DESIGN AND FABRICATION OF AN ELECTRONIC SYSTEM FOR PRESSURE AND TEMPERATURE MEASUREMENT IN THIN FILM DEPOSITION SYSTEMS

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A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science (Electronics and Instrumentation) in the School of Pure and Applied Sciences of Kenyatta University

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree or any other award in any other University

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DEDICATION

This thesis is dedicated to my parents.

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LIST OF ABBREVIATIONS AND ACRONYMS

AD	Address and data signals
ADC	Analog to digital converter
C	C programming language
C#	C sharp programming language
C++	C plus plus programming language
CLK	Clock signal
CMR	Common mode rejection
CPU	Central processing unit
DMA	Direct memory access
ECP	Extended capability port
EISA	Extended industry standard architecture
Emf	Electromotive force
EPP	Enhanced parallel port
FPGA	Field programmable gate array
GB/s	Giga bytes per second
GPIB	General purpose interface bus
GSM	Geographical service map
HP-IB	Hewllet-Packard interface bus
Hz	Hertz
IBM	International business machine
IC	Integrated circuit

IEEE	Institute of electrical and electronic engineering
I/O	Input/ output
ISA	Industry standard architecture
KB/s	Kilo bytes per second
LabVIEW	Laboratory virtual instrument engineering workbench
LPT	Line printing terminal
LSB	List significant bit
LVDT	Low voltage differential amplifier
MB/s	Mega bytes per second
MCA	Micro channel architecture
MHz	Mega hertz
MSB	Most significant bit
PCB	Printed circuit board
PCI	Peripheral component interconnect
PCIe	Peripheral component interconnect express
PID	Digital proportional integral derivative
PORT I/O	Input/output port
RS	Recommended standard
RTDs	Resistance temperature devices
TCP/IP	Transmission control protocol/Internet protocol
USB	Universal serial bus
Vi	LabVIEW program
VL-BUS	Video electronic standard association bus

LIST OF SYMBOLS

AlO_xN_y	Aluminum oxynitride
f	frequency
I_g	grid current
K_B	Boltzman constant
SnSe	Tin selenide
T	Temperature

ABSTRACT

Temperature and pressure are quantities of great importance in various applications such as integrated circuit (IC) manufacture and vacuum coating just to mention a few. Therefore, their accurate measurement is inevitable. However, it is tiresome to measure and record these quantities manually by pen and paper when operating a thin film deposition system. This approach is not only time consuming but also causes human errors on the measured physical parameters. To solve this problem, an automated instrumentation and measurement system was designed to offer a more reliable and fast method of measuring pressure and temperature in thin film deposition systems. It is based on thermocouple type K temperature sensor and pressure sensor MP20C-01-F2 from Mindman Company based in USA. The voltage outputs from these sensors, proportional to measured temperature and pressure, were fed to a thermocouple amplifier (AD595CQ) and an operational amplifier 741, respectively. The amplified voltages were transmitted through the electronic filters to isolate the noise signals that might affect the true voltages obtained from the two sensors. The two signals were multiplexed by AD8180 multiplexer and then digitized one at a time by the ADC0804LCN analog to digital converter before feeding to the computer through the parallel port interface for processing. A software design using LabVIEW graphical programming language was used to access the digital signals from the parallel port, process and display the temperature and pressure data to the user. The functionality of the designed electronic temperature and pressure measuring system was tested in Edward auto 306 magnetron sputtering system. The designated process parameters: pressure and temperature, were measured in-situ by the designed system during evaporation of SnSe and sputtering of AlO_xN_y thin films samples in the chamber and stored their values in a text file. The designed system had temperature and pressure ranges of 0 to 1251 ^{o}C and 0 to 1.01 x10^{3} mbar, respectively and temperature error of ± 1 ^{o}C. However, the designed system recorded varied pressure errors. In higher vacuum, pressures range 1 to 1x10^{-2} mbar, the error was ± 1x10^{-2} mbar and in the lower range 1x10^{-4} to 1x10^{-5} mbar, the error of 1x10^{-5} mbar was observed. These errors were within acceptable range and therefore, the system is viable to be used in thin film deposition systems to automate the measurement of process parameters: temperature and pressure.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The present day personal computers are fairly versatile and can be interfaced to an experimental set up, using numerous sensors for high speed and large data storage (Chaudhry *et al.,* 2004). Hence modern data acquisition systems integrate digital computers for high speed data processing, storage and analysis. Therefore, recent developments in instrumentation and measurement have merged the use of digital computers (Prasad, 2005) and development of new sophisticated sensors for process control.

This approach is seen in particular areas of industrial data acquisition and control which in an attempt to streamlining and effectively tailoring process control, has probably received more careful attention concerning the application of computers than nearly any other area (Coury, 1998). In this regard, designing an efficient instrumentation and measurement system, that acquires data in the form of electrical signal in real time, is of immense importance in different fields of science and engineering applications. Furthermore, the use of digital computers in process monitoring and control applications has expanded to include many production areas outside the industrial processes mostly in agriculture (Groover *et al.,* 2002).

However, since a large number of transducers, such as pressure and temperature transducers, are of analogue type, an analog to digital converter has to be employed between the sensors and the computer. This requirement is governed by the form of data that a computer needs, in all cases communication via computer requires data in digital form, for both input and output (Chaudhry *et al.*, 2004). Therefore, efficient and effective communication between the computer and peripheral sensors necessitates an analog to digital converter, to convert the analog signal to readable digital codes for the computer.

A transducer capable of detecting small changes in chamber pressure enables the production of defect free semiconductor devices. This is important not only in processes such as transistor and IC manufacture and thin film technology but also in the design of commercial electronics (Horowitz *et al.*, 2003). Related to pressure control is the temperature regulation, which is also a significant parameter in semiconductor manufacturing industries, food processing industries among others. Therefore for precise process control, accurate measurements are inevitable.

On the other hand, numerous computer interfaces have been developed in an attempt to enable communication between the computer and the external peripherals. For instance, the parallel port and the serial port which are commonly used currently as links for communication between the computer motherboard and the external peripherals are common interfaces. Other interfaces include IEEE 488 (GPIB), Ethernet (TCP/IP), IEEE 1394 (Firewire), Universal Serial Bus (USB), RS-422 and RS-485.

In conclusion, the field of instrumentation and control engineering has experienced an upsurge in the growth and development of computer based measuring and data acquisition systems. Real time data acquisition is one of the major challenges in the field of instrumentation and measurement. Designing an efficient instrumentation and measurement system, that acquires data in the form of electrical signal in real time, is of immense importance in different fields of science and engineering applications. In this work the two quantities were measured accurately using a computer based data acquisition system via the parallel port digital interface board and integrated LabVIEW software to automate the measurement process.

1.2 Statement of the research problem

Vacuum deposition process parameters are largely controlled manually despite the fact that modern computers have a high speed of information processing, analysis and storage. This manual control and supervision of thin film deposition parameters, mostly temperature, pressure and film thickness, is time consuming and prone to human errors due to fatigue while transferring process parameter data from one application to another for analysis. In addition, little attention has been paid to the computer based measurement and storage of these parameters.

1.3 Objectives of the research study

1.3.1 Main objective

The main objective of this research study is to design and fabricate a computer based electronic system to measure precisely process parameters; temperature and pressure, in thin film deposition systems.

1.3.2 Specific objectives

(i) To design a digital interface board that senses, conditions and digitizes the analog signals for communication between the peripheral sensors and the PC.
(ii) To develop and implement a LabVIEW based control software to drive the entire electronic system.
(iii) To test the interface design concept by measuring temperature and pressure in Edward auto 306 magnetron sputtering system using designed electronic system.

1.4 Rationale

Modern personal computers have a high speed of information processing and large data storage capabilities. These features can be utilized in measurement of temperature and pressure in thin film deposition systems. These process parameters are of great importance in thin film preparation and affect largely on their properties hence their accurate measurement is in evitable. Therefore there was need to develop an electronic system that measures accurately and stores the deposition temperature and pressure in a computer memory. The stored values of the process parameters could be retrieved for other applications in the analysis of thin film properties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A lot of research work has been done on computer based instrumentation and measurement systems for pressure and temperature measurements. However, modern researchers are shifting their efforts towards developing almost entirely sophisticated electronic devices for easier measurement and control of process parameters. Therefore, in this chapter, contributions of earlier researchers in the field of automated instrumentation and measurement of pressure and temperature are discussed. It gives a clear description of the work already done in this field and brings out the knowledge gap existing and where the designed system will fit. Computer based temperature and pressure measuring systems and their limitations are discussed.

2.2 Computer based temperature measuring systems

Benghanem (2010) studied a low cost computer based wireless data acquisition system for weather station monitoring. He used RS-232 computer interface and LM335 temperature sensor for temperature measurement. LabVIEW software program was used to access data from the RS-232 interface to the computer memory. However, RS-232 interface uses serial communication protocol which made the system slow. In addition, LM335 temperature sensor measures up to a maximum of 100 ^{o}C and hence cannot be used in thin film deposition systems where temperatures normally rise above 1000 ^{o}C. Conling *et al.* (2005) designed a non destructive computer based measuring system to monitor individual cucumber plant conditions: temperature, humidity, and light intensity, in a green house. LM35 temperature sensor which can measure temperatures upto a maximum of 150 ^{o}C was used. This system cannot be used in thin film depositions systems since temperatures normally rise above 1000 ^{o}C. Charles *et al.* (1977) carried out a research on a computer based controller for temperature measurement for application in a high resolution mass spectrometer. A high level programming language, BASIC was used for software driver development while the thermocouple functionalized as a temperature sensor. As an interface between the computer and the temperature sensor, RS-232 digital bus was used. The drawback of their approach was attributed to the fact that the data transfer rate was slow because RS-232 interface is serial and full duplex at a rate governed by the cable capacitance.

