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# The testing machine for micro-sensors subjected to different states of Pressure and temperature

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***Abstract*—The primary purpose of this research is to design and build up a test machine which provides a testing environment for semiconductor micro sensors made by micro-electro-mechanical systems (MEMS) technique. It combines computer auxiliary software SPARTAN into the global data-gathering system in addition to the main frame of the pressurized chamber. Different states of temperature and pressure subject to the testing of commercial pressure sensors was not only successfully achieved but the real-time sampling of the MEMS sensor output also worked well.**

## I. Introduction

The fields of the application about pressure sensor are so wide such as mechanical, aerospace and chemical industry even biomedical. It is a very mature process using MEMS technology to fabricate a micro pressure sensor in commercial yield. In the academic and industry opinions, they are points of coming pressure sensor process to broaden the usage range, raise the precision and lower the cost [1-4].

There is a great quantity market demand on the extreme high load pressure sensor (1000 psi to 3000 psi) used in the industry application filed. We utilized intrinsic superiors of the silicon and used MEMS silicon-base technology to fabricate a high pressure sensor successfully [5]. The testing of pressure sensor mentioned above involves a wide range pressure load, from ambient pressure to extreme high pressure, however it is not easy to find a suitable testing machine to process the experiment. That is why we design a testing machine to measure the different states of pressure and temperature and address a novel method of data post process. We designed and fabricated a pressure testing machine which can supply a high pressure load and control the temperature in the testing chamber, the picture of this machine is shown in Fig.1. We also used a data gathering instrument to record some parameters including the output voltage of chip (V), chamber pressure (P) and chamber temperature (T), then we used software, Matlab, to process the data what we recorded. Finally, we can get a three dimension curve (P-V-T curve) used to realize the performance of the pressure sensor.

## II. Design principle

Temperature drift is a very important issue in the application of silicon pressure sensors. Temperature-induced errors of piezoresistive sensors' output voltage can be defined by two paramters: temperature effect on offset and temperature effect on span (sensitivity). Although the end-user is interested only in the combined effect, these two parameters must be treated separately during making the temperature compensation for micro sensors. There are three techniques used to compensate the temperature effect of piezoresistive sensors in general: passive compensation at the sensor, active compensation in the signal-conditioning electronics and software compensation when using a microprocessor. No matter what kinds of compensation approaches are used, we must find out the performance of a sensor at final. Conventional testing methods may be as follows: put the sensor into a sealing chamber, which can adjust temperature and pressure; then record the output of this sensor. According to the equation of state correlating pressure with temperature in a control volume of a thermodynamic system, temperature raises automatically as increasing the pressure in a sealing chamber. In our research, we also put a homemade high pressure load pressure sensor into a sealing chamber then we apply different pressure and temperature to this chamber. We use a data acquisition setup to record three parameters, P, V and T, and store a large number of data in an Excel file. We use a heated setup containing temperature control module, thermal couple, SCR heated module and heated coil to fix the temperature on a desired temperature no matter how the pressure is regulated. We hope that the solution can be used to reach the purpose what control temperature and pressure simultaneously.

The main problems what we meet in our research can be separated two parts: first trouble is the coupled effect on pressure and temperature, the second one is the safety and pressurization of testing machine. As we know that according to the ideal gas law ( $P \cdot \overline{V} = nRT$ ) pressure and temperature are coupled-physics in a control volume, in other words, temperature will be raised by an increasing of the pressure in a sealing chamber. We can not only get the unique parameter subject to some controlled state but also continued variation changed with variable state after setting a data acquisition in our research. For example we can gather the output voltage of a pressure sensor undergoing the sustained changes of chamber pressure and temperature. We fit the parameters (P, V, T) to get an equation has a functional relation V=f(P, T) in which the output voltage(V) is corresponding to the temperature(T) and pressure(P), and plot the equation as a 3-D surface. If we fix one of three variables we can derive a two dimension curve from the equation. That is to say, we can fix the chamber temperature (T) to get a 2-D curve which has two variables, P and V, and the meaning of this curve is that we can find the relationship between chamber pressure and output voltage during a constant temperature. By the same way, we can get an equation contains variables, T and V, in a constant pressure condition. We can realize the thermal effect of silicon-base pressure sensor relying on this approach.

