Valuation on MEMS Pressure Sensors and Device Applications

Nurul Amziah Md Yunus, Izhal Abdul Halin, Nasri Sulaiman, Noor Faezah Ismail, Ong Kai Sheng

Abstract**—**The MEMS pressure sensor has been introduced and presented in this paper. The types of pressure sensor and its theory of operation are also included. The latest MEMS technology, the fabrication processes of pressure sensor are explored and discussed. Besides, various device applications of pressure sensor such as tire pressure-monitoring system, diesel particulate filter and others are explained. Due to further miniaturization of the device nowadays, the pressure sensor with nanotechnology (NEMS) is also reviewed. The NEMS pressure sensor is expected to have better performance as well as lower in its cost. It has gained an excellent popularity in many applications.

Keywords**—**Pressure sensor, diaphragm, MEMS, automotive application, biomedical application, NEMS.

I. Introduction

PRESSURE acts as an essential parameter in many real life applications. The pressure always be monitored and maintained at appropriate and constant level to prevent overpressure the device or system, which may cause very severe damages. With this requirement, the pressure measurement becomes a critical issue and this can be done by using a pressure sensor [1], [2]. Generally, the pressure is defined as applied force per unit area. The mathematical expression of pressure, P is given by:

$$P = F / A \tag{1}$$

where F is applied force and A is the area where the force is applied.

This resulting mechanical movement in the elements, which is proportional to the applied pressure, can be used to determine the magnitude of the pressure.

Basically, a pressure sensor is an electronic device used to detect the pressure of an element state. When a pressure is applied to the sensor, the elements inside the sensor, for example a diaphragm, undergo a deformation or change in shape. As a result, this mechanical movement produces an electrical signal that can be easily recognized, detected and measured by other electrical devices [3]. This electrical signal can either be current, resistance, capacitance or voltage. The block diagram shown in Fig. 1 summarizes this process.

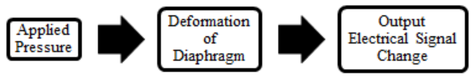

Fig. 1 Basic operating principle of pressure sensor

The micro-electromechanical system (MEMS) is a technology used to create micro-miniature electronic mechanical device. The MEMS pressure sensor is a MEMS sensing device that can detect and measure the external stimuli such as pressure, and then it can response to the measured pressure by having some mechanical movements, for example rotation of motor, to compensate the pressure change. The materials used to fabricate the MEMS pressure sensor are in micro-sized [4]. On the other hand, the demands of MEMS pressure sensor are growing with the vast development in various engineering fields. These include the biomedical application, automotive industry, control system and weather forecast.

Due to further miniaturization and technological development as discussed in our research before [5], the MEMS device is evolved into nano-electromechanical system (NEMS) device [6]. The NEMS is defined as a technology used to create nano-miniature electronic mechanical device [7], [8]. The NEMS pressure sensor is fabricated by using nano-sized wire and nano-sized sensing element. Furthermore, the pressure sensor with NEMS technology has slowly gained an excellent popularity in many applications. This may outstanding due to it will have more advantages than the MEMS technology, especially in term of performance and cost. Thus, the NEMS pressure sensor is estimated to have better performance and lower cost as well as low power consumption [9]. The details of NEMS pressure sensor will be discussed in following part.

II. Type of Pressure Sensor

There are many different types of pressure sensor have been implemented today. They can be classified according to their applications such as high pressure and low pressure, type of measurements such as absolute pressure and differential pressure or their sensing element such as piezo resistive, piezoelectric and capacitive.

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A. Classification Based on Type of Pressure Measurement

The pressure sensor can be classified according to the targeted type of pressure measurement, for example absolute pressure measurement, differential pressure measurement and gauge pressure measurement [10], [11].

