

## APPLICATION OF SEMICONDUCTOR STRAIN GAUGE FOR CONTINUOUS MEASUREMENT OF INTRACRANIAL PRESSURE

HAJIME NAGAI, ATSUSHI IKEYAMA AND SHIGERU MAEDA

*Department of Neurosurgery, Nagoya University School of Medicine  
(Director: Prof. Shin Hoshikawa)*

TAKEO CHIKU AND ISEMI IGARASHI

*Toyota Central Research and Development Laboratories, Inc.*

In order to record intracranial pressure continuously, we have recently developed a microminiature pressure transducer using semiconductor strain gauges. The pressure cell has a small disk-shaped structure, and it can be directly inserted into the intracranial cavity through a small burr hole.

Previous investigations of the semiconductor strain gauge have dealt almost exclusively with the field of technology. In 1954, the first piezoresistive measurements for semiconductors were made in connection with a basic research for the transistor technology. Shortly after the original measurements, efforts were made toward applications.

One of us, Igarashi, studied the piezoresistive semiconductor strain gauges of Germanium and Silicon in 1956<sup>(9)</sup>, and devised a miniature pressure cell in 1965 for the purpose of measuring the pressure in the technological field<sup>(1)</sup>.

The semiconductor strain gauge is generally small in size. Although it has about 70 times higher sensitive gauge factor than that of the wire strain gauge, the former is affected by temperature about 10 times more than that of the latter. It might be, therefore, adopted into the living body as a device for measuring intracranial pressure, if only the compensation for temperature effects is ascertained.

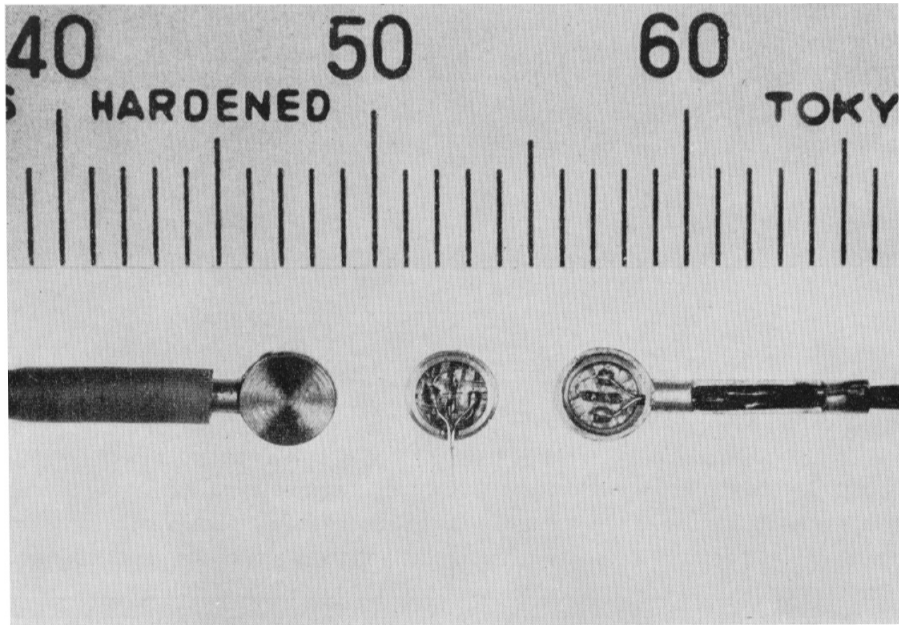
In this paper, a newly devised microminiature pressure cell is introduced and its clinical as well as experimental use is demonstrated.

### METHODS

The microminiature pressure transducer was made by using two semiconductor strain gauges (n type Ge [111]). It was very small in size, enough to be inserted into the intracranial cavity without any difficulty. The device

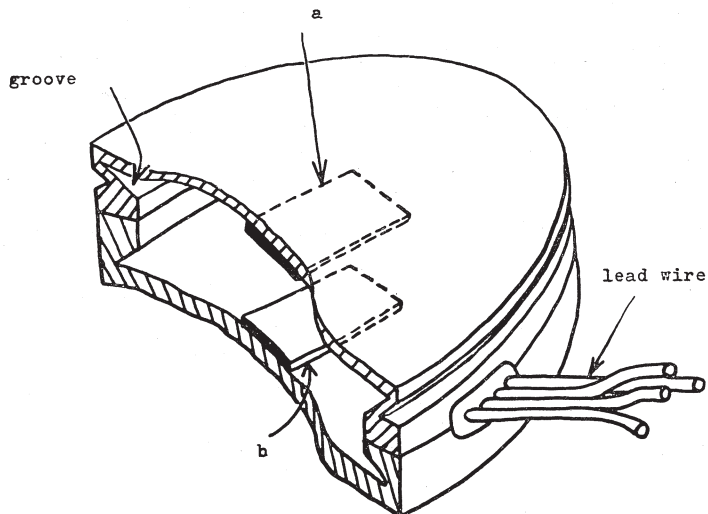
---

永井 肇, 池山 淳, 前田 成, 知久健雄, 五十嵐伊勢美  
Received for publication May 26, 1970.