## III. Mechanism Design

The pressure sensor testing is usually processed in a sealing chamber, and its output signals varying with the pressure variation in the chamber are recorded. They are very important that the operating staff's safety and the leakage against of a chamber when the positive pressure of the chamber becomes more and more high. We design a positive pressure system containing a heated module to solve the problems expounded above. The system can be separated four parts: first part is the framework of global testing machine; the second is a positive pressure transmitting system; the third is positive pressure chamber with a safety mechanism, and the final is a module for heating. Every part of this system is described as follows.

### A. *Framework of testing machine*

The global dimension of the testing machine is 100cm×70cm×70cm and its schematic diagram is shown in Fig. 2. We assemble the strengthen wheels under the chassis as a wagon for moving conveniently even if it bears the dead weight, and a nitrogen gas cylinder is presented to supply gas pressure for the chamber. The frame is made up by L-section medium carbon steel for sustaining the structure stability. We dispose two kinds of AC voltage inputs of 110V and 220V respectively, to deal with different power requirement. The higher voltage is provided as a power to heat the headed coil and another is used to supply the other usages.

### B. *Positive pressure transmitting system*

We use an extreme pressure tube (EP tube) which can withstand a pressure more than 8000psi and 8mm steel tube to connect high pressure nitrogen gas cylinder with a sealing chamber by a stainless tube with 8mm diameter, and install a filter in the outlet of a gas cylinder. To make sure the precision of the experiment, we set up an accurate gas regulator in the entrance of chamber. The pictures of these parts after fabrication and assembly are shown in Fig. 3, and Fig. 4 is a sketch map of piping disposition.

### C. *Positive pressure chamber and safety mechanism*

A pressure in the chamber is very high when we perform the experiment. The sidewall inside a chamber must stand the pressure larger than 300psi. In other words, it bears the pressure over 20 kilogram weight per square meter, so the chamber is made by stainless steel and its stiffness should be strong enough. Besides, we lock 12 screws around the periphery of the chamber to ensure the safety for operators during experiment.

We use a hydraulic pumping system to control the open and closing of the heavy cap of the high pressure chamber. For avoiding gas leakage during operation, we choose a special feed-through cluster which contains 20 wires to transmit the input and output signals. We flange on the interfaces of upper cap and lower chamber-holder, and use a ceramics sealing made of oxygen-free copper (OFC) as a packing to make sure the perfect contact is airtight. Fig. 5 is a sketch map of wire connection and the picture of the chamber after assembly is shown in Fig. 6.

### D. *Heating module*

We use a traditional heating module containing a heating coil and a heat spread instead of using an IR heating lamp. The quartz lamp of IR heater can't withstand the high pressure larger than 100psi, so it doesn't fit to the requirement of the test machine herein. Another point that we think about is to search a suitable gasket against the leakage at the interfaces between chamber and electric wires of the heated module. A thermocouple connected with a thermal feedback controller to manipulate the temperature of the chamber is shown in Fig. 7.

## IV. Experiment Testing and Discussion

The experiment setup in our research is instilled as Fig. 4 and Fig.5. A homemade piezoresistive pressure sensor is assembled within the testing machine to be tested, and a picture of the sensor is shown in Fig. 7. We used a power supply offering a constant 5V voltage as a bias to this sensor. After checking all of the safety mechanism including the valves and the screws, we adjust the pressure regulator to control the pressure in the chamber. We raise the pressure from 0 to 100 psi first, and drop the pressure back to the normal atmospheric pressure. The data gathering equipment records the pressure sensor output voltage (V) and temperature (T) and pressure (P) in the chamber. The gathering frequency is 500 ms and the testing process maintains about 10 minutes. When we finish a testing round, the quantity of the data including P, V and T what we can get is more than one thousand, all of them will be stored in an Excel file. Then, we use mathmatical software, Matlab, to process so many experiment results for curve-fitting of PTV-surface

We set the output voltage of sensor as a function, $z = f(x, y)$, where x is the pressure and y is temperature, and assume that the equation of function f as follows:

$$\begin{aligned} f(x,y) = z &= a_0 + a_1 y + a_2 y^2 + a_3 y^3 \\ &+ b_0 x + b_1 xy + b_2 xy^2 + b_3 xy^3 \\ &+ c_0 x^2 + c_1 x^2 y + c_2 x^2 y^2 + c_3 x^2 y^3 \\ &+ d_0 x^3 + d_1 x^3 y + d_2 x^3 y^2 + d_3 x^3 y^3 \end{aligned} \quad (1)$$

The $a_0$、$a_1$、$a_2$、$a_3$、$b_0$、$b_1$、$b_2$、$b_3$、$c_0$、$c_1$、$c_2$、$c_3$、$d_0$、$d_1$、$d_2$、$d_3$ are undetermined coefficients, then we use least-square error method: set $S = \sum (Z - Z_i)^2$

and $\frac{\partial S}{\partial a_0} = 0$ 、 $\frac{\partial S}{\partial a_1} = 0$ 、 $\frac{\partial S}{\partial a_2} = 0$ and so on, where the Zi is experiment values, to get 16 equations. We can use Gaussian elimination to solve the undetermined coefficients. Substituting the coefficients into the equation we can get the output voltage equation. We use Matlab to plot the curve, shown in Fig. 8.