The absolute pressure sensor will measure and detect the pressure with reference to an absolute pressure as shown in Fig. 2, or sometimes it is called as perfect vacuum pressure. The perfect vacuum is a state where there is no element appears in this particular atmosphere. However, the absolute pressure sensor only has limited range of applications because in reality, it is impossible to attain an atmospheric condition with perfect vacuum. Besides, the pressure sensor can also be classified as differential pressure sensor. In differential pressure measurement type, the pressure is measured relative to a known reference pressure as shown in Fig. 3. In other words, the differential pressure sensor measures the difference between these two pressures, which are applied pressure and reference pressure. Nonetheless, the gauge pressure sensor operates the same principle as differential pressure sensor. But it measures and senses the pressure with reference to the ambient atmospheric pressure as shown in Fig. 4. This kind of pressure sensor has wide range of application, for example blood pressure measurement and tire pressure monitoring system. However, the measurement of gauge pressure sensor is not consistent. This is because the reference pressure, which is atmospheric pressure, varies according to altitude. Thus, the gauge pressure sensor is only suitable for non-critical application. Sometimes, the gauge pressure sensor is also called as relative pressure sensor.

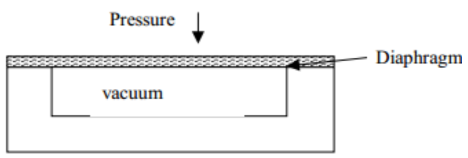

Fig. 2 Absolute pressure sensor [11]

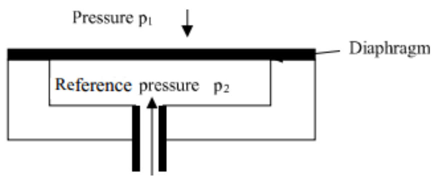

Fig. 3 Differential pressure sensor [11]

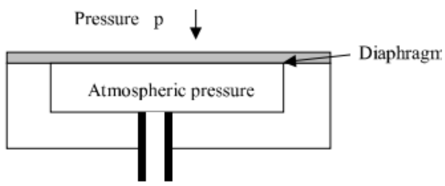

Fig. 4 Gauge pressure sensor [11]

B. Classification Based on Sensing Element

The pressure sensor can also be classified according to its sensing element used. This includes piezoresistive pressure sensor, piezoelectric pressure sensor and capacitive pressure sensor.

Piezoresistive pressure sensor uses the effect of piezoresistive to detect the applied pressure. In other words, the piezoresistive pressure sensor will change in its resistance when it is submitted to a pressure [12]. The piezoresistive pressure sensor consists of an elastic diaphragm mounted with piezoresistive element. When the diaphragm is stretched and deformed due to the applied pressure, the piezoresistive element will change its resistance. The piezoresistive pressure sensor is normally implemented together with Wheatstone bridge circuit to convert the change in resistance into the change in electrical potential. The Wheatstone bridge also provides some advantages to the pressure sensor for example maximizes the sensitivity of the sensor and minimizes the error of the sensor.

As indicated by its name, a piezoelectric pressure sensor will detect the applied pressure by changing its electrical potential as the output of sensor [13]. By comparing with piezoresistive pressure sensor, this type of pressure sensor provides only a change in electrical potential, not the change in electrical resistance. When a pressure is applied, the diaphragm of piezoelectric pressure sensor is deformed. An electrical voltage is generated due to this deformation. The piezoelectric pressure sensor consists of metallized quartz or ceramic material as sensing element. Normally, this type of pressure sensor is designed together with an amplifier to enhance the electrical interface. However, the piezoelectric pressure sensor is very susceptible to shock and vibration.

Capacitive pressure sensor will change in its capacitance proportional to the applied pressure [14]. A capacitive pressure sensor has two conductive plates, which are measuring plate and reference plate. The measuring plate will be flexed when it is subjected to a pressure, whereas the reference plate acts as the reference to the measuring plate with fixed position. Once the measuring plate is flexed, the distance between these two plates is altered. By measuring the distance between these two plates, the value of capacitance will be known as the distance between two plates representing the value of capacitance. The capacitive pressure sensor has some advantages than the piezoresistive and piezoelectric pressure senor. It has very stable operation and the output of measurement is highly linear. However, it is very sensitive to high temperature and its construction is more complex than other types of pressure sensor.

III. Theory of Operation

In this section, the theory of operation of piezoresistive pressure sensor, piezoelectric pressure sensor and capacitive pressure sensor are discussed. Each of these types of pressure sensor use different operating principle. For example, piezoresistive pressure sensor uses the principle of change in resistance, piezoelectric pressure sensor uses the principle of change in electrical potential and capacitive pressure sensor uses the principle of change in capacitance.

C. Piezoresistive Pressure Sensor

The piezoresistive pressure sensor detects the change of external pressure by changing its resistance. The piezeoresistive pressure sensor consists of a semiconductor material such as silicon mounted on the elastic diaphragm as shown in Fig. 5. This semiconductor material acts as piezoresistive sensing element in the pressure sensor to detect the pressure change.