Mathew (2001) studied a micro-computer controlled system for ten channels high precision temperature data acquisition system. The temperature sensing elements used were platinum resistance thermometer devices type A (RTDs). An IEEE 488 interface bus formally known as *Hewellet-Packard* (HP-IB) that was later renamed as *General Purpose Interface Bus* (GPIB) in 1975 by the IEEE 488 (1975) committee was used in this work. However, the temperature range of 4 K to 1064 ^{o}C precludes them from process conditions involving higher temperatures above 1064 ^{o}C. GPIB bus has a data transfer rate of upto 8 MB/s. Michalski *et al*. (2002) designed a computerized temperature measuring system where they used platinum RTD type A as a temperature sensing element and an RS-232 digital interface. However, the system had limited sampling rate of 1 bit at a time and the narrow temperature range of 4 K to 1064 ^{o}C limits them from applications with temperatures above 1064 ^{o}C. Higeki *et al*. (2005) developed a computer based temperature measuring system with a thermocouple as a sensing element and an RS-232 bus as an interface between the computer and the thermocouple. The system had limited sampling rate of 1 bit at a time. An attempt at robust and complex process control is seen in the work of (Wang *et al.*, 2008). This work entails the development of a computer based measuring system to study the frictional characteristics of human intestines. A multifunction data acquisition device incorporated USB 1.0 standard as an interface between the computer and the sensors while the data processing was performed using the LabVIEW software. This new approach was limited in data transfer rate due to design constraints to serial data communication using the USB 1.0.

Dechousek *et al*. (2009) studied a Digital Proportional Integral Derivative (PID) velocity controller used in the Mossbauer Spectrometer implemented in the field programmable gate array (FPGA). The system is based on the National Instruments compact RIO embedded system and LabVIEW graphical programming tools and accessible via the Ethernet computer interface. However, internet security concerns remain a key obstacle to their subsequent rollout. Wen-bin *et al*. (2007) studied a chemical virtual instrument based on LabVIEW for determining temperatures and pressures. They used serial port (RS-232) as an interface between the computer and the platinum resistance thermometer (Pt100) hence the system had lower data transfer rate due RS-232 interface. Farooq *et al*., (2005) designed a tunable laser diode near 2.5 ɥm for temperature detection. Unfortunately this temperature sensor operated at nearly room temperature and hence cannot be used to measure temperatures of about 1200 ^{o}C. Huange *et al.* (2000) designed a computer based temperature measuring system for application in industrial furnace where the temperatures were ranging from 25 ^{o}C to above 1600 ^{o}C. He used a CCD camera as a temperature sensor and PCI card as a computer interface. However, CCD camera cannot be fixed in a vacuum deposition chamber since during evaporation; the CCD camera lenses will be coated by the respective thin films and affect the accuracy of the system.

2.3 Computer based pressure measuring systems

Benghanem (2010) designed a low cost computer based wireless data acquisition system for weather station monitoring of atmospheric pressure. RS-232 computer interface and Motorola MPX5100A pressure sensor were used for communication of data between the sensor and the computer and measurement of atmospheric pressure, respectively. This pressure sensor is unable to sense vacuum pressure of order 10^{-3} mbar and cannot be used in thin film deposition systems where chamber pressures fall below 10^{-3} mbar during deposition process.

Zhang *et al*. (2009) studied a pressure sensing and measurement system using a fiber brag grating (FBG) pressure sensor. This sensor is based on the strain and stress applied to it to sense the variation of pressure. However, this sensor has a major limitation. It is sensitive to both pressure and temperature variations. Therefore requires accurate temperature compensation and this is always not easy to achieve in hardware designed. Hence this system cannot be used in the designed electronic system. Huang *et al*. (2008) studied measurement of air pressure in the vane segments of a rotating wheel. The strain gauge type pressure transducer was utilized to sense the air pressure. However, this type of pressure sensor requires moving air for it to sense pressure, hence cannot be used in a vacuum where there is no air. Chen (2010) carried out a research on pressure measurement using fiber optic pressure sensor. Fiber optic sensors are known to exhibit high sensitivity, fast response and immunity to electromagnetic interference and have light weight and low cost. However, in his work he used an RS-232 computer port for communication of data between the computer and the sensors. Hence the system was slow due to RS-232 interface.

Wang *et al.* (2010) studied measurement of radial pressure distributions of piston rings in order to propose ways of minimizing the wastage of lubricating oils. He also used the serial port (RS-232) for transfer of data between the computer and the pressure sensors. RS-232 uses a serial communication protocol and data transmission was slower than that of a parallel communication implemented in this research project.

Therefore, there was need to design computer based instrumentation and measurement system for temperature and pressure measurement in thin films deposition systems. The designed electronic system comprised of a thermocouple type K for temperature measurement and pressure sensor MP20C-01-F2 fitted in the vacuum chamber in Edward auto 306 magnetron sputtering system. The designed system implemented parallel port computer interface that uses parallel communication protocol with a data transfer rate of 2.5 MB/s which is higher than that of RS-232.

CHAPTER THREE

THEORETICAL BACKGROUND

3.1 Introduction

Temperature and pressure sensors are very vital components of the computer based temperature and pressure measuring system. In this chapter, theoretical overview of temperature and pressure transducers is outlined. The chapter also describes computer ports and buses and highlights graphical and text based programming languages. Lastly, signal conditioning elements that include ADC, amplifiers and filters are also presented.

3.2 Pressure measurement

The techniques for pressure measurement are quite varied depending on whether the pressure is low or high and also whether static or dynamic, (Chaudhry *et al.,* 2004). A transducer is a device used to convert a physical phenomenon into an electrical signal, (Klarzar *et al.,* 2009). Hamner (2008) discussed the development of nano-materials designed at microscopic scales that yields novel pressure-sensitive coatings. Pressure sensors range from low end ICs to complex designs that cost over fifty thousand Kenya shillings.

3.2.1 Low pressure measurement

Measurement of very low gas pressures approaching vacuum is referred to as vacuum measurement of pressure, (Prasad, 2005). There are various instruments used to measure these pressures and each one of them has its own unique accuracy and range of pressure that it measures. Among these sensors is the thermocouple vacuum gauge in which the thermocouple and heater element are enclosed in a glass or metal envelop which is sealed into the vacuum. The temperature of the heater element is dependent on the amount of the heat lost to the surrounding gas by conduction and convection. Therefore, the voltage produced in the thermocouple circuit, which is a function of temperature and hence a function of pressure gives approximate value of pressure. Hence the output is not linear since the thermocouple has nearly parabolic output relation as indicated by equation 3.4.

The second instrument is the pirani vacuum gauge which operates on the principle of thermal conductivity. The temperature of the heater element is measured by the change of heater resistance which forms an arm of the Wheatstone bridge. Thirdly, the ionization vacuum gauge is the low pressure sensor that measures very low pressure. In this sensor, electrons are emitted from the cathode, which is enclosed in a tube connected to the vacuum, are accelerated by the positive grid within the tube producing grid current I_g . Collision of these electrons with gas molecules knock out electrons from the gas molecules.

The positive ions are attracted by the negatively charged plate within the tube producing plate current I_p . Bayard and Alpart ionization gauge measures pressure range 10^{-3}-10^{-11} mmHg, (Horowitz *et al*., 2003). The Knudsen gauge is another instrument used to measure low pressure. It operates on the fact that heated gas molecules have kinetic energy and move within the chamber. They rebound from fixed plates on the sides of the chamber with greater momentum than from the movable vane on the top. Thus impart a net force on the movable vane on which the mirror is attached. The magnitude of the force is measured by measuring the angular displacement of the mirror. Hence, gas pressure P is given by equation 3.1.

$$P=kF/(T/T_o-1)^{1/2} \tag{3.1}$$

Where F is the net force, k is a constant, T is the temperature of the fixed plates on the sides of the chamber and T_o is the temperature of movable vane. However, the instrument does not generate electrical data that is easily transmitted.

3.2.2 High pressure measurement

Although the designed computer based measuring system was concerned with low pressure measurement, techniques for measuring high pressures are discussed in this section. The hydrostatic compression gauge is one such sensor used to measure high pressure**.** It is based on the electrical resistance change of alloy wire, manganin or gold-chrome, with hydrostatic pressure due to bulk compression effects. Its simple diagram is shown in figure 3.1, A and B are outputs electrical signals while P is applied pressure.

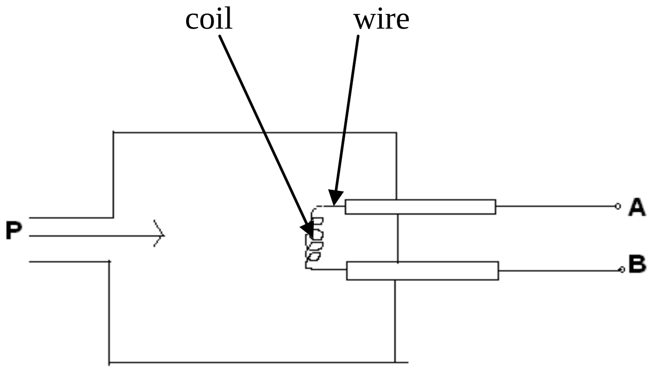


Fig. 3.1: Hydrostatic compression gauge, (Chaudhry *et al.*, 2004).