When we finish the post-process to fit the PTV surface and get its equation, we can fix one parameter among others, for example the temperature T, to get the P-V curve, we also can get the T-V curve by the same way, they are shown in Fig. 9. and Fig. 10. Using those curves, we can get more information about the performance of sensor output, for example the linearity, sensitivity, hysteresis and so on...

## V. Conclusion

We can realize the performance of a pressure sensor relying on the purpose in our research. We can use our testing machine to control the temperature and pressure in the chamber and record the output signals simultaneously, and estimate some characteristic of a sensor quickly by the novel data post-process.

## VI. Figures

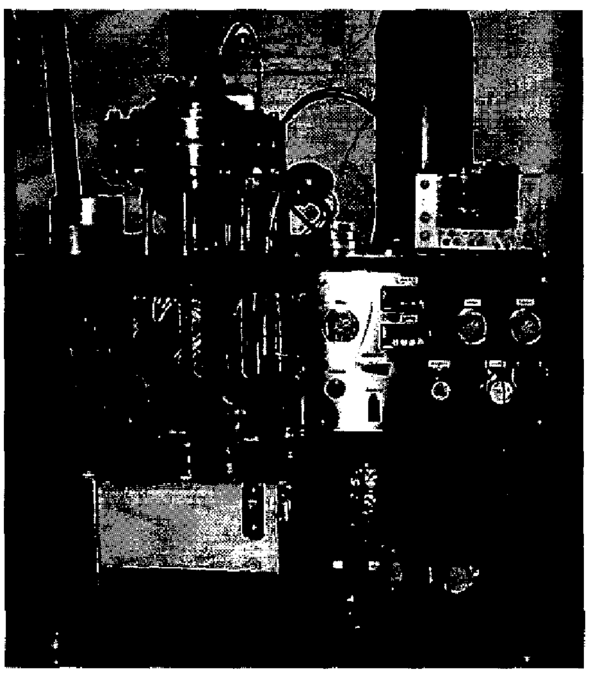


Fig. 1. Pressure testing machine

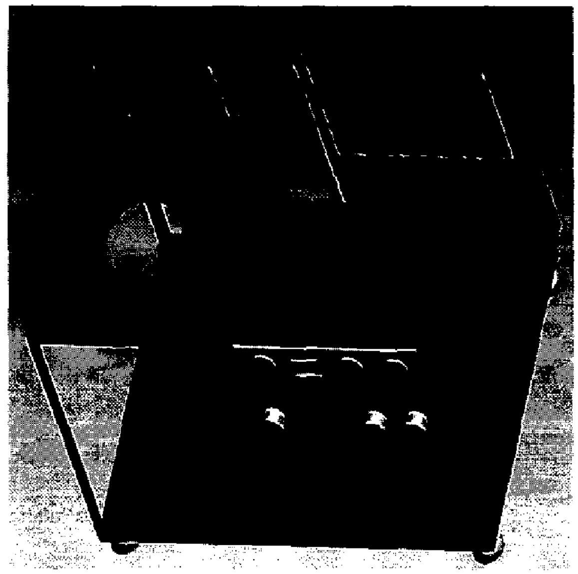


Fig. 2. Framework of testing machine