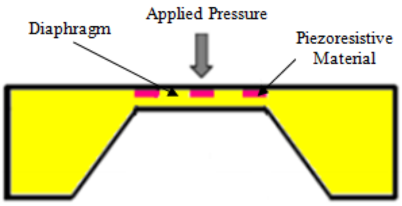

Fig. 5 Piezoresistive pressure sensor

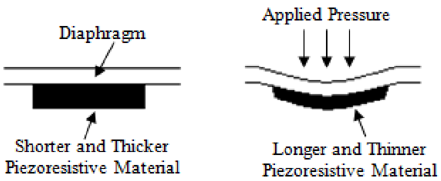

Fig. 6 Deformation of piezoresistive material

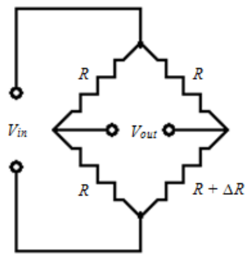

Fig. 7 Piezoresistive pressure sensor in Wheatstone bridge

When a pressure is applied, the diaphragm is flexed as well as the piezoresistive material. This means that the applied pressure causes the piezoresistive material to become slightly longer and thinner as shown in Fig. 6. This deformation results in the change in resistance of the piezoresistive material, and the mathematical expression of the resistance, R is given by:

$$R = \rho L / A \tag{2}$$

where ρ is the resistivity of the material, L is the length of the piezoresistive material and A is the cross-sectional area of the piezoresistive material. Since cross-sectional area is equal to the width multiply with thickness; therefore, (2) becomes:

$$R = \rho L / (Wt) \tag{3}$$

where w is the width of the piezoresistive material and t is the thickness of the piezoresistive material. Since the piezoresistive material becomes longer and thinner when it is subjected to a pressure, from (3), it can be said that the resistance of the piezoresistive material is increased. On the other hand, the piezoresistive pressure sensor is normally implemented on a Wheatstone bridge as shown in Fig. 7. The piezoresistive pressure sensor implemented on a Wheatstone bridge provides more linear output, more sensitive to the pressure change and reduce the measuring error.

From Fig. 7, the ΔR is the resistance change of the piezoresistive pressure sensor and the R is a resistor with fixed resistance. Hence, the expression of output voltage in Fig. 7 is given by:

$$V_{out} = -\,(0.5\Delta R / (2R + \Delta R))\, V_{in} \tag{4}$$

where V_{out} is the output voltage of Wheatstone bridge and V_{in} the input voltage of Wheatstone bridge. Thus, by measuring the output voltage of Wheatstone bridge, the change in pressure can be determined.

D. Piezoelectric Pressure Sensor

When a pressure is applied to the piezoelectric pressure sensor, this will result in change in electrical potential. The sensing element of piezoelectric pressure sensor is made from crystal element such as quartz or ceramic, which is mounted on the diaphragm as shown in Fig. 8. The natural electrical properties of crystal make it suitable to be used as sensing element in piezoelectric pressure sensor [15]. This electrical property is an electrical positive charge will be generated when the crystal is stressed as indicated in Fig. 8. The stronger the crystal is stressed, the more the positive charge will be generated.

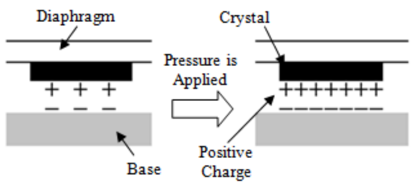

Fig. 8 Piezoelectric pressure sensor

The generated positive charge from the crystal results in a flow of electrical charge. This means that an electrical potential is produced between the crystal and the base in the pressure sensor. The relationship between generated potential, V and the charge, Q is given by:

$$V = Q / C \tag{5}$$

where C is the capacitance between the crystal and the base of piezoelectric pressure sensor.

From (5), it can be said that the generated voltage is directly proportional to the generated charge from the crystal. When the applied pressure in increased, more charges is generated, therefore the generated voltage is also increased. By measuring the potential difference between the crystal and the base, the value indicates the pressure that is applied to the pressure sensor. The relationship between applied pressure and the generated potential by piezoelectric pressure sensor is shown in Fig. 9.