The coil is enclosed in a flexible bellows (not shown in figure 3.1) filled with kerosene for transmitting the applied pressure to be measured to the coil. The change in the resistance of the wire between A and B is measured by Wheatstone bridge. Piezo-electric pressure transducer externally applied forces exert pressure to the top of the piezo-electric crystal. This produces an e.m.f. across the crystal proportional to the magnitude of the applied pressure. These types of pressure transducers have increased sensitivity.

Another sensor in this category is elastic diaphragm with LVDT or capacitance or resistance strain gauge transducers. The motion of the elastic diaphragm is communicated to the capacitor, coil or resistance strain gauges. The displacement of the diaphragm gives output voltage proportional to it. Since the motion of the elastic transducer is proportional to the applied pressure, the output voltage is also proportional to the pressure.

A bourdon gauge is another commonly used sensor for pressure measurement. The tube uncoils since the inner and outer arc lengths remains almost equal to their original lengths. The motion of the end of the tube is indicated by the pointer on the scale. Finally, manometer which consists of liquid in a tube is the simplest device for measuring pressure. The magnitude of the displacement of the liquid column used in this instrument is proportional to pressure. However it does not produce a voltage or a current signal.

3.3 Temperature measurement

Temperature is a very important parameter in semiconductor manufacturing industries, food processing industries and in weather forecast just to mention a few. Therefore its accurate measurement is inevitable. However, it cannot be measured directly but must be measured by observing the effects that causes on the measuring instrument, (Chaudhry *et al.*, 2004). A thermometer is an instrument used to measure this parameter and there are various methods of measuring it.

To begin with, there are electrical methods of temperature measurement. These are the preferred methods as they generate an electrical signal which can be easily detected, amplified, transmitted and used for control purposes, hence can be used in computer based systems. Within this class are electrical resistance thermometers. The change in resistance of various materials, which varies in reproducible manner with temperature, forms the basis of these important techniques. Variations of resistance of metals and semiconductors with temperature are different, (Chaudhry *et al*., 2004).

For metal resistance thermometers or resistance temperature detectors (RTDs) they have a positive temperature coefficient of resistance. Hence, as temperature increases, their resistance also increases. Examples of metals used in this class of thermometers are platinum, copper, tungsten and nickel. However, they have low sensitivity and relatively high cost as compared to other temperature sensors. In addition, their output is quadratic at temperatures above 0 ^{o}C as indicated in equation 3.2. The resistance R at absolute temperature T is given by the same relation 3.2.

$$R=R_o(1+ \alpha T+\beta T^2) \quad (3.2)$$

Where R_o is resistance at 0 °C, α and β are experimentally determined constants. However, for semiconductor resistance sensors, they have negative temperature coefficient of resistance which is of the order of ten times higher than that of platinum and copper, hence extremely sensitive device, (Chaudhry *et al.*, 2004). However, they have problem of self heating and non-linear temperature characteristic which is exponential given by equation 3.3. The resistance R measured at temperature T is given by the same relation 3.3.

$$R=R_o \exp [\beta(1/T-1/T_o)] \quad (3.3)$$

Where R_o is resistance at the reference temperature T_o (Kelvin), and β experimentally determined constant for the given thermister material.

Another class of electrical methods of temperature measurement is the use of a thermocouple. This is a temperature transducer that develops an electromotive force (e.m.f.) which is a function of temperature between the hot and the cold junctions. The relationship of temperature to voltage induced in a thermocouple type K is given by the relation given by equation 3.4.

$$V = aT + bT^2 \quad (3.4)$$

Where V is the induced voltage, T is the temperature difference between the hot and cold junctions of the thermocouple, a and b are constants.

It is design by joining two wires of different materials and the two junctions kept at different temperatures such that, a voltage is developed in the circuit. A suitable cold junction may be obtained by the use of melting ice, (Klarzar *et al.*, 2009). It is the most popular temperature transducer since it is relatively inexpensive, rugged device that can operate over a wide range of temperatures. Figure 3.2 shows thermocouple type K, which is the most popular temperature sensor in industrial application.

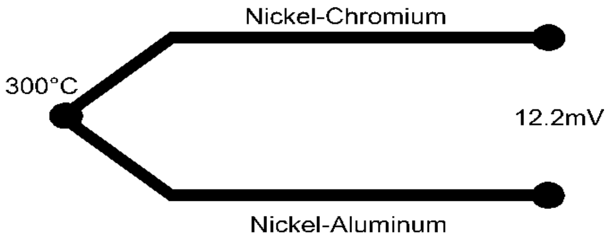


Fig. 3.2: Type K thermocouple sensor (Nikhil, 2009).

In figure 3.2, the type K thermocouple at 300 ^{o}C will produce 12.2 mV. Different thermocouple types have different temperature range as indicated in table 3.1.

Table 3.1: Temperature ranges of different thermocouple types (Microstar Laboratories 2008).

Thermocouple type	**Overall range ^{o}C**
B	20 to 1820
E	-270 to 910
J	-210 to 1200
K	-270 to 1370
N	-270 to 1300
R	-50 to 1760
S	-50 to 1760
T	-270 to 400

The second category of temperature measurement method is based on the change in the resonant frequency of the crystal which is directly proportional to the temperature change. It provides a highly accurate and sensitive method of temperature measurement. A good example of this category is the quartz thermometer. However, it has a limited measuring range (-40 to 230 ^{o}C) and has a strong cross sensitivity for pressure change if it occurs simultaneously in the temperature measuring system.

The third category of temperature measurement method is based on solid state temperature sensors. Solid state diodes and transistors form the basis of this temperature measuring technique. They have inherent linear operating characteristics with excellent accuracy of the order of ± 1 ^{o}C. They also exhibit a stable and reproducible response to temperature. However, they operate at lower temperature range (-55 to 150 ^{o}C) and cannot be used with the proposed system since the dc magnetron sputtering system machine work with higher temperatures than this.

The fourth category of temperature measurement techniques are the radiation methods. The radiant energy in the form of heat and light from the test body is focused on the thermally sensitive device usually thermocouple, (Prasad, 2005). Examples of instruments that falls in this category of temperature measurement techniques include total radiation pyrometers which are sensitive to all radiations of the spectrum that enters the instrument, selective radiation pyrometers that are sensitive to only a particular wavelength of the radiations of the spectrum that enters the instrument, infrared radiation pyrometers that are sensitive only to infrared section of the spectrum and finally the optical radiation pyrometers where the brightness of the radiations from the hot body is compared with the brightness of a standard source which has been calibrated according to the temperature measured.

However, any filtering material such as smoke, gases, dust and windows which were not present during calibration will reduce the energy received and cause an error. In addition, any surface having emissivity other than the one used in the calibration will cause an error, hence not an accurate temperature indicator, (Chaudhry *et al.*, 2004). Lastly but not least, the non electrical methods of temperature measurement are usually used in weather stations and school laboratories. They do not generate electrical signal hence cannot be used in a computer based measuring systems. The instruments used in this method include bimetallic thermometer which employs the principle of solid expansion and contraction. It consists of two metals of different coefficient of thermal expansion, welded together so that relative motion between them is prevented. An increase in temperature causes the deflection of the free end along a scale. The limitation of this instrument is its inability to measure rapidly changing temperature due to its relatively higher thermal inertia.

The second example is fluid expansion thermometer which is based on the principle of liquid and gas expansion and contraction due thermal energy. These include liquid-in-class thermometers and pressure thermometers. Liquid-in-class thermometers are fragile and induce a time lag in the measurement of dynamic temperatures. On the other hand pressure thermometers suffer a problem of ambient temperatures.

Finally, pressure and temperature signals from pressure and temperature sensors are fed into the computer through a port as an interface. In the next section, various computer interfaces and buses are discussed.

3.4 Computer ports and buses

The **t**able in appendix V shows the bus widths and bus speeds for various computer buses used to connect peripheral devices to the computer motherboard. These buses have different data rate transfer and bus speeds.

3.4.1 The parallel port

The parallel port is a very important interface between the personal computer and the external world. Normally, a parallel port outputs data to a printer via a personal computer and hence constitutes reasonable parallel communication interfaces for data acquisition systems, (Spencer, 1990). However, as technology progresses and the need for greater external connectivity increases, the parallel port has become the means by which higher performance peripherals like pressure and temperature sensors communicate with the personal computer. The parallel ports in modern PC transfer data at a rate of 2.5 MB/s in parallel mode. The female DB-25 parallel port is found on the rear part of the personal computer with 25 pins as indicated in figure 3.3 and detailed description of the function of each pin is given in appendix II.

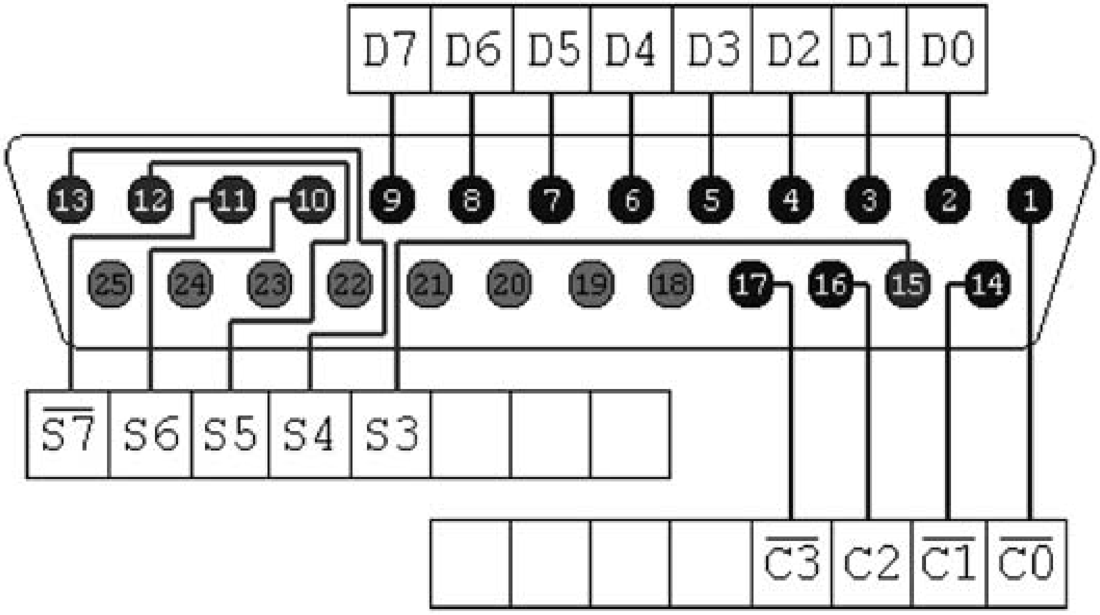


Fig. 3.3: Typical example of a parallel port (Fanti *et al*., 2005).