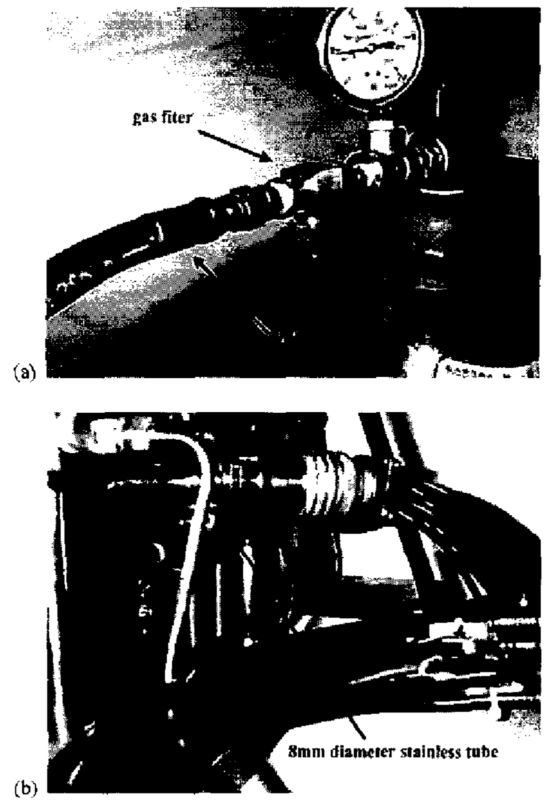



Fig. 3. Positive pressure transmitting system

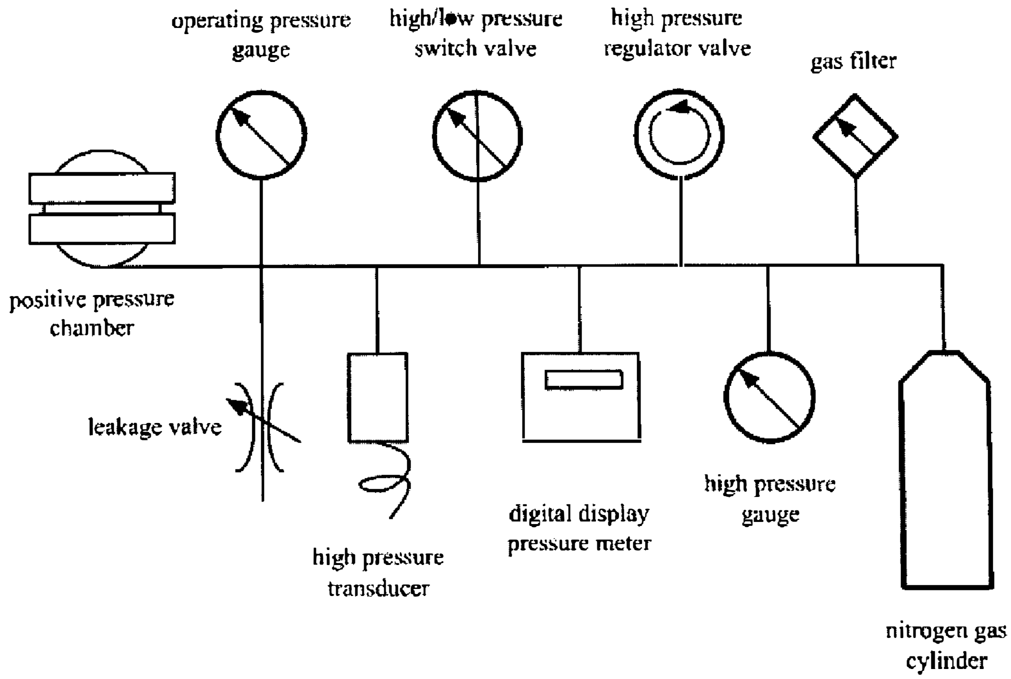



Fig. 4. Sketch map of piping

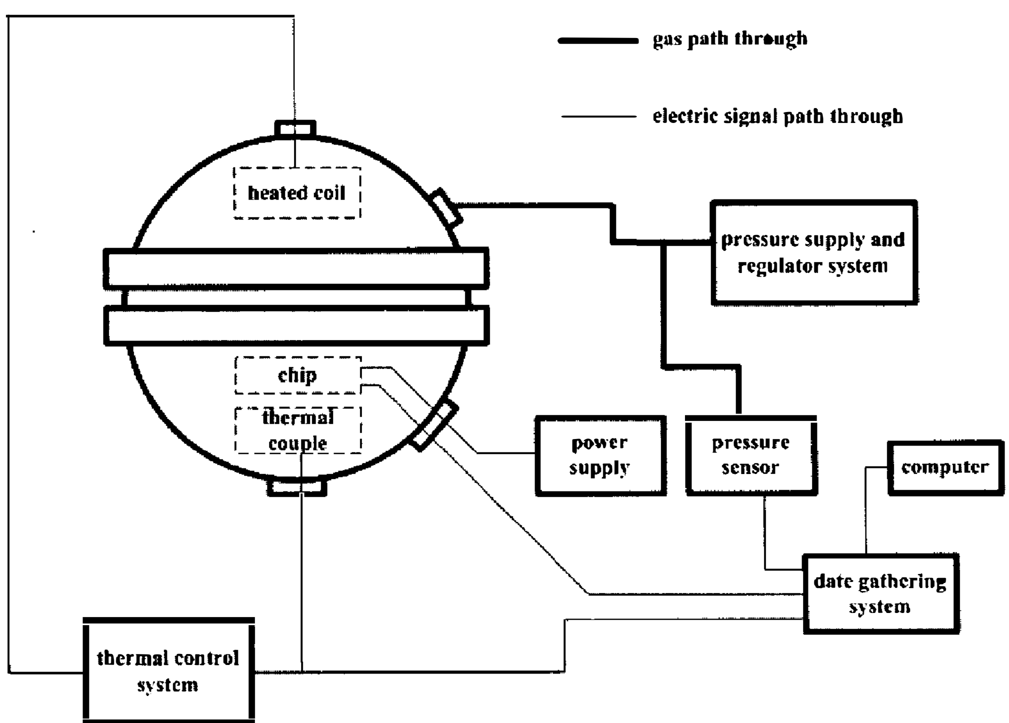



Fig. 5. Sketch map of wire connection

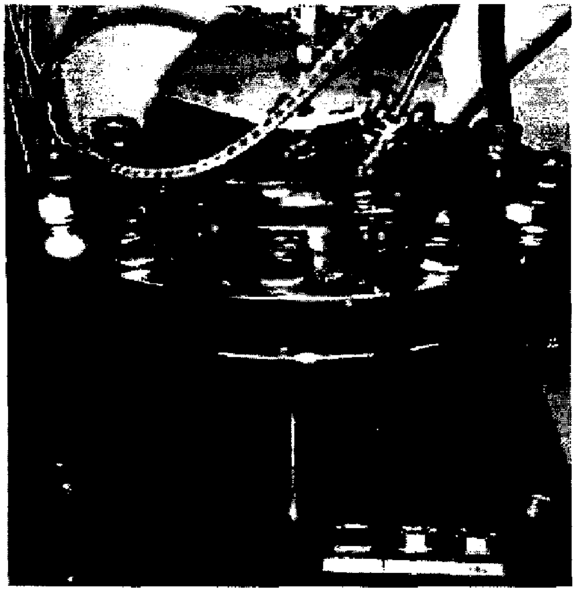
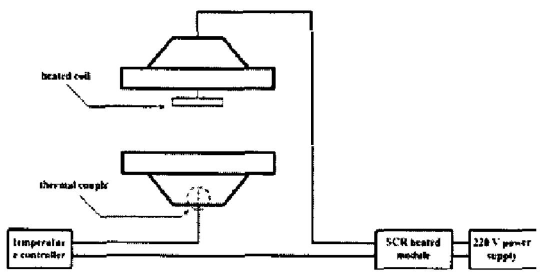
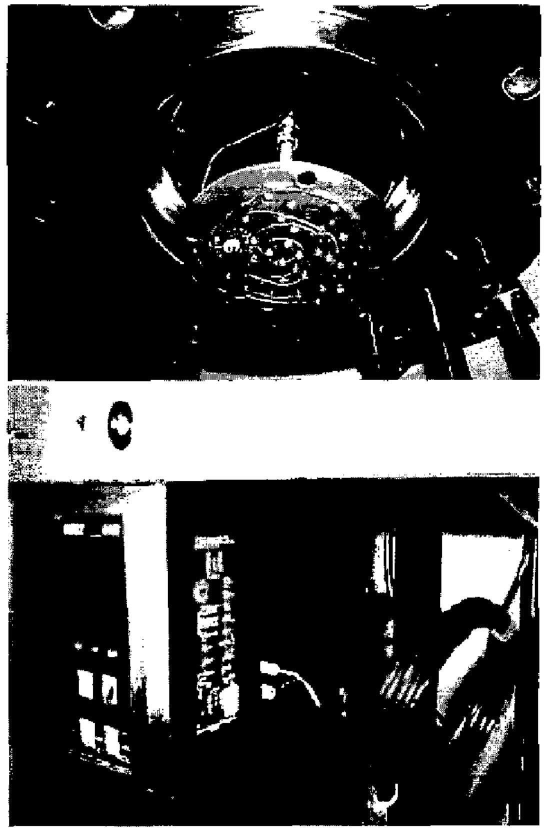


Fig. 6. Positive pressure chamber and safety mechanism




(a)

(b)



(c)