E. Capacitive Pressure Sensor

As mentioned above, a capacitive pressure sensor will change in its capacitance when it is subjected to a pressure. A capacitive pressure sensor contains two conductive plates and an elastic diaphragm as shown in Fig. 10.

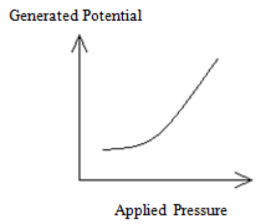

Fig. 9 Structure of capacitive pressure sensor

When a pressure is applied on the diaphragm, the conductive plate that is attached to the diaphragm is flexed together with the diaphragm. The bending of the plate causes the distance between these two plates to be decreased. By applying the equation of capacitance, *C*:

$$C = \varepsilon_r \varepsilon A / d \tag{6}$$

where ε_r is relative permittivity, ε is dielectric constant, *A* is the area of the conductive plates and *d* is the distance between two plates.

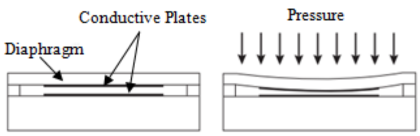

Fig. 10 Structure of capacitive sensor

Thus, from (6), it can be said that the capacitance is inversely proportional to the distance between two conductive plates. In other words, the higher the applied pressure, the shorter the distance between two conductive plates, the higher the capacitance is generated. The relationship between applied pressure and the generated capacitance by capacitive pressure sensor is shown in Fig. 11.

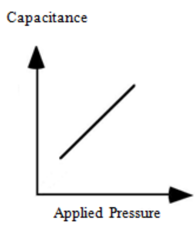

Fig. 11 The relationship of applied pressure and generated capacitance

To improve the sensitivity and accuracy of measurement, the structure of capacitive sensor is normally designed as indicated in Fig. 12. It can be observed that the diaphragm is designed at the center of two conductive plates. With this design, two capacitors are formed in the pressure sensor, such as C_1 and C_2. The equivalent circuit of this design is also shown in Fig. 12. It can be seen that these two capacitors form a voltage divider circuit. The voltage across the capacitor, C_2 can be known by calculating the reactance of the capacitors and applying the equation of voltage divider. The reactance of a capacitor, *X* is given by:

$$X = 1 / j\omega C \tag{7}$$

where *j* is a complex number and ω is the angular frequency. And the equation of voltage divider according to Fig. 12 is given by:

$$V_2 = X_2 V_{DD} / (X_1 + X_2) \tag{8}$$

where V_2 is voltage across capacitor C_2. This voltage across the capacitor, C_2 is related to the capacitance of C_2. This means that the change in the external pressure can be detected and determined by measuring the output voltage of C_2.

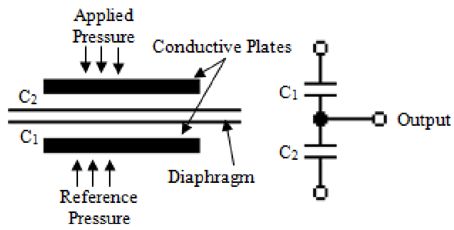

Fig. 12 Capacitive pressure sensor with equivalent circuit

IV. Fabrication of Pressure Sensor

There are few important steps to fabricate the pressure sensor, for example, deposition, etching, photolithography, bulk micromachining and oxidation.

At the beginning of the process, a pure silicon wafer is used as the substrate as shown in Fig. 13 (a). Diffusing oxygen to the silicon substrate through thermal oxidation forms a thick oxide layer. The silicon reacts with the oxygen to form silicon dioxide. This thermal oxidation is shown in Fig. 13 (b).

Then, a thick layer of silicon is deposited by using radio frequency (RF) sputtering and followed by a thick layer of aluminum film by using thermal evaporation. From Fig. 13 (c), it is observed that a thick layer of silicon film is formed on the silicon dioxide layer and followed by a thick layer of aluminum film on the silicon film. After that, photolithography and etching process are carried out to pattern the silicon and aluminum layer as indicated in Fig. 13 (d) to form the piezoresistors.

The position of these piezoresistors plays an important role in determining the sensitivity of the pressure sensor. Theoretically, when a pressure is applied to the diaphragm, the maximum pressure will be occurred at the edges of the diaphragm [16]. As a result, piezoresistors should be located as close as possible to the edges of the diaphragm. After the formation of piezoresistors, the aluminum later is etched away by using wet chemical etching process, and the silicon layer is etched away through the reactive ion etching process by using SF_6 plasma.

