The selection of MEMS technology has the probability to revolutionize brain multimodality monitoring by integrating all the desired function into a single unit.

To obtain accurate and real-time readings of the temperature variation, distinct implantable temperature sensors and probes have been developed using the principles of optical fiber, resistance temperature detector, thermocouple and thermistor.

2. What is Sensors?

Sensor is an electronic component whose purpose is to detect events or changes in its environment and send the information to the other electronics mostly a processor. A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. A sensor converts the physical parameter into a signal which can be measured electrically. The most common parameter measured is temperature. At present temperature is the only parameter covered in detail. Sensors are used in everyday objects such as touch-sensitive elevator buttons, lamps which switches off or on by touching its base. With advances in micromachinery and convenient microcontroller platforms, the uses of sensors have expanded beyond traditional fields. Sensors are usually designed to have small effect on what is measured making the sensor smaller often improves this and may introduce other advantages. Sensors used in temperature measurement have an electrical property that is sensitive to temperature changes. Since the range of the output signal is always limited, the output signal will eventually reach a minimum or maximum when the measured property exceeds the limits.

Measurement of temperature is critical in modern electronic devices, especially expensive laptop computers and other portable devices with densely packed circuits which dissipate considerable power in the form of heat. Knowledge of system temperature can also be used to control battery charging as well as prevent damage to expensive microprocessors. Compact high-power portable equipment often has fan cooling to maintain junction temperatures at proper levels. To conserve battery life, the fan should only operate when necessary. Accurate control of the fan requires a knowledge of critical temperatures from the appropriate temperature sensor. Accurate temperature measurements are required in many other measurement systems such as process control and instrumentation applications.

3. Temperature Sensors

Temperature is the most common of all physical measurements. We have temperature measurement and control units, called thermostats, in our home heating systems, refrigerators, air conditioners, and ovens. Temperature sensors are used on circuit boards, as part of thermal tests, in industrial controls, and in room controls such as in calibration labs and data centers. Though there are many types of temperature sensors, most are passive devices: Thermocouples, RTDs (resistance temperature detectors), and thermistors. Thermocouples (T/Cs) are the most common type of sensor because they don't require an excitation signal. They consist of two wires made of dissimilar metals joined at the point of measurement. Based on the Seebeck effect, T/Cs operate on the basis that each metal develops a voltage difference across its length based on the type of metal and the difference in temperature between the ends of the wire. By using two metals, we get two different voltages V_1 and V_2. The difference (V_T) represents temperature. Note that there is no voltage across the thermocouple junction. It is often heard that a thermocouple develops a voltage across the junction, which is incorrect. The voltage is developed over the length of each wire.

Thermocouples are designated using letters. A Type-J T/C has iron and constantan (a copper-nickel alloy) wires. Most thermocouple wire is color coded. Thermocouples require that the far ends of the wire be at the same temperature and that temperature must be known. Thus, instruments that use thermocouples will have an isothermal block with an embedded sensor to measure the temperature at that point. This is called cold-junction compensation. With one end of the wires at an equal and known temperature, a circuit can measure VT and calculate the unknown temperature.

4. Design and Fabrication

Biomedical microdevices have been used in the clinical setting for quite some time and are instrumental to the delivery of care. Recent developments in microelectromechanical systems (MEMS)-based sensors prefer that the quality of diagnosis and treatment can be significantly enhanced once these advancements are translated into the targeted applications. MEMS-based sensors have advantages over traditional monitoring probes include smaller dimension, ability to integrate, faster response time, lower power consumption, lower cost, greater reliability and higher sensitivity. In addition, the advancement in fabricating the MEMS sensors on a flexible substrate offers a viable solution to one of key technical challenges of rigid monitoring probes the mechanical mismatch between the compliant brain tissue and the sensor substrate. A smart catheter was developed, which is capable of continuously monitoring multiple physiological and metabolic parameters.

Microsensors, wires and circuits were fabricated first on the flexible polymer substrate using standard MEMS technology, and then rolled spirally to make a tube structure. It combined the advantages of flexible MEMS technology with a spiral rolling technique to develop a multimodality probe applicable to monitoring TBI patients, while avoiding wiring and assembling problems associated with previous methods. Furthermore, catheter lumen patency is maintained for *in situ* drug delivery, insertion of medical tools, or drainage of cerebrospinal fluid (CSF) or blood. For use in multimodality neuromonitoring with the smart catheter, it has evaluated the performance, accuracy and long-term stability of smart catheter temperature sensor (SCT) based on thin-film resistance temperature detector (RTD) with 4-wire configuration.

