# THE DESIGN AND FABRICATION OF IMPLANTED INTRACRANIAL PRESSURE SENSOR

Tian Bian, Zhao Yulong and Jiang Zhuangde
*State Key Laboratory for Manufacturing Systems, Xi'an Jiaotong University, Xi'an 710049, China*

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Abstract: For the purpose of intracranial pressure measurement, implantable intracranial pressure monitoring sensor applying to the long-term and real-time monitoring to the intracranial pressure of the brain patients, a pressure sensor was designed based on the piezoresistive principle. The fabrication of pressure sensor adopted the technology of bulk micromachining to form the structure, and used the ion implanted technique to form resistances. The packaging was successfully fabricated by using biocompatible material, such as titanium alloy and polyurethane. The output characteristic of the sensor is measured. It was demonstrated that this pressure sensor has good performance, include linearity, accuracy and sensitivity for medical applications.

## 1 INTRODUCTION

The intracranial pressure (ICP) is extremely valuable in many cases in order to monitor and control the clinical condition of a patient. Presently there are essentially three types of intracranial-pressure sensors: (a) the sensors requiring handling of the cephalorachitic intraventricular liquid or cisternal liquid, (b) the so called sub dural sensors to be implanted in the subdural space between the dura mater and the arachnoid, (c) the extra-dural sensors to be implanted on the dura mater between this dura mater and the skull.

The sensors of the first type (a) measure directly the pressure of the cephalorachitic liquid which is transmitted by a catheter to a transducer. The sensors of the second type (b) measure the intracranial pressure by using the arachnoid as an interface, the arachnoid being a very fine and very flexible membrane capable of integrally transmitting the pressures. In both cases the pressure to be measured is directly accessible, without there being distortions, whereby the measurement provides significant information without need for special precautions and while making use of conventional pressure sensors which are merely selected to have the required sensitivity.

However implanting the sensors (a) or (b) entails effraction of the dura mater necessitating a far more complex surgical intervention than that required by an extradural implant (c) and carries risks well known to the practitioners; in particular, only the extradural implant is suitable for danger-free, long-term surveillance.

In this study, compared with conventional monitoring, adopted the type of extradural implant, a pressure sensor based on MEMS was designed for ICP motoring. Considering minimized size and low range of sensor, the corresponding finite element analysis modules of the pressure sensor was set up. The material and structure design of packaging were also involved for compliant and stable implantation purpose.

## 2 STRUCTURE DESIGN AND FABRICATION

The ICP monitoring was evaluated at the standard of 2.00KPa, normally, the ICP under 2.00KPa, but the lightly increased value of ICP is between 2.00KPa to 2.70KPa. Compared with other kind of pressure sensors, piezoresistive pressure sensors have more advantages which could satisfy the demand of ICP monitoring, such as micro size, simplicity fabrication process and high sensitivity. To fulfill the requirement of pressure measurement for high sensitivity and low range applications, this paper presents a piezoresistive pressure sensor developed on Si wafers.


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In this research, it was utilized the anisotropy characteristic along different orientation of single crystal silicon. The piezoresisitance characteristic is used to produce the pressure sensor. There is the largest piezoresistance coefficient along the crystal direction [110] or [$1\bar{1}0$]. However there is almost no piezoresistance coefficient along the crystal direction [100] and [010] in (100) silicon. The simulation was done for the pressure range 0~10kPa by finite element method (FEM) software ANSYS. Since the pressure sensor device is a quartered symmetry, the quarter FEM of pressure sensor was established, and the stress distribution of structure is showed in Fig 1. The stress concentration zone is located at the edge of the membrane, where the resistors are implanted. The mechanical stresses obtained by FEM should be transformed into output voltage in such a way that the simulation stress value can be applied to predict the equivalent output electrical signal. All the four piezoresistances of the pressure sensor are formed the Wheatstone bridge circuit. Eq. (1) indicates the output voltage, resistance and stress variation relation , $\pi_l$ is the longitudinal piezoresistance coefficient and $\pi_t$ is the transverse piezoresistance coefficient. $\sigma_l$ is the uniaxial stress, and a transverse stress $\sigma_t$ :

$$\frac{\Delta V}{V_{in}} = \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} = \sigma_1 \pi_1 + \sigma_t \pi_t \qquad (1)$$

The pressure sensor chip is processed from a 4 inch (100) orientation silicon wafer using conventional lithographic technology. The thickness of silicon wafer is 400 $\mu m$ . The single crystal silicon is n-type. The fabrication and the packaging processes comprise several steps, a schematic view of the device layout is showed in Fig 2.