Next, the annealing process is carried out to deposit a layer of polysilicon [16]. The polysilicon is patterned through etching process as shown in Fig. 13 (e). A layer of aluminum is deposited on the top through thermal evaporation, and the excessive aluminum layer is etched away by using aluminum etchant to pattern the aluminum layer as shown in Fig. 13 (f). At the end of this process, an electrical connection is formed to connect the piezoresistors.

In the following step, the oxide layer at the bottom of substrate is patterned from backside to form a cavity as shown in Fig. 13 (g). The remaining oxide layer acts as a mask during the anisotropic etching of the substrate. Then, the anisotropic etching process is performed on the silicon substrate. This etching process is performed in potassium hydroxide solution to form the diaphragm. The result of this process is shown in Fig. 13 (h).

The processes of Figs. 13 (g) and (h) will determine the dimension of the diaphragm. Consequently, the dimension of the diaphragm will determine the sensitivity and the pressure operating range of the pressure sensor [16]. The thicker diaphragm will have wider pressure operating range, but lower sensitivity. Besides, the thinner diaphragm will have higher sensitivity, but shorter pressure operating range. Thus, the etching time of the oxide layer and the silicon substrate must be controlled precisely to enhance the design with optimized specification. The longer the etching time, the more the layer is removed, the thinner the diaphragm is.

Finally, the entire oxide layer at the bottom of the silicon substrate is etched as shown in Fig. 13 (i), and a thick layer of glass is bonded at the bottom of the silicon substrate through thermal anodic bonding process. The bonding process of glass is shown in Fig. 13 (j). With this, the fabrication processes of a pressure sensor are completed. These fabrication processes are summarized in Fig. 13.

V. Device Application

Nowadays, the MEMS pressure sensor plays an essential role in many fields of applications such as automotive applications and biomedical applications to monitor and measure the external pressure. In automotive applications, the MEMS pressure sensor is integrated into the automotive system to ensure the safety of the driver and passengers, for example, tire pressure monitoring system, diesel particulate filter, brake booster and others. On the other hands, the MEMS pressure sensor is also used in biomedical applications. This includes the blood pressure monitoring system, respiratory monitoring system, kidney dialysis regulation system and others.

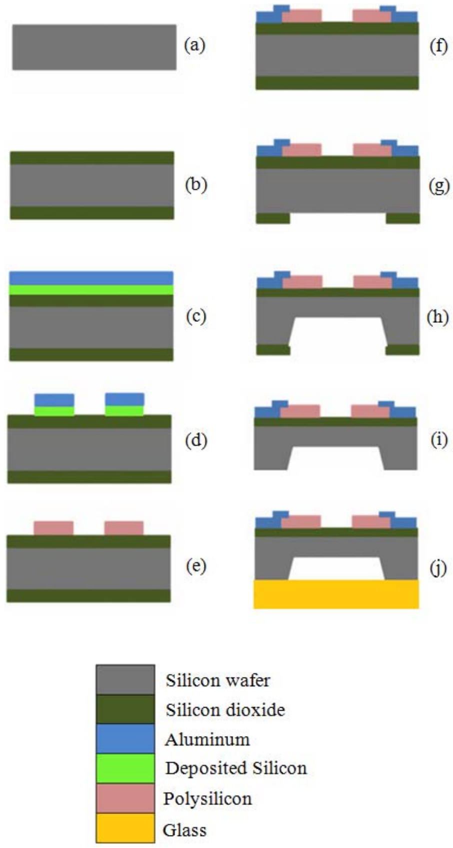

Fig. 13 Summary of fabrication processes of a pressure sensor (a) Pure silicon wafer as substrate. (b) Thermal oxidation to form oxide layer. (c) Deposition of silicon and aluminum layer (d) Etching and patterning of silicon and aluminum layer to form piezoresistors. (e) Annealing process to deposit polysilcon. (f) Depostion and patterning of aluminum to form electrical connection. (g) Patterning of oxide layer to form a mask for anisotropic etching. (h) Anisotropic etching of silicon substrate to for the diaphragm. (i) Etching of entire oxide layer. (j) Anodic bonding of glass

F. Automotive Applications

In automotive application, the MEMS pressure is widely used in different vehicle systems. The MEMS pressure sensor is integrated into the tires of the vehicle, either internally or externally to measure and monitor the pressure of tires [17]. Normally, the tire pressure monitoring system is a closed-loop system that consists of a MEMS pressure sensor, analog-to-digital converter (ADC), microcontroller, and radio frequency (RF) transmitter. The MEMS pressure sensor will monitor the pressure of tires from time to time, and transmit the tire pressure information to the screen display through radio frequency signal. If the pressure of tires is dropped below certain limit, the pressure sensor will send a signal to warn the driver.