The lines in DB-25 connector are divided into three groups: data lines; D_0 - D_7, control lines; C_0 - C_3 and status lines; S_3 - S_7. As the name refers, data is transferred over data lines, control lines are used to control the peripheral and of course, the peripheral returns status signals back the computer through status lines. These lines are connected to data, control and status registers internally. The details of parallel port signal lines are given in table 3.2 and appendix II.

Table 3.2: Parallel port pin names and their assignments.

Pin No. (DB 25)	**Signal name**	**Direction**	**Register bit**
1	$\overline{\text{Strobe}}$	Out	Control_0
2	D0	Out/In	Data_0
3	D1	Out/In	Data_1
4	D2	Out/In	Data_2
5	D3	Out/In	Data_3
6	D4	Out/In	Data_4
7	D5	Out/In	Data_5
8	D6	Out/In	Data_6
9	D7	Out/In	Data_7
10	$\overline{\text{Ack}}$	In	Status_6
11	Busy	In	Status_7
12	Paper-Out	In	Status_5
13	Select	In	Status_4
14	Linefeed	Out	Control_1
15	$\overline{\text{Error}}$	In	Status_3
16	$\overline{\text{Initialize}}$	Out	Control_2
17	$\overline{\text{Selelct-Printer}}$	Out	Control_3
18-25	Ground	-	-

The registers found in standard parallel port are, data register, status register and control register. The registers are virtually connected to the corresponding lines so whatever you write to these registers, will appear in corresponding lines as voltages. Data register is connected to data lines and stores data from the external peripherals into the PC or from the PC to the external peripherals. Control register is connected to control lines and the PC uses these signals for handshaking purposes with the external peripheral.

Status register is connected to status lines and stores status information about the peripheral connected to the PC. In a PC, these registers are I/O mapped and will have unique address. These addresses are important to work with parallel port. However, a typical PC can have two parallel ports; LPT 1 and LPT 2. The base address of LPT 1 is 0x378 and that of LPT 2 is 0x278. The data register resides at this base address, status register at base address + 1 and the control register is at base address + 2. Table 3.3 shows the register addresses of LPT 1 and LPT 2.

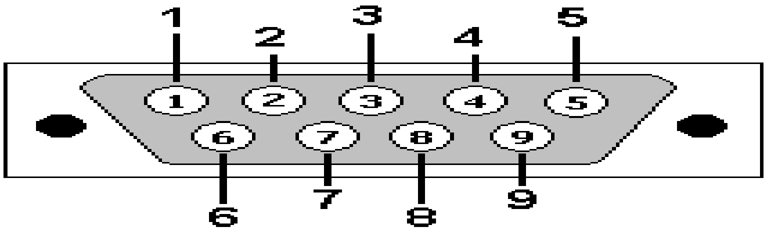
Table 3.3: Parallel port address.

Register	**LPT 1**	**LPT 2**
Data register (base address + 0)	0x378	0x278
Status register (base address + 1)	0x379	0x279
Control register (base address + 2)	0x37a	0x27a

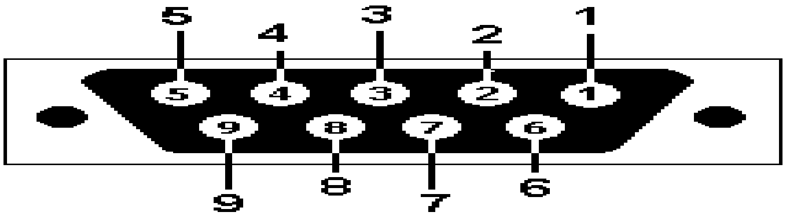
The IEEE 1284 standard which was published in 1994 defines five modes of data transfer for parallel port. They are compatibility mode, nibble mode, byte mode, enhanced parallel port (EPP) and extended capability port (ECP).

3.4.2 The serial port (RS-232)

Serial communication is a popular means of transmitting data between a computer and a peripheral device such as a printer, a plotter, or a programmable instrument. Serial communication uses a transmitter to send data, one bit at a time, over a single communication line to a receiver. This method of communication is common when transferring data at low rates or over long distances. For instance, serial data can be transferred via modems, over standard telephone lines. Limitation of serial communication, however, is that a serial port can communicate with only one device at given time. To accommodate several devices, you must use a board with multiple serial ports or a serial port multiplexer box. A typical serial port on the rear of a PC and its pin numbers is shown in figure 3.4. The function of each pin is given in appendix III.



(a) Male connector.



(b) Female connector.

Fig. 3.4: Typical example of a serial port (Anguiano, *et al*., 2009), (a) view looking into male connector and (b) view looking into female connector.

Serial communication using RS-232 serial port is slower than in the parallel port. Data transmission is bitwise unlike in parallel port where a whole byte is transmitted at a time. Therefore such a communication protocol was not used in the designed electronic temperature and pressure measuring system in this project. Firewire, RS-422, RS-423, USB (universal serial bus), and RS-485 are other examples of interfaces between the computer and the external devices for serial communication. The name of each pin of a serial port is described in table 3.4.

Table 3.4: Serial port pinouts (D25 and D9 Connectors).

D-Type-9 Pin No.	**D-Type-25 Pin No.**	**Abbreviation**	**Full Name**
Pin 1	Pin 8	DCD	Carrier Detect
Pin 2	Pin 3	RXD	Receive Data
Pin 3	Pin 2	TXD	Transmit Data
Pin 4	Pin 20	DTR	Data Terminal Ready
Pin 5	Pin 7	SG	Signal Ground
Pin 6	Pin 6	DSR	Data Set Ready
Pin 7	Pin 4	RTS	Request To Send
Pin 8	Pin 5	CTS	Clear To Send
Pin 9	Pin 25	RI	Ring Indicator

3.4.3 IEEE 1394 (Firewire)

Firewire ports also known as IEEE 1394 are serial interface devices for connecting peripherals to the computer motherboard. It uses the bus cable to power these devices.

However, many devices require more power than the bus can deliver which limits them for use in instrumentation and measurement devices that require above 5 V for powering purposes. This interface is declining in popularity as an interface for scientific instruments in the face of competition from USB and Ethernet interfaces. In addition, digitized data signals are transmitted one bit at a time hence a lower data transfer rate relative to the parallel port interface is observed for the Firewire ports. This limitation precludes the application of this protocol for the designed electronic project.

3.4.4 USB (Universal Serial Bus)

This is a computer port that uses serial communication protocol for data transfer between the PC and peripherals like modem, mouse, keyboard and printers just to mention a few. It has four pins; pins 1 and 4 for power supply to the USB device and pins 2 and 3 for data transfer. The pin assignment for this port is indicated in figure 3.5 and pin description is given in table 3.5. Device holders hold the USB device in place when it is plug into the port for data transfer.

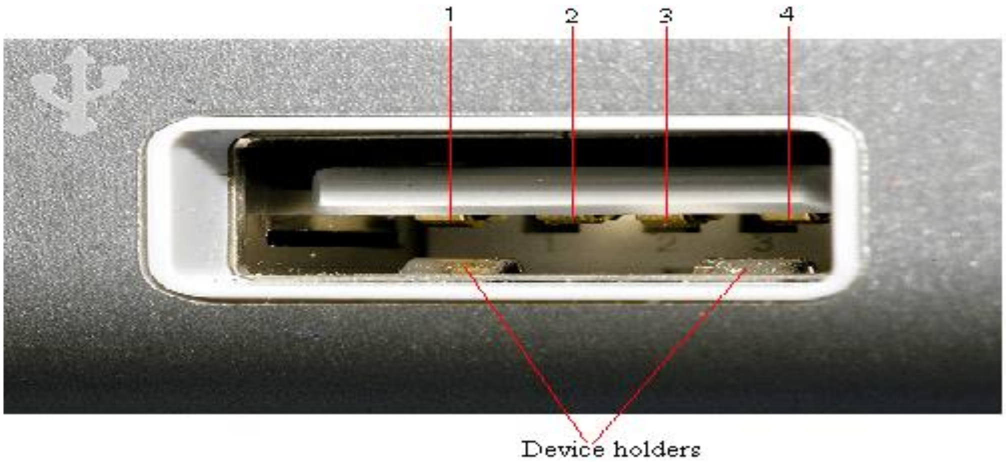


Fig. 3.5: USB port on the PC (Intel *et al*., 1996).