Left is a photograph of the transducer.  
 Middle shows inside of the active diaphragm.  
 Right shows inside of the dummy diaphragm.  
 A semiconductor strain gauge is bonded to each diaphragm.

FIG. 1. Microminiature pressure transducer.



a and b designate active and dummy gauges of semiconductor elements with the same size and characteristics.

FIG. 2. Section of the device.

had the disk-shaped structure (3 mm in diameter, 1 mm in thickness) and had two diaphragms of different thicknesses as shown in Fig. 1.

The structure of this device was as follow.

1) As shown in Fig. 2, grooves were cut around the supporting parts of the diaphragms so that the stress conditions were equalized to the simply supported ones. Such a structure was able to produce a high output voltage.

2) Two diaphragms of the same material (stainless steel 18-8) but with different thicknesses were used to compensate the temperature effects and to reduce noise due to acceleration in this device. A section of the device is shown in Fig. 2; a and b designated active and dummy gauges of semiconductor elements with the same size and characteristics, respectively. Lead wires entered and left through a supported neck. The electric circuit of the device is shown in Fig. 3.

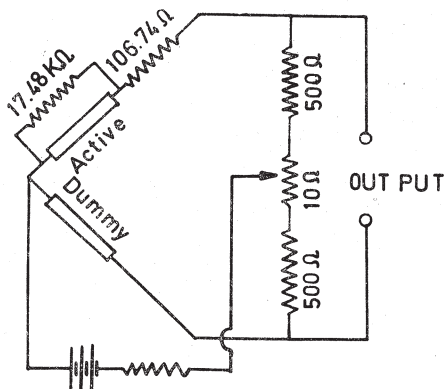
Temperature compensation in this device was made by the following three ways.

a) Active and dummy gauges were connected to the adjacent arms of a Wheatstone bridge circuit to cancel the resistance change due to temperature at the level of the output.

b) Stationary resistors were coupled to one of the gauges to equalize the temperature coefficients of both gauges.

c) For the purpose of keeping a constant current in the bridge circuit, a high resistor which had 10 times higher impedance than that of the bridge circuit was connected to it. In this experiment, the device was checked at body temperature in each case just before it was used.

Experimentally, the output voltage was amplified by a highgain preamplifier model-18\* and was recorded on the 8 channels recorder model WI-380\*\*. In the clinical cases, it was recorded on a potentiometer model-2T\*. Am-



The carbon resistor which has 10 times higher impedance than that of the bridge circuit is connected to the bridge circuit.

Active and dummy gauges are coupled to the adjacent arms of the bridge circuit to cancel resistance changes due to temperature.

FIG. 3. Electric circuit of the device.

\* ToA Electronics Ltd. Tokyo.

\*\* Nihon Kohden Kogyo Co., Ltd. Tokyo.

plification rate was about 80 db., and input impedance was about 50 m $\Omega$ .

## RESULTS

### *In vitro observation:*

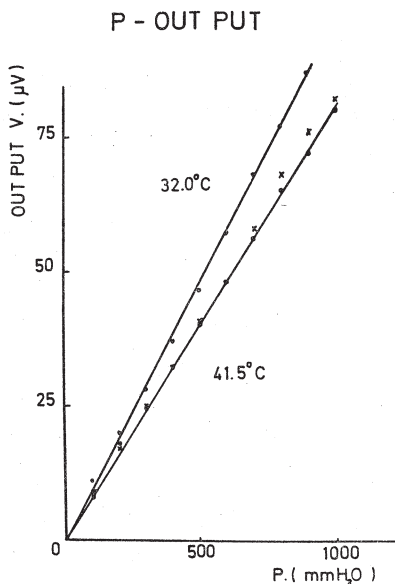
The following three points were examined.

#### 1) Pressure-output relation

Pressure-output relation in range of pressure between 0 and 1,000 mm of water revealed a straight line as shown in Fig. 4. This fact indicated that the output voltage may be sufficiently amplified without noises if only the temperature in the device was kept constant.