First, a silicon oxide layer with the thickness of 120 nm is deposited on the substrate silicon by high thermal way, and patterned by the mask for the piezoresistance of pressure sensor. Then the boron ion is implanted to the substrate through the pattern of the mask to a depth of 2 ~ 2.5μm at the dose of $2.0\times10^{15}$ cm-2 with the energy of 80keV. This forms resistors patterns of pressure sensor. The purpose of resistance is about 25Ω /□. A Si3N4 layer with depth of 120 ± 20nm is formed using Low Pressure Chemical Vapor Deposit (LPCVD) to protect the circuit of the sensors. And then etch the backside of the substrate to form a 25μm silicon diaphragm. An aluminum film which thickness is 1.5 microns is splashed to form the interdigitated electrode and connecting wire in the chip. The fabricated sensor was showed in Fig 3. The size of pressure sensor is $5500\mu m \times 5500\mu m \times 400\mu m$ , and the membrane is $4500\mu m \times 4500\mu m$ .

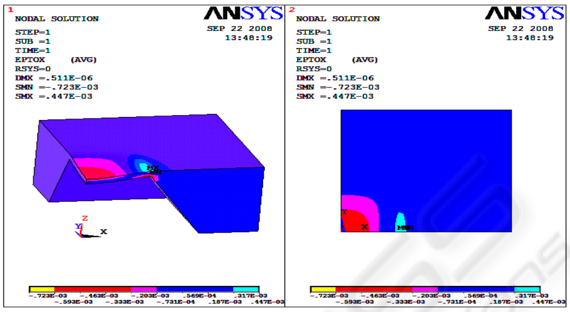



Figure 1: Stress distribution of structure.

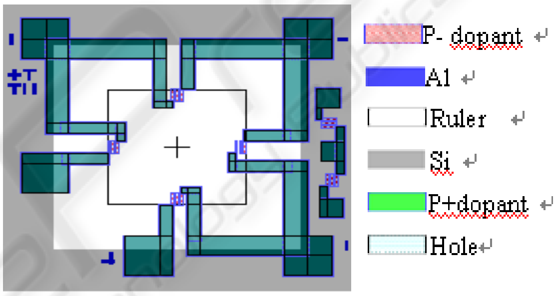



Figure 2: Schematic view of the device.

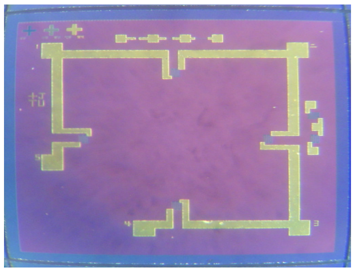
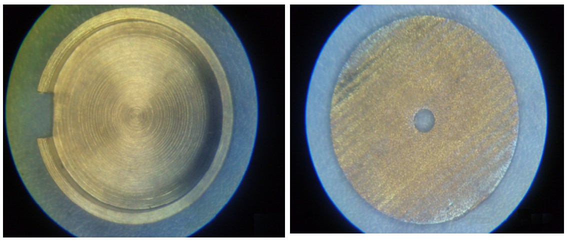


Figure 3: Photo of the fabricated sensor.

## 3 PACKAGING OF SENSOR

### 3.1 Titanium Alloy Packaging

Light, strong and totally biocompatible, titanium is one of few materials that naturally match the requirements for implantation in the human body. The high strength, low weight, outstanding corrosion resistance possessed by titanium and titanium alloys have led to a wide and diversified range of successful applications which demand high levels of reliable performance in surgery and medicine. The natural selection of titanium for implantation is determined by a combination of most favourable characteristics including immunity to corrosion, bio-compatibility, strength, low modulus and density and the capacity for joining with bone and other tissue - osseointegration. For the advantages above, the titanium alloy TC4 type was used for the material of packaging. As showed in Fig 4, the shell of titanium alloy packaging has two parts, the cover and foundation. The extended wire was connected with outer through the hatch of the cover. The liquid was introduced to the pressure senor through the hole of foundation for sensing.



a. Cover b. Foundation

Figure 4: Shell of titanium alloy packaging.

## 3.2 Extended Wire

The extended wire introduced the signal of pressure sensor to peripheral part for monitoring. For the requirement of biocompatible and possibility of long-term implants, the wire is covered with polyurethane for medical application. Polyurethane film's performance and characteristics make it a perfect fit for use in the medical industry. Polyether's unique combination of strength, biocompatibility, and innate anti-microbial qualities make it an ideal material for extensive use in the medical field. The diameter of extended wire is 1.45mm, and the photo of wire is showed in Fig 5.