The implementation of MEMS pressure sensor in tire pressure monitoring system provides many advantages. This system ensures the safety of driver. Under-inflated tires have higher probability in sudden tire failure, which will lead to severe accident. With this monitoring system, the driver can take early precaution to prevent the tire failure from happening. Moreover, the pressure sensor in tire monitoring system has extended the life of tires and decreased the frequency of maintenance. This is because this monitoring system reduces the occurrences of under-inflated tires that may result in tire failure.

On the other hands, the MEMS pressure sensor is also designed in airbag firing system. When the vehicle experiences the strong impulsive force, there is a sudden change of pressure where the impulsive force is applied. The MEMS pressure sensor will detect this sudden change of pressure and will send a signal to fire the airbag as shown in Fig. 14. In newer vehicle system, the side airbag is also installed in the vehicle doors [18]. The fastest way to fire the side airbag can be achieved by measuring the sudden pressure change inside the door, which is deformed during the crash. When the door is deformed, the pressure inside the door experience sudden increment of pressure, thus the MEMS pressure sensor will detect this sudden change of pressure and send a pulse signal proportional to the pressure change inside the door to launch the airbag.

The diesel particulate filter is used to reduce the diesel particulate matter or soot from the exhaust gas. The accumulated particulate can be burning off by using active technology. The active technology will burn the filter to a very high combustion temperature by using fuel burner. As soon as the filter load reaches a pre-determined level, the engine will inject the exhaust gases and heat it. In this active filter system, the pressure of injected exhaust gas is measured to ensure adequate amount of gases is injected [18]. In this application, the gauge pressure sensor is normally used. The MEMS pressure sensor in exhaust system of diesel particulate filter is shown in Fig. 15.

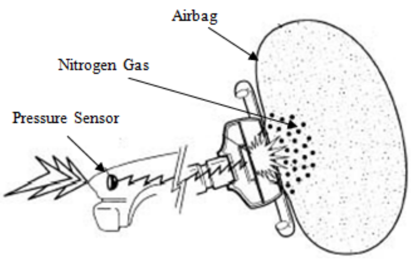

Fig. 14 MEMS pressure sensor in airbag firing system

The MEMS pressure sensor is also implemented in the exhaust gas recirculation system of a vehicle [17]. The product of combustion in engine system is nitrogen oxide, which is a pollutant gas. To reduce the emission of nitrogen oxide, a portion of this exhaust gas will be recirculated back to the combustion engine. A MEMS pressure sensor is implemented at the exit of the combustion engine to control the valve of recirculation system. If the released exhaust gas is high in concentration, the pressure sensor will detect the sudden increase in pressure at the exit of the combustion engine. The pressure sensor will send a signal to the valve of recirculation system so that the valve will open with larger dimension. AS a result, more exhaust gas is recirculated back to the combustion engine.

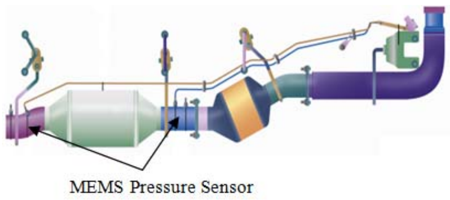

Fig. 15 MEMS pressure sensor in exhaust system of diesel particulate filter

In addition, the MEMS pressure sensor is also used as brake booster in vehicle braking system [18]. The brake booster is used to amplify the braking force applied by the driver to the brake pedal. The MEMS pressure sensor used has two pressure chambers that are divided by an elastic diaphragm as shown in Fig. 16. In idle condition, both chambers have an equal vacuum pressure. When the brake pedal is pressed, an air valve opens and allows the pressure of one of the chambers to increase to atmospheric pressure. Since the chamber with atmospheric pressure has higher pressure than the chamber with vacuum pressure, this causes the diaphragm to flex. The deformation of the diaphragm increases the force applied by the driver to the braking system.