Table 3.5: USB port pin description

Pin number	**Pin name**	**Description**
1	Vcc	+5 V_{dc}
2	D-	Data-
3	D+	Data+
4	GND	Ground

3.4.5 RS-422 and RS-485

The serial port RS-232 sends only 1 bit at a time but it is multidirectional so it can send 1 bit and receive 1 bit at a time. Several standards have evolved to supersede RS-232 standards. They support higher data rates transfer and greater immunity to electrical interference and offer backward compatibility. RS-422 is used for long distance transmission, maximum cable length is 1250 m while RS-485 is good for short distance transmission, maximum cable length is 15 m. Due to their serial data communication protocol, these standard have lower data rate transfer than the parallel port interface.

3.4.6 IEEE 488 (GPIB)

IEEE 488 is a short range digital communication bus specification designed for automated test equipment. It is an 8 bit parallel bus which acts as an interface between the computer motherboard and the external peripherals comprising of eight data lines, eight ground lines, and eight control lines with a data transfer rate of 8 MB/s. This standard allows up to 15 devices to share a single physical bus of up to 20 m total cable length. This device has been in use since its inception in 1965. Formally, the interface was christened as the Hewlett-Packard (HP-IB) Interface Bus but was later renamed to General Purpose Interface Bus (GPIB) in 1975 by the IEEE 488 committee for standardization intents. The interface come as an expansion card that is plug into the expansion slot in the PC motherboard. Its pin arrangement is as indicated in figure 3.6.

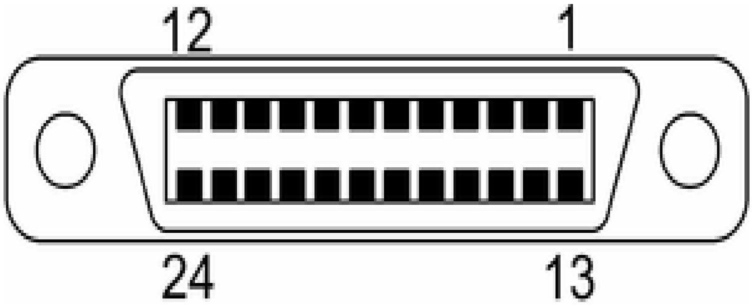


Fig. 3.6: A schematic of a GPIB port (Hewlett-Packard, 1975).

3.4.7 Ethernet (TCP/IP)

Ethernet device is a serial port that provides an interface between the computer and the internet networks that makes sharing of data easy. Fast data transfer is possible, up to 1 GB/s if the network infrastructure is good. A web enabled device behaves like a website and can be operated with a standard browser. Systems based on these devices can make use of existing Ethernet networks. However, it is very difficult to secure any device connected to the public internet and extreme caution and full evaluation of the risks involved is essential in every case.

3.4.8 Industry standard architecture (ISA) bus

The ISA bus operates at 8 MHz with a 16 bits data bus and a 24 bit address bus using +12 V, -12 V, +5V, -5V signaling and has 15 interrupt lines. An ISA card with 62 pins on either side is plugged into an ISA bus to act as an interface between the computer motherboard and the computer peripherals such as spectrophotometer used in optical analysis of thin films. A maximum number of 8 expansion slots were provided on IBM compatible motherboards hence up to 6 devices can be connected on this bus. It was synchronous with the CPU clock and uses parallel communication protocol to transfer data between the peripherals and the computer motherboard and was replaced by micro channel architecture (MCA) bus developed by IBM Computer Company in 1987 in an effort to regain control of the PC architecture and the PC market. Currently, most computer manufacturers do not include this bus technology in modern PC. They have been replaced by the PCI bus technology discussed in section 3.4.11.

3.4.9 Extended industry standard architecture (EISA) bus

The EISA bus, depicted in figure 3.7, is a standard bus technology used to connect external peripherals to the computer motherboard. It operates with a bus speed of 8.33 MHz, data transfer rate of about 32 MB/s with 32 bits wide data bus compatible with ISA bus. Therefore, an ISA card connector will work in an EISA slot on the computer motherboard, but an EISA card connector will not work in an ISA bus slot. It used parallel communication protocol to transfer data between the peripherals and the computer motherboard and was developed to replace micro channel architecture (MCA) bus. However, it was somewhat expensive to implement this standard hence never became particularly popular in desktop PCs.

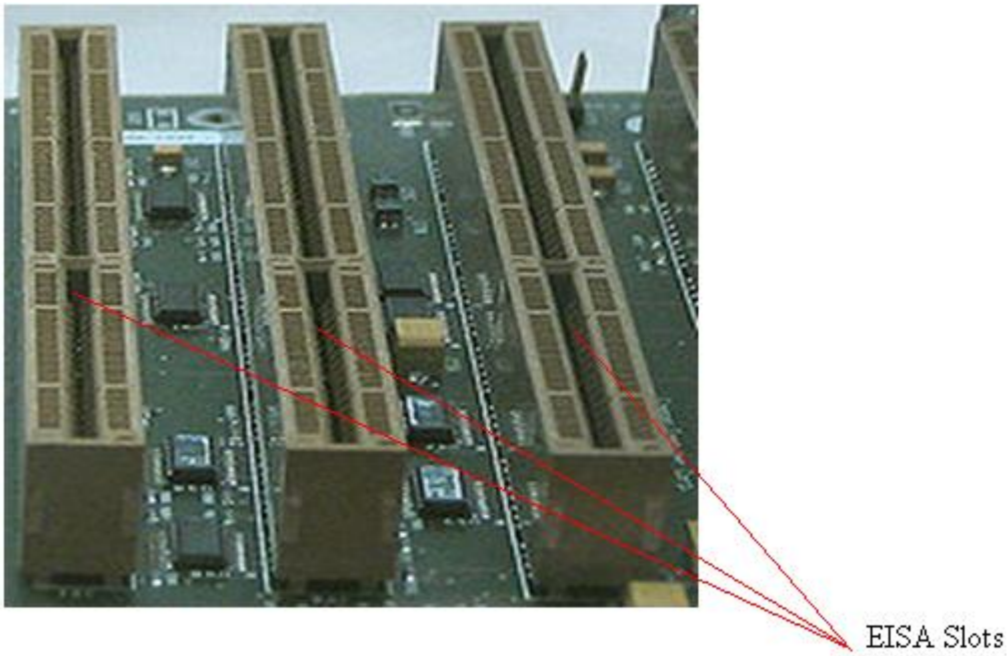


Fig. 3.7: A photograph of three EISA slots on a PC motherboard (Intel, 1989).

Fig. 3.8: A photograph of an EISA connector card that plugs into an EISA slots on a PC motherboard (Intel, 1989).

The EISA connector with I/O ports, shown in figure 3.8, is plugged into an EISA slot depicted in figure 3.7. The data signals from peripherals to the computer memory or vice versa, flow through these ports and EISA bus.

3.4.10 Video electronic standard association local bus (VL-bus)

Video Electronic Standard Association Local bus (VL-bus), is a computer bus that is used to connect peripherals to the computer motherboards. It was designed as a stop gap solution to the problem of the ISA bus's limited bandwidth. It has a bus speed that ranges from 25-33 MHz and worked alongside the ISA bus; it acts as a high speed conduit for memory mapped I/O and direct memory access (DMA) with 16 bit or 32 bit data transfers. The VL-bus resides on a standard 16 bit ISA card with the additional pins required by the VL-bus interface residing after the ISA pins, allowing an ISA card to be plugged into the same slot on the VL-bus in the computer bus as the VL-bus connector. However, the VL-bus connector shown in figure 3.9 could not be plugged into the ISA slot in the computer motherboard.

Fig. 3.9: A VESA card (Intel, 1991).

VL-bus relied heavily on the Intel 80486 CPU’s memory bus design, however, when the Pentium processor started to gain mass acceptance, there were major differences in its bus design. Therefore, VL-bus was not easily adaptable to these Pentium processors. This made moving VL-bus to Pentium processors nearly impossible hence abandoning the bus since it had become obsolete.

3.4.11 Peripheral component interconnect (PCI)

The name PCI is the initials formed from peripheral component interconnect. It specifies a computer bus shown in figure 3.10, for attaching peripheral devices to a computer motherboard. These devices can take either the form of an integrated circuit fitted onto the motherboard itself, called a planar device, in the PCI specification or an expansion card that fits into a socket. The PCI specification defines two types of connectors that may be implemented at the system board level: One for systems that implement 5 V signaling levels and the other for systems that implement 3.3 V signaling levels.

In addition, PCI systems may implement either 32 bits or 64 bits connector. Most PCI buses implement only the 32 bits portion of the connector which consists of pins 1 to 64. Advanced systems which support 64 bit data transfer implements the full PCI bus connector which consists of pins 1 through 94. The PCI bus treats all transfers as a burst operation where each cycle begins with an address phase followed by one or more data phases which may be repeated indefinitely, but are limited by a timer that defines the maximum time that the PCI device may control the bus.

Fig. 3.10: A photograph of PCI slots on a computer motherboard (Intel, 1995).

The PCI add in board indicated in figure 3.11 has the following pins: the system pins, the address and data pins, interface pins, arbitration pins, error reporting pins, the interrupt pins, cache support pins, additional pins, the bit bus extension pins and finally the boundary scan pins.

PCI express (PCIe) has replaced accelerated graphics port discussed in section 3.4.12 as the default interface for graphics cards on new systems. With a few exceptions, all graphic cards being released as of 2009 uses PCIe, which is a serial interface between external peripherals and the computer memory with a data transfer rate of 250 MB/s.

Fig. 3.11: A photograph of a PCI card (Intel, 1995).

3.4.12 Accelerated graphics port (AGP)

The accelerated graphics port, also called advanced graphics port, often shortened to AGP, is a high-speed dedicated point to point channel for attaching a video card to a computer's motherboard, primarily to assist in the acceleration of three dimensional graphics. It links the graphic controller on a PC directly to the computer's memory. An AGP card for plugging into AGP slot is depicted in figure 3.12. The AGP is a 32 bits bus and has a maximum bus speed of 2133 MB/s with parallel transmission of data.