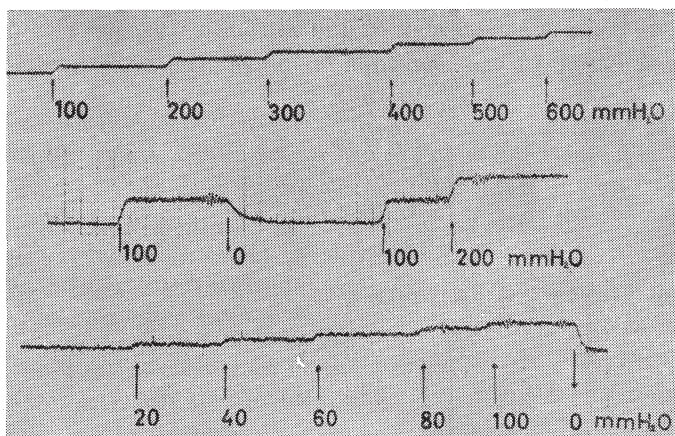
#### 2) Sensitivity

As shown in Fig. 5, a pressure change of 100 mm of water was easily discriminated by this device. If the temperature



Two straight lines are obtained. The change in temperature of 9.5°C caused a 5 to 10 per cent decrease in the output voltage.

FIG. 4. Pressure-output relation at the temperature of 41.5°C and 32.0°C.



Upper two figures show that a pressure change of 100 mm of water is detected easily, and that its reproducibility is sufficient.

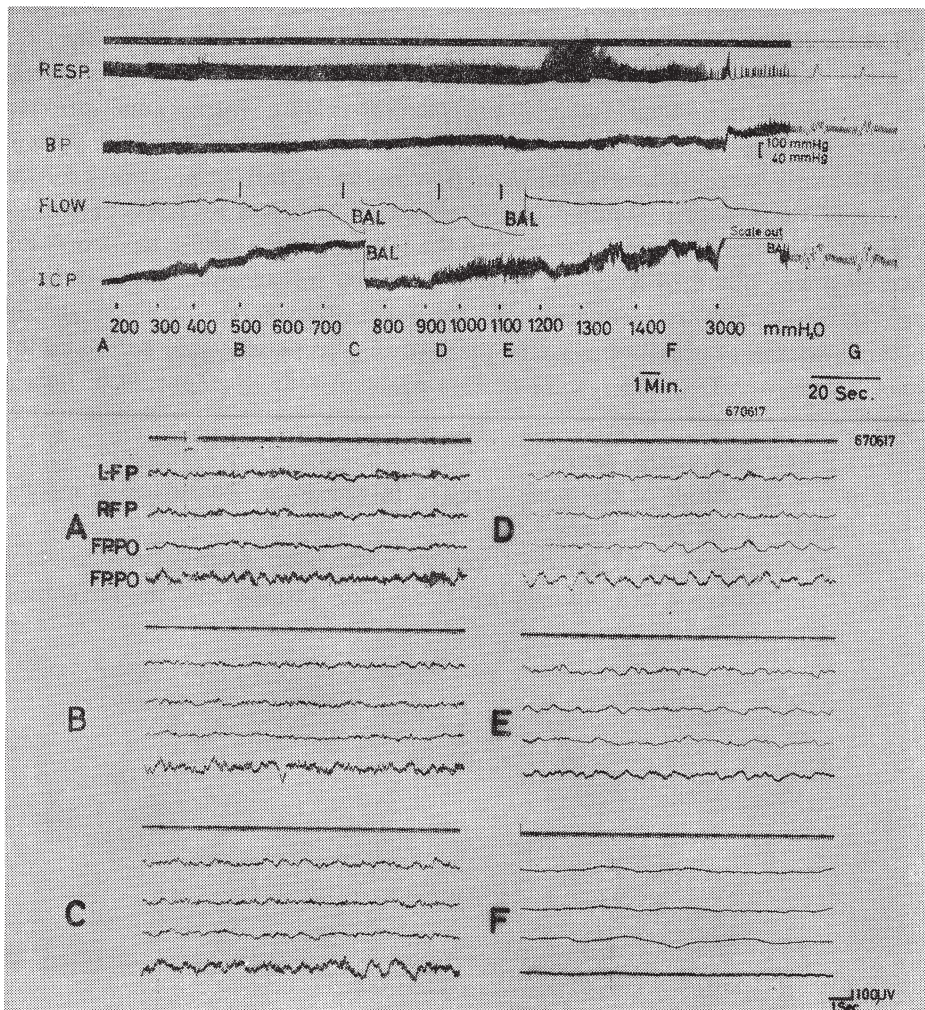
Lowest one shows that a pressure change of 20 mm of water can be detected by this device.