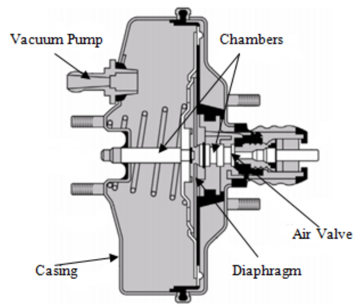

Fig. 16 MEMS pressure sensor asbrake booster [18]

G. Biomedical Applications

The MEMS pressure sensor has a wide application range in biomedical field. The most popular application of MEMS pressure sensor in biomedical field is blood pressure measuring system [19]. An analog-to-digital converter (ADC) is usually used together with the MEMS pressure sensor so that the measured pressure can be digitized and the data can be transmitted and viewed from a computer. The blood pressure measuring system using MEMS pressure sensor provides lower manufacturing cost if compared to the conventional blood pressure monitoring system. This because the MEMS pressure senor has very small size, which is in micro-scaled. Thus, the MEMS pressure sensor can be easily sterilized in a pre-calibrated package after each use. Besides, since the MEMS pressure sensor is in micro-scaled, it only occupies little amount of space and will not block the sight of doctor especially during operation as shown in Fig. 17. Fig. 17 is a blood pressure monitoring system by using MEMS pressure sensor. The pressure data is transmitted in radio frequency signal. By using the MEMS pressure sensor in blood pressure measuring system, the vital sign of a patient can be monitored anytime especially during emergency case in ambulances.

Moreover, in eye surgery, the MEMS pressure sensor is used to measure and control the vacuum level of the fluid pump machine [19]. This machine is used to remove the fluid from the eye that is cleaned of debris. The MEMS pressure sensor plays an important role to maintain the pressure in the machine, which is lower than the atmospheric pressure, so that the fluid can be removed as fast as possible from the eye.

The MEMS pressure sensor is also used in ventilator to monitor the respiratory of patients as well as the breathing cycle [19]. When the patient is inhaling, the pressure sensor will indicate a high-pressure value. When the patient is exhaling, the pressure sensor will indicate a low-pressure value. With this, the medical contained in the ventilation system can be released accurately into the body of patients at the proper time during the breathing cycle.

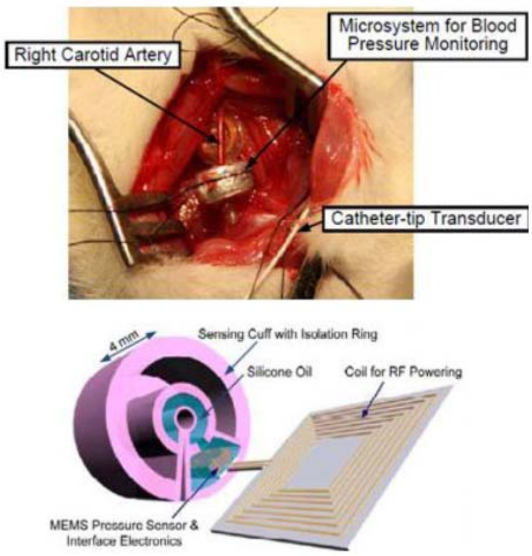

Fig. 17 MEMS pressure sensor in blood pressure monitoring system

Furthermore, the MEMS pressure sensor is also used in kidney dialysis. Two pressure sensors are used at the inlet and outlet artery to monitor the blood pressure of patient and the pressure of dialysis solution. Besides, it is also used to regulate the flow rates of dialysis solution into the body. If the pressure sensor detects the sudden increment or decrement of the flow rate, a signal will be sent to the solution-controlling valve to slower down or speed up the flow rate. As a result, the flow rate of dialysis solution is maintained at a constant speed by controlling the solution pressure.