Fig. 3.12: A photograph of an AGP based graphics card (Intel., 1998).

AGP provides a much faster and more efficient way for your PC to get the information it needs to render complex graphic to the user. Since 2004, AGP has been progressively phased out in favor of PCIe. As of mid 2009, PCIe cards dominate the market, but new AGP cards and motherboards are still available for purchase.

For all these interfaces to transfer data from the sensors to the computer accurately, the electrical signals from sensors have to be digitized, amplified, filtered and if necessary, multiplexed through a single channel. The foregoing sections describe these signal conditioning techniques and electrical components used.

3.5 Amplification

Because real world voltage signals are often very small in magnitude, signal conditioning can improve the accuracy of the data. Amplifiers boost the level of the input signal to better match the range of the analog to digital converter (ADC), thus increasing the resolution and sensitivity of the measurement.

3.5.1 Instrumentation amplifiers

The instrumentation amplifier offers two useful functions: amplify the difference between inputs and reject the signal that’s common to both inputs. The latter is called common mode rejection (CMR). These amplifiers are generally used to amplify the small output voltages from various sensors. A few applications for an instrumentation amplifier are: differential voltage measurements, bridge outputs, strain gauge outputs, or low level voltage measurement. A typical instrumentation amplifier is depicted in figure 3.13 and the overall gain of the amplifier is given by equation 3.5 below (National Semiconductors, 2007).

$$\frac{V_O}{V_S} = \left(1 + 2\frac{R_1}{R_2}\right)\frac{R_5}{R_4} \tag{3.5}$$

Where, $R_1=R_3$ and $R_5/R_4 = R_7/R_6$, V_o and V_s are output and input voltages, respectively.

Instrumentation amplifiers are actually made up of 2 parts: buffered operational amplifiers XOP1, XOP2 and a basic differential amplifier XOP3. The differential amplifier part is often essential when measuring sensors output voltages. The buffered amplifier XOP1 and XOP2 not only provides gain, but prevents the sensor resistance from affecting the resistors in the op amp circuit

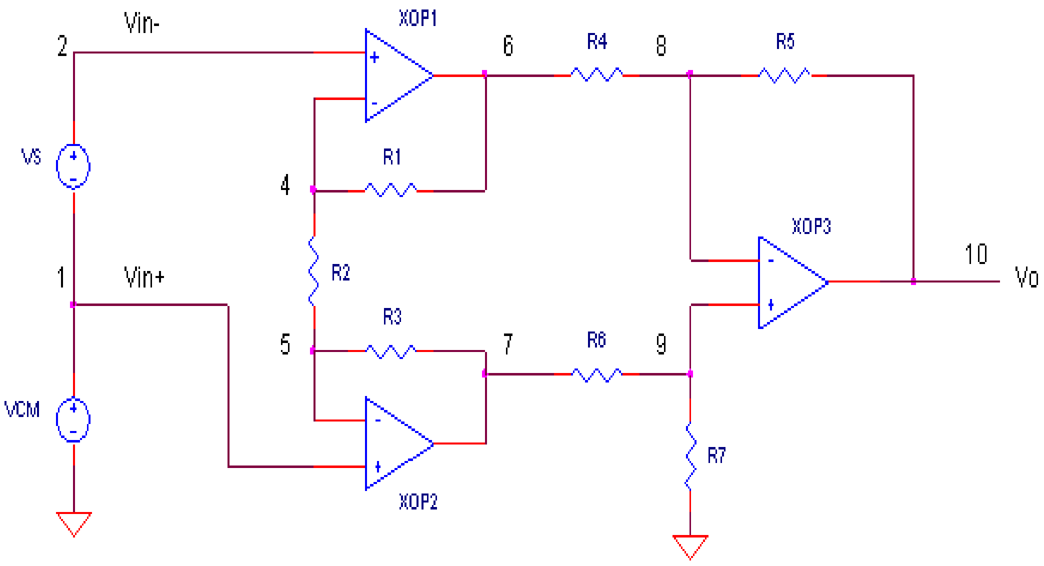


Fig. 3.14: An instrumentation amplifier (National Semiconductors, 2007).

3.5.2 Thermocouple amplifier (AD595CQ)

A thermocouple amplifier (AD595CQ) is a specific instrumentation amplifier used to amplify the output voltage from a thermocouple type K sensor. Minute thermocouple outputs signals can be multiplied up to 100 times or more by a thermocouple amplifier to drive meters or instruments which otherwise are not sensitive enough to be driven by the small output voltage of a thermocouple type K sensor. The AD595CQ is a complete thermocouple amplifier and thermocouple cold junction compensator on a monolithic chip. It produces a high level (10mV/^{o}C) output directly from a thermocouple signal (Analog Devices, 1999). It is a 14 pin DIP that combines an ice point reference with a pre-calibrated amplifier to produce a high level output voltage from a thermocouple output. It is powered by a V_{cc} voltage of + 5 V and has a calibration accuracy of ± 1 ^{o}C.

3.6 Analog to digital converter (ADC)

Typically, the analog to digital converter is the most expensive part of a data acquisition system. An ADC accepts an analog voltage or current at its input and converts it into a set of binary bits often called digital codes. The ADC output signal can be serial or parallel. If the ADC has a serial output signal, it produces on one output pin a single output signal voltage or current that is a timed sequence of high and low voltages representing the 1’s and 0’s of the set of binary bits. If the ADC has a parallel output signal there is an output signal voltage or current for each bit and each bit appears simultaneously on a dedicated output pin of the ADC as a high or low voltage or current representing a 1 or a 0 in the set of binary bits. The input signal to the ADC is a continuous time signal and the output signal is a discrete time signal. The number of binary bits produced by the ADC is finite. Therefore the number of unique bit patterns it can produce is also finite

3.7 Multiplexers

An electronic multiplexer can be considered as a multiple input, single output switch which connects data from several sources into a single output. This is referred to as multiplexing in electronic. By multiplexing, you can sequentially route a number of signals into a single line, thus achieving a cost effective way to greatly expand the signal count of your system. There are 4 to 1, 8 to 1, 16 to 1, 32 to 1, 16 to 8, 8 to 4 and 32 to 16 multiplexers.

3.8 Electronic filters

Electronic noise is a random fluctuation in an electrical signal, a characteristic of all electronic circuits. Noise generated by electronic devices varies greatly as it can be produced by several different effects. Thermal (Johnson) noise, generated by random thermal motion of charge carriers and quantum mechanical fluctuations in an electrical component and shot noise, which arise from statistical fluctuations in the flow of charge carriers are inherent to all electronic devices. The root mean square voltage due to thermal noise V_n, generated in a resistance R (Ω) over bandwidth Δf (Hz), is given by equation 3.6.

$$V_n = \sqrt{\left(4K_B TR\Delta f\right)} \tag{3.6}$$

Where k_B is Boltzman constant (J/K) and T is the resistor's absolute temperature (K).

Avalanche noise, burst noise and flicker noise, also known as $1/f$ noise are other common electronic noises that affect the sensitivity of an electronic measuring system. Electronic filters are therefore necessary to reject these electronic noises within a certain frequency range. Almost all applications are subject to some level of noise picked up from power lines or machinery and are not immune to electronic noises. Low pass and high pass filters are available for this purpose.

3.9 Input buffer

The buffer 74LS244 IC, shown in figure 3.17 is used to improve both the performance and parallel port bus oriented receivers. The eight output lines, pins 11-18 of ADC0804, are connected to the octal buffer 74LS244 whose outputs are connected to the PC's parallel port by a 25 way male connector. The output data from the buffer are usually controlled by two active low enable lines, pins 1 and 19, indicated in figure 3.14 as 1OE and 2OE, respectively. They are grounded to enable the output data to flow from the buffer to the parallel port. Otherwise if left unconnected or high, the buffer is in a high impedance state disconnecting the circuits at the input and the output pins.

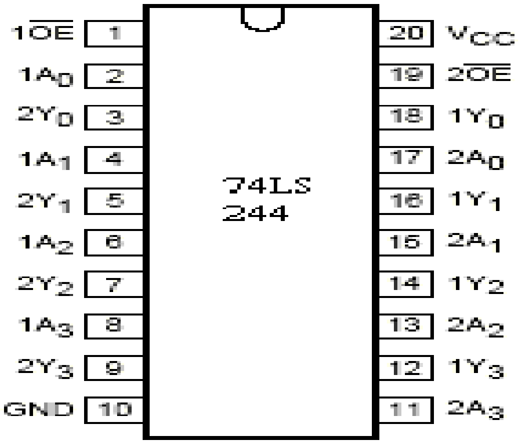


Fig. 3.14: Pin assignment of 74LS244 IC buffer (Texas Instruments, 2002).

3.10 Etching

Etching is the art of cutting thin lines into the surface of a material using either acids, bases, UV light or using a low voltage or current and is done on variety of materials including glass, semiconductors and metals. In hard ground etching the plate, usually of copper or zinc, is given a thin coating or ground of acid resistant resin. This is sometimes smoked so that lines scratched through the resin with a needle will be clearly visible. The needle exposes the metal without penetrating it. When the design is completed, the plate is submerged in an acid solution that attacks the exposed lines. During the bath the plate is frequently removed, and such lines are bitten to sufficient depth. The lines receiving the longest exposure to the acid will be the heaviest and darkest in the print. In printing, all varnish is removed and the plate is warmed, coated with etcher's ink, and then carefully wiped so that the ink remains in the depressions but is largely or wholly removed from the surface. It is then covered with a soft, moist paper and run through an etching press. The ICs used in the design of the project in this work were etched on a PCB board. These are ADC0804, thermocouple amplifier chip, multiplexer chip AD8180, output buffer 74LS244 chip and pressure sensor circuits.