5. Materials Used

Standard microfabrication processes were used for development of the first-generation neural catheter Lactate sensor. Concisely, the polyimide PI2611 was spin-coated silicon wafer. The polyimide was cured under nitrogen atmosphere in a programmable oven at 400 °C for 30 min with a ramp rate of 4 °C/min to minimize thermal stress. A second PI2611 layer was then spin-coated to form a 7 µm thick passivation layer to insulate the interconnection lines. The cured second polyimide layer was etched in oxygen plasma for 10 min. For the catheter temperature sensor Polydimethylsiloxane (PDMS) was spin-coated on a 6-inch Silicon wafer and cured at 65 °C for 1 h. A 7.5 µm thick Kapton film (type HN) was cleaned and attached to the PDMS surface. 1.5 µm thick Parylene film was to smooth the film surface and enhance the resistance to moisture transmission. Electrodes for the temperature sensor were fabricated by depositing and patterning an Au (1,200 Å) layer with an adhesion layer of Ti (150 Å) using an E-beam evaporator, followed by standard lithography and etching processes.

After that, the electrical leads of the temperature sensor were electroplated with 2 µm thick Cu to reduce the lead resistances. Then 2 µm Parylene, 1,500 Å Cu, and 2 µm Parylene were deposited in sequence to prepare the surface to develop the flow sensor. The electrodes for the flow sensor were fabricated by depositing and patterning the 150 Å Ti /1200 Å Au layers. The electrical leads of the flow sensor were also electroplated with 2 µm thick Cu to reduce the lead resistances. Finally, 3 µm thick Parylene film was deposited as an outermost layer.

The electrical leads of the flow sensor were also electroplated with 2 µm thick Cu to reduce the lead resistances. Finally, 3 µm thick Parylene film was deposited as an outermost layer. The film with the temperature and flow sensors were cut into size and spirally rolled over the metal rode based on our previous work to form an intraventricular. The film with temperature and other microsensors were cut into size (width=2.5 mm; length=150 mm) and spirally rolled over the metal rode based on our previous work to form an intraventricular catheter. The smart catheter was designed to have the same inner diameter (ID= 1.3 mm) as the Codman intraventricular catheter for compatibility with existing ventricular drainage techniques. After spiral-rolling, a post treatment is performed to enhance stability and durability. SCTs were electrified for aging with a 20 mA current for 12 h based on self-heating. Through the post treatments, the structural defects and internal stress are eliminated, and accordingly, the stability and TCR of the SCTs are enhanced. Each SCT was then calibrated.

6. Current Status of Sensors

A variety of new strategies have been developed toward biosensors with clinical applications. In principle, biosensors are analytical devices composed of a biological recognition element and an optical/electronic transducer. The type of biosensors can be categorized by the nature of recognition, that is, enzyme-based biosensors, immunological biosensors, and DNA biosensors. Alternatively, based upon the type of transducers, there are electronic biosensors (electrical or electrochemical), optical biosensors (fluorescent, surface plasmon resonance, or Raman), and piezoelectric biosensors (quartz crystal microbalance).

Environmental monitoring is another important aspect wherein biosensor technology is required for rapid identification of pesticidal residues to prevent health hazards. Traditional methods, such as high-performance liquid chromatography, capillary electrophoresis and mass spectrometry, are effective for the analysis of pesticides in the environment yet, there are limitations for instance complexity.. Hence, simple biosensors seem to have tremendous advantages yet, it is cumbersome to develop unified one for analyzing various classes of pesticides.

The incorporation of gold nanoparticles or quantum dots with the use of micro-fabrication provides new technology for the development of highly sensitive and portable cytochrome P450 enzyme biosensors for certain purpose. More recently, hydrogels, used as DNA-based sensor, are emerging materials for immobilization usage with fiber-optic chemistry. Compared to other materials, immobilization in hydrogels occurs in 3D which allows high loading capacity of sensing molecules. Hydrogels (polyacrylamide) are hydrophilic cross-linked polymers and can be made into different forms for immobilization ranging from thin films to nanoparticles

7. Conclusion

Despite the rapid progress in biosensor development, clinical applications of biosensors are still rare, with glucose monitor as an exception. This is in sharp contrast to the urgent need in small clinics and point-of-care tests. We believe the following requirements are necessary. First, high sensitivity: Sensitivity improvement is an ever-lasting goal in biosensor development. It is true that the requirement for sensitivity varies from case to case. For example, one does not need a very high sensitivity for glucose detection since glucose concentration is high in blood. This is a part of reason for the success of glucose monitors. However, in many cases it is very important to develop highly sensitive biosensors, optimally single-molecule detection, to meet the requirement of molecular diagnostics and pathogen detection. Second, high selectivity: This might a major barricade in the application of biosensors. Most biosensors reported in the literature work very well in laboratories, however, may meet series problems in test real samples. As a result, it is essential to develop novel surface modification approaches to avoid non-specific adsorption at surfaces. Third, multiplexing is critical for saving assay time, which is especially important for assays performed in laboratories or clinics. It is important to develop miniaturized biosensors to increase portability, thus meet the requirement of field and point-of-care test. Fourth, an ideal biosensor should be integrated and highly automated. Current lab-on-a-chip technologies (microfluidics) offer a solution toward this goal. We can expect that successful biosensors in the future may incorporate all these features and can conveniently detect minute targets within a short period.