FIG. 5. Stability and sensitivity of the device.

was kept constant, even a pressure change of 20 mm of water could be differentiated. A pressure change less than 20 mm of water, however, could not be detected due to electric noises and drifts from the apparatus.

### 3) Temperature effects

The pressure-output relation at the temperature of 41.5°C and 32.0°C is shown in Fig. 4. Two straight lines were obtained. The change in temperature of 9.5°C, from 32.0°C to 41.5°C, caused a 5 to 10 per cent decrease in



Saline is injected gradually into the cisterna magna to elevate the intracranial pressure. Respiration, systemic blood pressure, cerebral blood flow and intracranial pressure by this device are continuously recorded.

A, B, . . . , F show the points where EEG was recorded.

FIG. 6. Cerebral hemodynamics in intracranial hypertension.

the output voltage. Such a deviation due to changes in temperature was decreased by one-third by maintaining a constant current in each gauge.

*In vivo observation:*

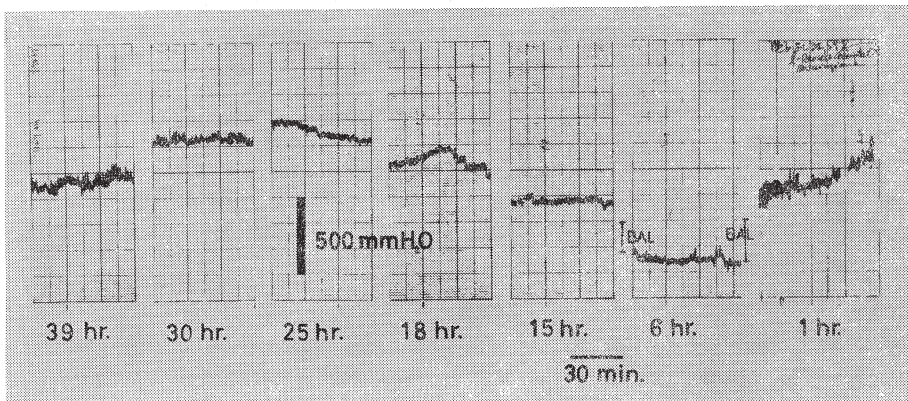
1) Experimental use of the device

Relationship between increased intracranial pressure and cerebral hemodynamics was studied<sup>9)</sup>. Respiration, systemic blood pressure, cerebral blood flow by the heat clearance method<sup>5)</sup>, PvO<sub>2</sub> in the confluence sinus, EEG and intracranial pressure by this device were continuously recorded on polygraph experimentally. The pressure cell was slipped forward through a burr hole into the subdural space under the intact bone. Normal saline was injected into the cisterna magna for the purpose of raising intracranial pressure. One of the experiments is shown in Fig. 6. As the intracranial pressure was gradually increased, cerebral blood flow began to fall at point B. Further raising of the pressure resulted in the elevation of blood pressure at point C. When the intracranial pressure reached the level of the systolic blood pressure, flattening was noted in EEG. Thereafter, as the intracranial pressure raised, systolic blood pressure increased. At the level of 3,000 mm of water at point G, the intracranial pressure came to respond synchronously only to the systolic blood pressure. Detailed results of this problem will be reported in another paper.

2) Clinical use of the device

A serial recording of the postoperative intracranial pressure was made in three patients using this device.

One of the cases, a 59 year-old woman with huge meningioma, is shown in Fig. 7. The device was inserted into the epidural space, and the intracranial



Intracranial pressure is continuously recorded by this device. On the third postoperative day, the device was easily withdrawn from the patient.

FIG. 7. Follow up study of intracranial pressure after removal of meningioma.

pressure was continuously recorded for three postoperative days. As shown in Fig. 7, the pressure decreased gradually for the first several hours. Then gradual increase in the pressure was observed. The increased intracranial pressure after the operation might imply cerebral edema. On the third postoperative day, the device was withdrawn from the epidural space without a separate operation.

#### DISCUSSION

Studies on the physiology of intracranial pressure and its relation to cerebral function have been limited because of the lack of a simple and reliable method for carrying out the continuous record of intracranial pressure. Most of the techniques described rely upon the measurement of cerebrospinal fluid pressure in the lumbar sac or a lateral ventricle by insertion of a tube connected to a pressure transducer or manometer.

In these methods, however, it was necessary for the tube to be placed in the fluid space and to be maintained unobstructed communication with the recording apparatus. Such procedures were associated with a high degree of variance, artifact and inaccuracy. Furthermore, prolonged use of an indwelling ventricular tube might be followed by a risk of intracranial infection and other side effects.