Finally, after the electrical signals from the sensors have passed through the signal conditioning circuit and now at the computer port, the computer access and process these signal data using a computer program referred to as software driver. The detail of various ways of coding the software driver is discussed in the forgoing section.

3.11 Software drivers

Software drivers that are used to acquire data in instrumentation and measurement can be written either in text based or graphical programming languages. The two approaches are discussed in sections 3.11.1 and 3.11.2.

3.11.1 Graphical programming

Graphical software programming depicts program codes with icons connected with lines of different colours depending on the data types, appear on the block diagram rather than text codes in a text editor as in text based programming languages. This class of programming languages includes LabVIEW among others. In LabVIEW, icons are simply connected using virtual wires during program coding as shown in figure 3.15. This eliminates most of the syntax errors common in text based programming.

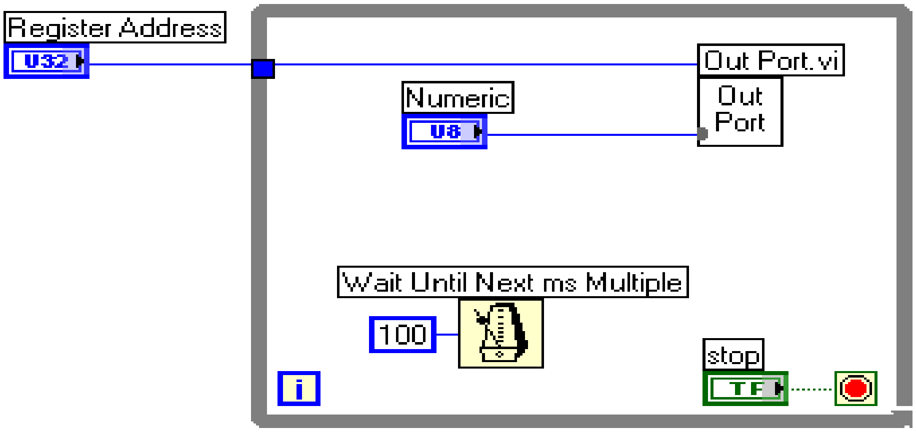


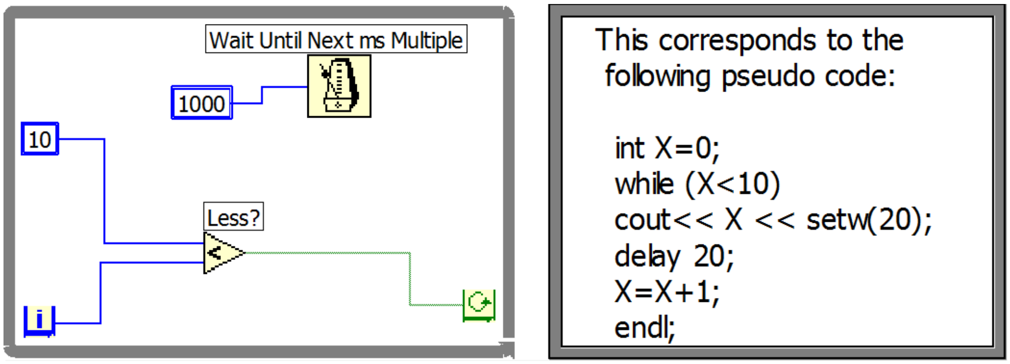
Fig. 3.15: A LabVIEW block diagram that output data to a parallel port after 100 milliseconds (National Instruments, 2000).

Furthermore, LabVIEW is capable of executing multiple operations concurrently thus enable the programmer to create multitasking codes that reduce the execution time of a larger program. In addition, LabVIEW has features that make it easy for device interfacing, data acquisition and data manipulation.

However, graphical softwares are quite expensive compared to text based softwares, hence not widely used. In addition, LabVIEW programs only run only on LabVIEW environment, therefore, LabVIEW software has to be installed in any computer that runs LabVIEW programs and this limits their use in software development.

3.11.2 Text based programming

This class of programming languages depicts program codes in text form in a text editor of the program compiler. Text based languages such as VB, C, C++, C#, FORTRAN, JAVA, Delphi and Matlab among others are examples of these languages. Although they are widely used in coding most of the softwares than the former, they are prone to syntax errors. One can omit the semicolons at the ends of the text program statement and result to syntax errors in C, C++ or C#. These technicalities are not present in LabVIEW as indicated in figure 3.16.



This corresponds to the following pseudo code:

```
int X=0;
while (X<10)
cout<< X << setw(20);
delay 20;
X=X+1;
endl;
```

Fig. 3.16: A LabVIEW while loop to compare with that of text-based programming (Natinal Instruments, 2001).

If a programmer in this case omits or substitutes the semicolons with a colon, then the program will not run. Moreover, a number of pages containing program codes necessary to accomplish a specific task are written in text based coding compared to simple objects in graphical coding. Text based programming can either be procedural or object oriented. The focus of procedural programming is to break down a programming task into a collection of variables, data structures, and subroutines, whereas in object oriented programming it is to break down a programming task into objects with each "object" encapsulating its own data and methods (subroutines). The most important distinction is whereas procedural programming uses procedures to operate on data structures, object oriented programming bundles the two together so as an "object" operates on its "own" data structure.

Despite the above mentioned shortcomings, text based programming languages are still widely used in software development since they are cheaper compared to graphical programming languages. Also the programs written in text based languages such as C, C++ or C# execute on other environments in which these softwares are not installed unlike LabVIEW programs.

CHAPTER FOUR

SYSTEM DESIGN

4.1 Introduction

This chapter presents a detailed description of the system design, which involves hardware and software designs. The design procedures of each circuit of the hardware component used in the project and specific LabVIEW codes used to access and manipulate the data from the parallel port interface is also given. The role of each component in the whole project and their interaction to accomplish the functionality of the designed electronic pressure and temperature measuring system is presented. Lastly, the organization of the hardware components in the designed electronic measuring system as a block diagram and how they are integrated with the software is given in the last section of this chapter.

4.2 The hardware design

4.2.1 Analog to digital converter, ADC0804 circuit

The analog to digital converter circuit was designed using ADC0804 chip on a breadboard and tested using LEDs. One terminal was used to provide $-V_{cc}$ and $+V_{cc}$ voltage supply to the chip while the other terminal, was used to provide variable voltage V_{in} to pin 6 of the ADC0804 chip to be digitized.

The connection diagram of ADC0804 IC chip used in the design is shown in figure 4.1. The depression on the upper part of the chip indicates where pin 1 is located on the left hand side and pin 20 on the right. A complete analogue to digital converter circuit using

ADC0804 was designed as depicted in figure 4.2. The conversion time of the ADC0804 used was 100 µs and its resolution was 8 bits (National Semiconductor, 1999).

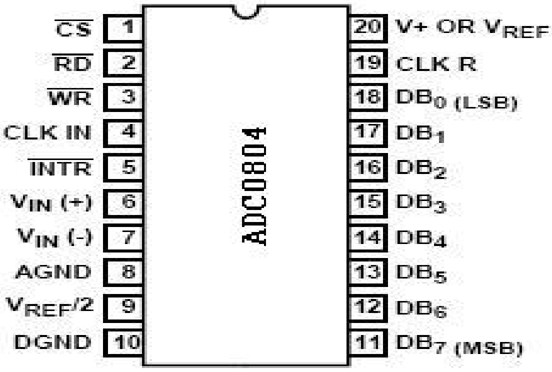


Fig. 4.1: An ADC0804 connection diagram (National Semiconductor, 1999).

Various voltages from the dual power supply were fed to V_{in}, pin 6 of the ADC0804 to be digitized while the chip was powered by +5 V dc. Pin 3 and 5 of the chip were momentarily grounded and put on a high impedance to start the conversion of the analogue voltage to 8 bit digital pulses when the V_{cc} supply was on. The output bits were 256 states in total, ranging from 00000000 to 11111111 corresponding to 0 V to 5 V, respectively. Table 4.1 indicates the sample of this output from ADC0804 during the design of analogue to digital converter circuit.

The values of R =10 K, C1 = 0.1 µF, C2 = 10 µF and C3 =150 pF were obtained by simulating the circuit in figure 4.2 using trial version of Multisim software from National Instrument until a stable output on the LEDs were observed.

Table 4.1: A sample of digital output from ADC0804 during ADC circuit design.

Voltage input to ADC in volts	**MSB**						**LSB**
0.0	0	0	0	0	0	0	0	0
0.5	0	0	0	1	1	1	0	1
1.0	0	0	1	1	0	1	1	1
1.5	0	1	0	1	0	0	0	0
2.0	0	1	1	0	1	0	1	0
2.5	1	0	0	0	0	1	0	0
3.0	1	0	0	1	1	1	1	0
3.5	1	0	1	1	0	1	1	1
4.0	1	1	0	1	0	0	0	1
4.5	1	1	1	0	1	0	1	0
5.0	1	1	1	1	1	1	1	1

The leads to the analog inputs, (pins 6 and 7) in figure 4.2, were kept as short as possible to minimize input noise coupling. Both noise and undesired digital clock coupling to these inputs could cause system errors. The source resistance for these inputs was kept below 5 KΩ since larger values of source resistance can cause undesired system noise pickup. Input bypass capacitor C1, placed from the analog inputs pin to ground, eliminated external noise that might affect the measured values of pressure and temperature.