Fig. 7. Sketch of the thermal module (a) The heated and controller module (b) Heated coil (c) Headed controller

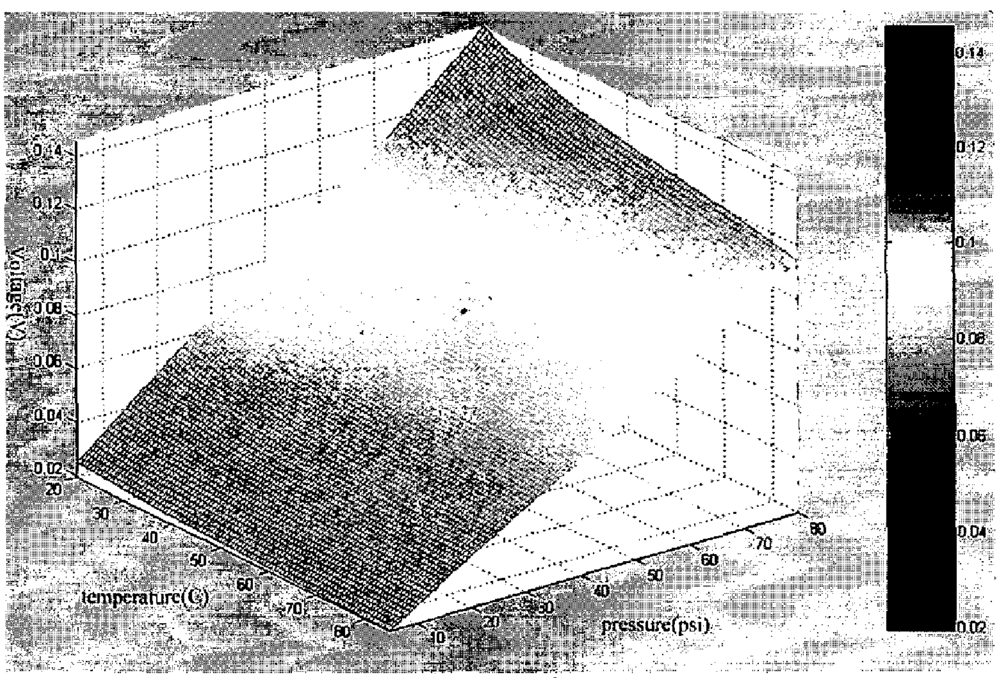



Fig. 8 P-V-T surface

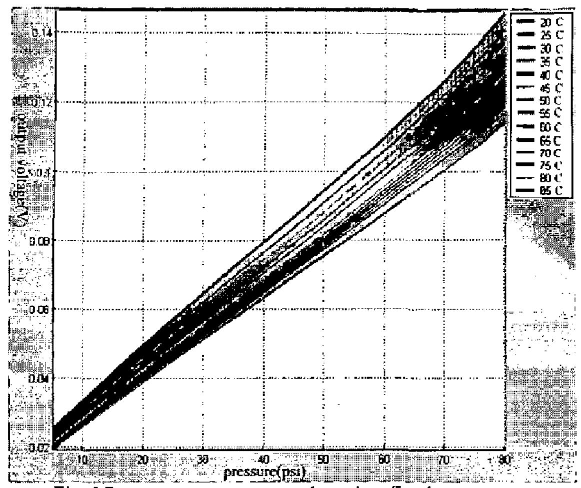



Fig. 9 Pressure versus output voltage in a fixed temperature

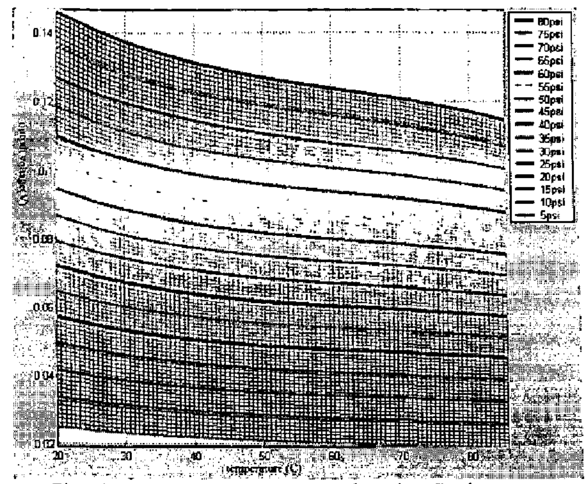



Fig. 10 Temperature versus output voltage in a fixed pressure

## VII. Reference

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