As indicated in Fig. 18, the MEMS pressure sensor is integrated into the pill, which is known as smart pill. This smart pill is used to monitor the flow rate in the stomach and intestine. It is also used to detect for obstructions and blockages in intestine when the pill is not properly delivered and digested by the patient. Nowadays, the smart pill is integrated with MEMS optical sensor, MEMS pH sensor and MEMS navigation sensor [20]. The MEMS optical sensor in the smart pill will be providing the optical image inside the body when it is activated. And of course, the MEMS pH sensor in the smart pill is used to detect the pH level of certain body part. Besides, the smart pill with MEMS navigation sensor will provide the location of the pill inside the body. It will indicate the blockages in the digestive system if it is found that the smart pill has stayed at fixed location for a certain periods of time. All of this detected data will be transmitted wirelessly to a receiver through radio frequency signal.

Fig. 18 MEMS pressure sensor in smart pill

VI. Nanotechnology

Further miniaturize of MEMS pressure sensor into NEMS device offers better performance and lower manufacturing cost. The NEMS pressure sensor consumes less energy than the MEMS technology. With these advantages, the NEMS pressure sensor has increasingly attract attentions in recent years.

By reviewing the IEEE research paper with entitled "Design and Simulation of Low Pressure Piezoresistive NEMS Sensor Using Analytical Models for Biomedical Applications" by Saloni Chaurasia, the NEMS pressure sensor is designed by using a square diaphragm as shown in Fig. 19 [21]. The diaphragm is designed with the length of 1500nm and thickness of 100nm. The NEMS pressure sensor is designed for a pressure operating range of 5kPa. These design parameters is tabulated in Table I.

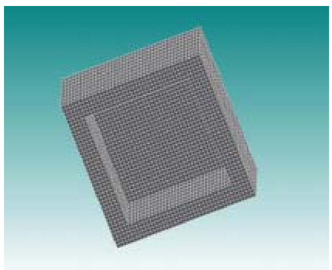

Fig. 19 NEMS pressure sensor with square diaphragm [21]

TABLE I
THE NEMS PRESSURE SENSOR DESIGN PARAMETERS [21]

Pressure Range (kPa)	Diaphragm Length (nm)	Diaphragm Thickness (nm)	Diaphragm Deflection (nm)	Sensitivity (mV/V)
5	1500	100	3.753	0.156

The designed NEMS pressure sensor is simulated as finite element model (FEM) by using Conventorware CAD software. The results of simulation are shown in Figs. 20 and 21. Fig. 20 shows that the deflection of diaphragm is directly proportional to the applied pressure. Besides, Fig. 21 also shows linear relation between the sensor output and applied pressure.

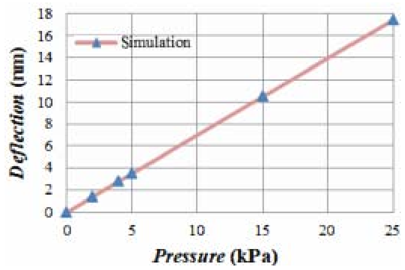

Fig. 20 Linear relation between diaphragm deflection and pressure [21]

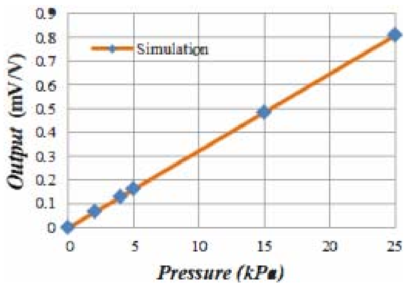

Fig. 21 Linear relation between sensor output and pressure [21]

Hence, from the results of FEM simulation, it can be concluded that the NEMS pressure sensor has highly linear output. Besides, the NEMS pressure sensor has high sensitivity, which is 0.16mV/V at the range of 5kPa [21]. And the diaphragm deflection of the designed NEMS pressure sensor is 3.486nm [21]. This design is potentially useful for the low pressure measurement applications.

VII. Conclusion

A pressure sensor is an electronic device used to detect and measure the external pressure. It can be classified either according to the types of pressure measurement such as absolute pressure, differential pressure and gauge pressure, or according to the types of sensing element, for example piezoresistive, piezoelectric and capacitive. Besides, the MEMS pressure sensor has wide range of application, especially in the fields of automotive and biomedical. The most popular uses of MEMS pressure sensor in automotive application are tire pressure monitoring system and airbag firing system. In addition, the most popular use of MEMS pressure sensor in biomedical application is blood pressure measuring system. Due to further miniature, the NEMS pressure sensor is introduced. The NEMS pressure sensor has many advantages than MEMS technology in term of cost, performance and energy consumption.

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