Other workers used a small fluid-filled latex tambour inserted into the subdural space<sup>2)</sup>. The results by this method were frequently affected by leakage of the fluid from the system.

Recently the following two excellent devices were added to the above. One was a small pressure transducer implanted in the skull<sup>3)</sup>, and the other a subminiature pressure transducer using foil strain gauge<sup>4)</sup>. The former required a separate operation for removal of the device. Though the latter was small enough to be inserted into the subdural space, and was used for continuous recording, its sensitivity was still not sufficient to detect the fine change in the intracranial pressure. Our microminiature pressure cell was introduced as a device overcoming all such problems.

The following two points, temperature compensation and sensitivity, were especially studied in this device.

#### Temperature compensation:

It is well known that the semiconductor strain gauge is much affected by changes in temperature. To prevent such effects, the use of the active and dummy gauges connected in the adjacent arms of a Wheatstone bridge circuit were considered at first. Secondly, to equalize the characteristics in both gauges, stationary resistors were applied to one of the gauges having a higher sensitivity. Thirdly, to maintain a constant current in the bridge circuit, resistors having 10 times higher impedance than that of the bridge circuit

was connected to the series. By the three methods above, zero drift of the bridge circuit due to temperature varying from 32.0°C to 41.5°C could decrease within 5 to 10 per cent of the output voltage. A more precise compensation for temperature was made by using a constant current circuit. As the body temperature did not change so much in practice, however, there was no need to apply such a precise compensation circuit.

#### Sensitivity:

As the semiconductor strain gauge is the most highly sensitive pressure detector in comparison with conventional ones, it is possible to apply its use for measurements of small strains, even a pressure change of 20 mm of water.

#### Other problems:

In order to minimize the effects of the size of transducer on pressure, it was made as small as possible. When the cell is inserted into the lateral ventricle (hydrostatic pressure), it records the true intracranial pressure. When it is directly inserted into other parts of the intracranial cavity, *e.g.* the epidural space, the subdural space or the inside of the brain, some forces other than hydrostatic pressure are added to the cell. In this condition, the pressure measured does not indicate a net intracranial pressure, but a relative one.

The advantages of this device are as follows.

- 1) It is small enough to be inserted into any convenient part of the intracranial cavity.
- 2) It is able to record the intracranial pressure continuously.
- 3) Its sensitivity to pressure is much higher than that of the wire strain gauge. It can discriminate a pressure change of 20 mm of water.
- 4) It can be removed easily from the patient.
- 5) It lowers the risk of infection.

#### SUMMARY

A new method for continuous and prolonged measurements of intracranial pressure, utilizing semiconductor strain gauge, is presented. The method offers advantages over previous methods, especially in sensitivity, size and freedom from artifact over long periods of time. The practical use is demonstrated in both man and animals.

#### ACKNOWLEDGEMENT

The authors wish to thank Professor Shin Hoshikawa and Dr. Kazuo Masuko for many helpful discussion and suggestions during this work.

#### REFERENCES

- 1) Chiku, T. and Igarashi, I., Some applications of semiconductor strain gauges. Presented



- to the 20th Annual ISA Conference and Exhibit. Los Angeles, Calif. October 4-7, 1965.
- 2) Hoppenstein, R., A device for measuring intracranial pressure. *Lancet*, **1**, 90, 1965.
  - 3) Hulme, A. and Cooper, R., A technique for the investigation of intracranial pressure in man. *J. Neurol. Neurosurg. Psychiat.*, **29**, 154-156, 1966.
  - 4) Jacobson, S. A. and Rothballer, A. B., Prolonged measurement of experimental intracranial pressure using a subminiature absolute transduce. *J. Neurosurg.*, **26**, 603-609, 1967.
  - 5) Maeda, S., Ikeyama, A. and Nagai, H., An improved thermoelectric flow meter. *Brain Nerve*, **20**, 709-713, 1968 (in Japanese).
  - 6) Miyamoto, F. and Igarashi, I., Elastic deformation and variation of conductivity in Germanium at room temperature. *Research Report Kogakuin Univ.*, **3**, 1-4, 1956.
  - 7) Miyamoto, F. and Igarashi, I., The application of a slice of Germanium single crystal to the strain gauge element. *Research Report Kogakuin Univ.*, **4**, 1-5, 1957.
  - 8) Nagai, H., Furuse, M., Oka, Y., Ikeyama, A., Maeda, S. and Hoshikawa, S., Effects of urea, mannitol and low-molecular dextran on cerebral edema. *Brain Nerve*, **19**, 519-525, 1967 (in Japanese).