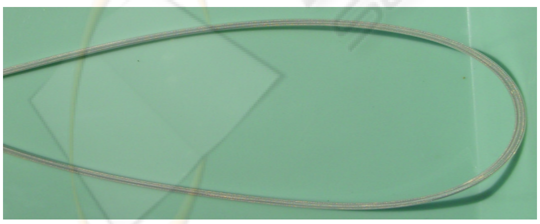


Figure 5: Photo of extended wire.

## 3.3 Process of Packaging

Considering minimized size of hatch which was punctured on skull, the diameter of packaged sensor was set to 11mm and 3mm high. The diameter of transfer circuit is 10mm and the height is 0.2mm. The structure of packaged sensor was showed in Fig 6, and the transfer circuit is showed in Fig 7. The process of packaging has several steps as follows:

First, the pressure sensor chip was covered by an insulated macromolecule material parylene film which transmited the pressure. The insulated film could conduct intracranial pressure indirectly and biocompatible with body. Through the technology of ultrasonic cleaning make the titanium alloy shell pure to achieve the standard for medical implanted. The inside packaging cover was spread with insulated material. The insulated material could descend the possibility of creepage which is due to the contact between wire and titanium alloy shell accidently. Second, pressure sensor chip and signal transfer circuit were glued on the foundation of shell by cyanoacrylate, and connected by spun gold welding. The extended wire was also weld to circuit. Finally, the cover of shell was glued on foundation part.

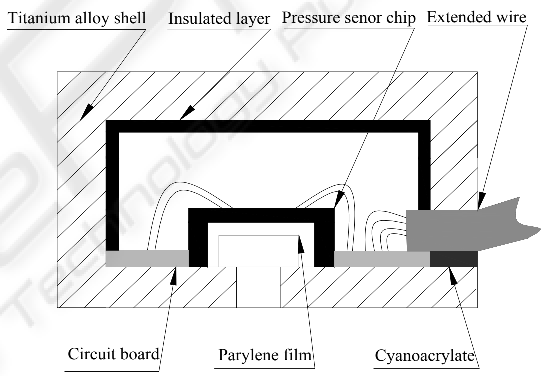



Figure 6: Structure of packaged sensor.

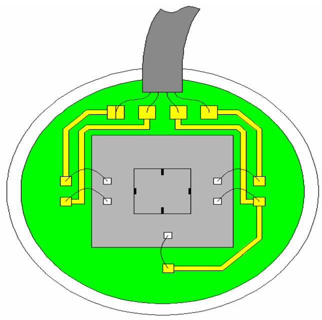


Figure 7: Transfer circuit.

# 4 RESULT AND ANALYSIS

The output of the pressure sensor is showed in Fig 8 and the performances of pressure sensor are showed in Table 1, respectively. The inc represents the pressure inputs from lower to higher, contrarily, the dec shows the outputs when pressure lower. The sensitivity is 5.66mv/KPa. The non-linearity and hysteresis of the sensor are less than 0.1%FS and 0.05%FS, respectively.

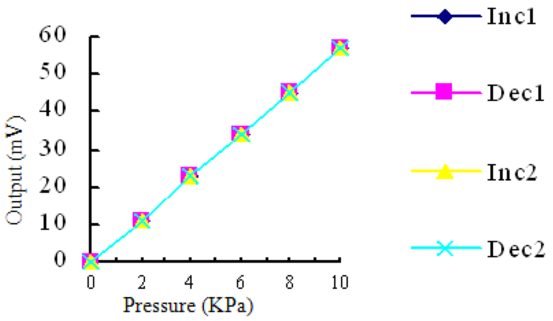



Figure 8: The output characteristic of the sensor.

Table 1: The performances of pressure sensor.

| Parameter | Value |
|---|---|
| Pressure range (KPa) | 10 |
| Repeatability (%FS ) | 0.03 |
| Non-linearity (%FS) | 0.01 |
| Accuracy(%FS) | 0.04 |
| Hysteresis (%FS) | 0.02 |
| System error (%FS ) | 0.01 |
| Diameter of sensor (mm) | 11 |

## 5 CONCLUSIONS

It has been shown that the design and fabrication of pressure sensor including packaging. The pressure sensor was fabricated for intracranial pressure monitoring based on MEMS. The sensor chip possesses the better characteristics including size, linearity, and accuracy. The packaging of the sensor was designed for well biocompatible implanted in skull. The pressure sensor chip is able to measure the parameter for the demands of less volume and less pressure range conditions for medical applications.

## ACKNOWLEDGEMENTS

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