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Flexible Platinum Thermoresistive Temperature Sensor Applicable to Ultrasonic Resonance Thrombolysis Device for Ischemic Stroke

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Abstract - This paper reports on a flexible and biocompatible platinum thermoresistive temperature sensor for the application of an ultrasonic resonance thrombolysis device for ischemic stroke. The proposed flexible platinum temperature sensor consists of a polyimide substrate, a platinum thermoresistive element and a polyimide insulation layer. The temperature coefficient of resistance (TCR) and sensitivity of the designed temperature sensor were measured and calculated to be 2.63×10^{-3} /℃ and 0.93 ℃/sec, respectively.

1. Introduction

Ischemic stroke occurs when an artery leading to the brain is blocked. From U.S. statics, ischemic stroke is the third leading cause of death behind heart disease and cancer. About 25% of sufferers die as a result of the stroke or its complications, and almost 50% have moderate to severe health impairments and long-term disabilities. Only 26% recover most or all normal health and function [1]. Medication of thrombolytic drugs is presently the most efficient method for treatment of ischemic stroke. However it has several restrictions in treatment, for instance, complex indication, applicable elapsed time from acute ischemic attack, and so forth. Several endovascular mechanical trombolytic devices have been continuously developed for this reason. The mechanical thrombolytic device guarantees various treatments without any restrictions, however, it has a heat generation problem due to the mechanical energy. Heat could cause another brain damages, therefore, a temperature sensing or a temperature control system should be studied altogether in these devices.

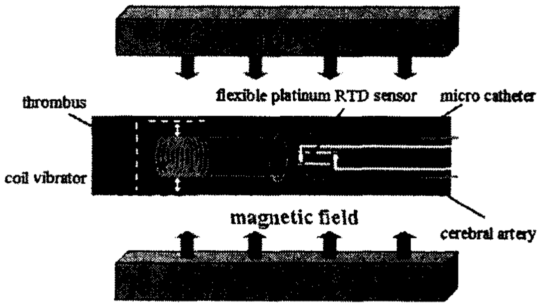
One of the most linear, stable, accurate and reproducible temperature sensor is a thermoresistive temperature sensor, sometimes referred to as a resistance temperature detector (RTD). A thermoresistive temperature sensor consists of a sensing element which respond to temperature change by changing its resistance. The sensor is connected to a readout instrument that monitors the resistance, typically through the use of a bridge circuit, and then converts resistance to temperature. For the application of the temperature sensor to thrombolysis device, it should be suitable to *in vivo* system. Nickel, copper and platinum are common elements used for a thermoresistive temperature sensor. Among those elements, platinum could be applied to the mechanical thrombolytic device owing to its properties such as the most linear characteristic and biocompatibility [2]. Polyimide exhibits an exceptional combination of thermal stability, excellent dielectric properties, mechanical toughness, chemical resistance, high degrees of ductility and inherently low coefficient of linear thermal expansion (CTE) compared to other organic polymers [3]. For these reasons, polyimide is readily implemented into a variety of microelectronic and biomedical applications.

In this paper, a flexible and a biocompatible platinum thermoresistive temperature sensor was designed and fabricated using polyimide for the application of an ultrasonic resonance thrombolysis device for ischemic stroke.

2. Design

2.1 Thrombolysis Device for Ischemic Stroke

The proposed thrombolysis device for treatment of ischemic stroke using ultrasonic resonance consists of micro catheter and vibrating coil. A schematic view of the device is described in figure 1. A brain of patients with ischemic stroke is placed between strong magnets and a micro catheter carries a coil vibrator to the blockage of arteries leading to the brain. When the coil vibrator is placed to the blockage through the micro catheter, it starts to ultrasonic resonate due to electromagnetic induction. The transferred ultrasonic energy from the coil vibration can generate the cavitation of blood that has the energy enough to dissolve cerebral thrombi without any thrombolytic drugs [4].

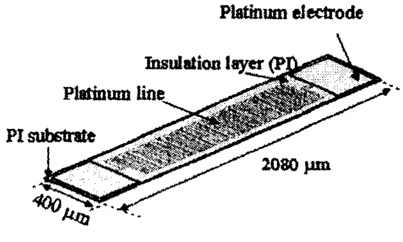


<Figure 1> A schematic view of the proposed device

The proposed thrombolysis device is expected that it could be applicable to diverse patients without any restrictions, however, it has a heat generation problem caused by coil vibration. Because the heat can cause the brain damage over 40 ℃, an accurate and realtime temperature sensing technology is indispensable.

2.2 Flexible and Biocompatible platinum temperature sensor

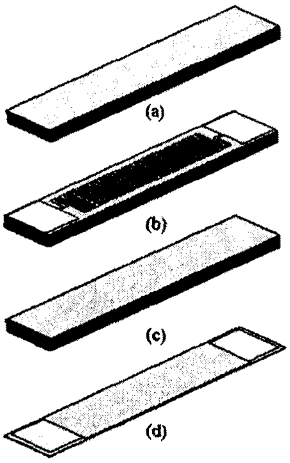
There are several requirements to applicate a temperature sensor to the proposed device. Firstly, the temperature sensor should be biocompatible for the application of *in vivo* system. Secondly, the temperature sensor should be close to the coil vibrator owing to the accurate detection of heat generation. Thirdly, the sensor should be smaller than cerebral arteries. A flexible thermoresistive temperature sensor was designed satisfying previously mentioned three conditions (figure 2). The proposed thermoresistive temperature sensor was designed to be placed on the outside of the micro catheter because in should be as close to the coil as possible. For this reason, the temperature sensor was designed as thin, biocompatible and flexible. A platinum was decided as a thermoresistive element due to its linear "R vs. T" characteristic and biocompatible property. PI was decided as a substrate and an insulation layer because it has biocompatible, ductile, mechanically tough and thermally stable characteristics. Total thickness of the proposed temperature sensor was 10 μm and the thickness of the PI substrate and the PI insulation layer were 5 μm, respectively. The platinum line was designed as 1 kΩ with meander shape to enhance a flexibility of the sensor.



<Figure 2> The proposed flexible temperature sensor

3. Fabrication

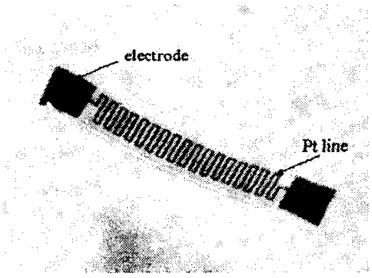
Fabrication process of the proposed flexible thermoresistive temperature sensor is described in figure 3. Firstly, aluminium sacrificial layer was evaporated on a glass substrate and 5 μm thick polyimide substrate layer (HD microsystems PI #2525) was deposited onto the sacrificial layer (figure 3. (a)). Then 1000 Å thick platinum line and electrodes were patterned using sputtering and lift-off process (Figure 3. (b)). After the patterning, 5 μm thick polyimide was deposited as an insulation layer (figure 3. (c)). The polyimide insulation layer was dry etched for an opening of electrodes and then the aluminium sacrificial layer was removed by aluminium etchant (figure 3. (d)). Finally, the completed temperature sensor was connected to a temperature monitoring instrument.



<Figure 3> Fabrication process of the proposed temperature sensor (a) sacrificial layer and polyimide layer deposition (b) platinum line patterning (c) polyimide insulation layer deposition (d) electrode opening and release

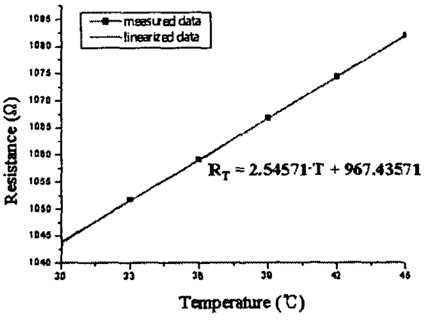
4. Measurement and Discussion

Figure 4 shows the fabricated flexible platinum temperature sensor. The resistance of the fabricated temperature sensor was 1.03 kΩ and its fabrication error was 3 %.



<Figure 4> Fabrication result

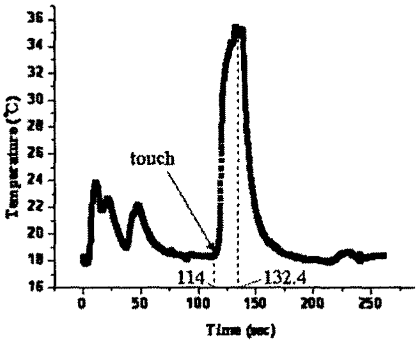
To find out the actual temperature coefficient of the fabricated sensor, resistance of the fabricated sensor by varied temperature was measured in thermal equilibrium chamber and measured values were linearized by origin as described in figure 5. The calculated TCR based on these measurements was 2.63×10^{-3} /℃.



<Figure 5> Measured resistance of the fabricated sensor by varied temperature in thermal equilibrium chamber

The temperature monitoring instrument was realized by a data acquisition board (DAQ, PCI-MIO-16E-1) and managed by a LabVIEW software package. The monitoring instrument can provide essential benefits such as a realtime temperature sensing and data storing. Wheatstone bridge was used as a converting circuit to transform the resistance of the proposed thermoresistive temperature sensor to the voltage. The output voltage of the converting circuit was amplified by an instrumental amplifier (AD524) and transferred to an analog input of the DAQ board. It was necessary to amplify the voltage from the thermoresistive temperature sensor because the actual voltage of the sensor was much smaller than the full input range of the DAQ board. The full input range of the DAQ board was from 0 to 10 volts. The amplification of the voltage enhanced the signal to noise ratio. The resolution of the implemented temperature monitoring instrument was restricted to 0.1 ℃.

Temperature sensing test was briefly performed and its result was compared with compared with the result of a mercury thermometer as described in figure 6. Both temperature sensors were located and stabilized at 18 ℃ clean room, and measured the temperature variation and elapsed time after touch. The tested temperature range was roughly from 18 to 35 ℃, and the sensitivity of the proposed temperature sensor and the mercury thermometer was 0.93 ℃/sec and 0.28 ℃/sec, respectively.



<Figure 6> The measurement result of the temperature sensing test

5. Conclusion

The flexible and biocompatible thermoresistive temperature sensor was designed and fabricated using platinum and polyimide films for the application to the ultrasonic resonance thrombolysis device for treatment of ischemic stroke. The proposed temperature sensor consists of a polyimide film substrate, a platinum thermoresistive element and a polyimide insulation layer. The platinum thermoresistive element can guarantee linear output and biocompatibility, and the PI can offer a high ductility, mechanical toughness and biocompatibility.

The measurement of temperature coefficient was performed in the thermal equilibrium chamber and the brief temperature sensing test was successfully carried out using the implemented temperature monitoring instrument. The measured temperature coefficient was about 2.5 Ω/℃ and sensitivity was 0.93 ℃/sec with resolution of 0.1 ℃.

Acknowledgement

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