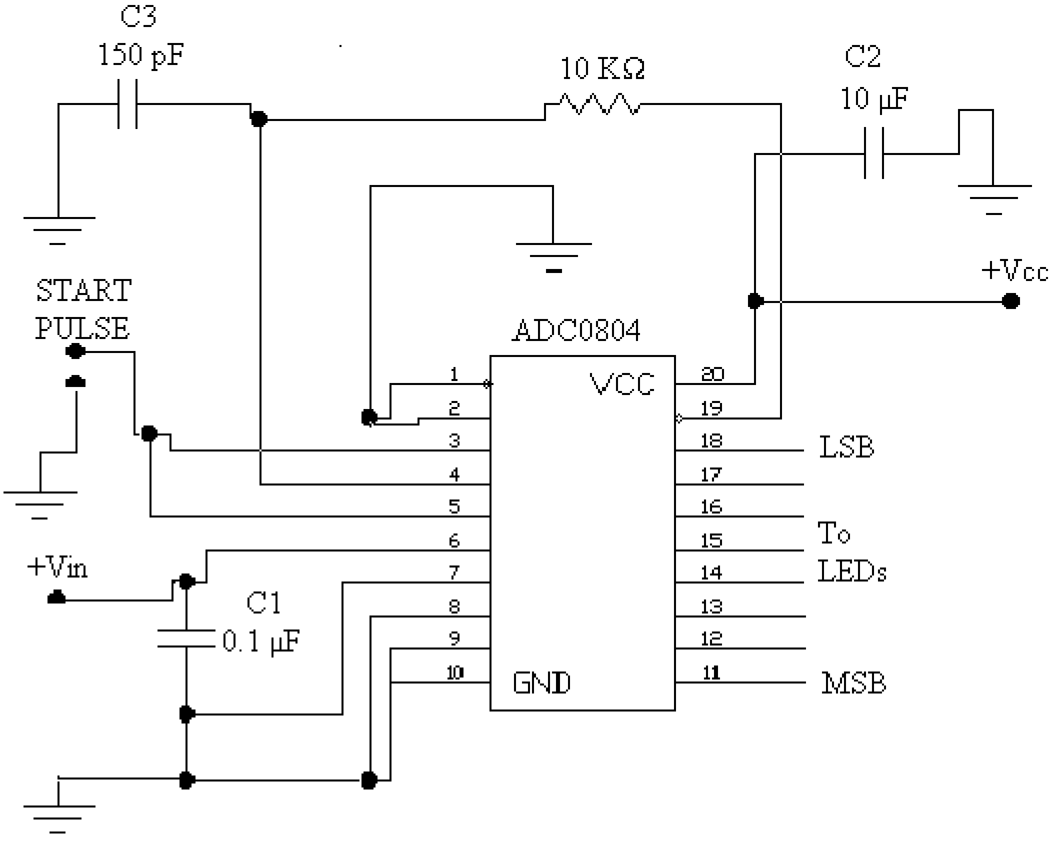


Fig. 4.2: Designed ADC circuit using ADC0804 and LEDs for displaying digital codes during testing.

4.2.2 Pressure sensor circuit

The voltage from the pressure sensor MP20C-01-F2 was in the range of 0 to 100 mV and was amplified using the 741 Op Amp as shown in figure 4.3 before feeding to the electronic low pass filter. The Op Amp configuration used in the design of pressure sensor circuit was non inverting mode therefore; the input voltage from the pressure sensor was in phase with the amplified output voltage. The 22 KΩ resistor in the circuit is the feedback resistor used to improve the gain of the circuit. The V_{cc} used to power the pressure sensor and 741 Op Amp was +5 V.

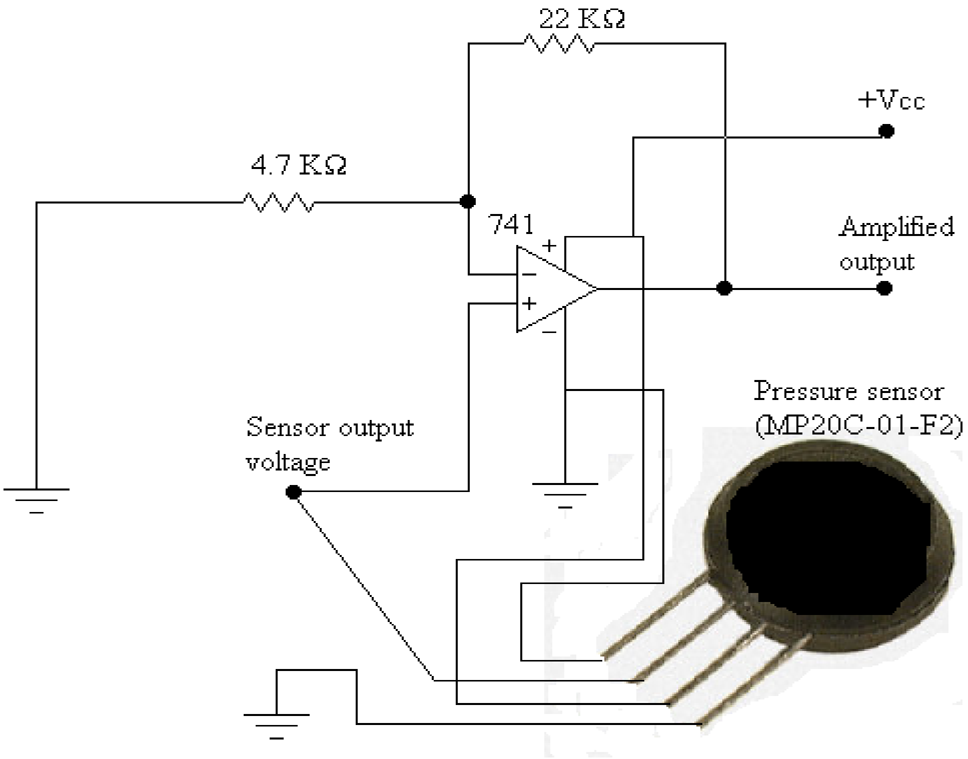


Fig. 4.3: Designed pressure sensor circuit.

The values of R =22 K, and R =4.7 K were obtained by simulating the circuit in figure 4.3 using trial version of Multisim software from National Instrument until a stable output was observed.

4.2.3 Temperature circuit design

The temperature circuit depicted in figure 4.4 was designed on the breadboard before etching on the printed circuit board. The positive terminal of the thermocouple type K was connected to pin 1 of the AD595CQ IC amplifier and its negative terminal to pin 14 using equal short copper wires during design procedures. The thermocouple wires were twisted over each other to minimize electrical field due to thermocouple voltage. The amplified output voltage was obtained from pin 9 and connected to pin 6 of the

ADC0804 IC. The V_{cc} supply voltage was connected to pin 11 with the $-V_{cc}$ connection at pin 7 strapped to power supply and the AD595CQ ground. The alarm output at pin 13 was not used, hence connected to the ground. The pre-calibrated feedback network at pin 8 was tied to the output at pin 9 to provide a 10 mV/ ^{o}C nominal temperature transfer characteristics. RC filter was used to eliminate electrical noise from the sensed thermocouple voltage. The value of the resistor R used was 10 KΩ and that of the capacitor C was 10 μF obtained from AD595CQ user manual (Analog Devices, 1999). Since cold junction compensation was done using a LabVIEW software, pins 2, 3, 5, 6, 10, 12 in AD595CQ which are meant for this purpose, were not connected. The V_{cc} used to power the AD595CQ thermocouple amplifier was +5 V.

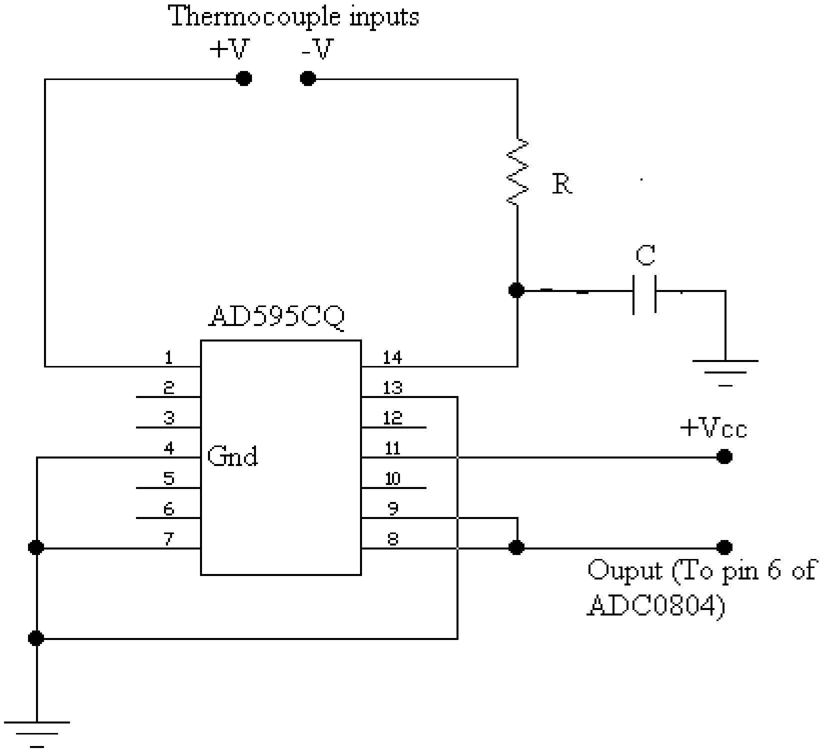


Fig. 4.4: Designed temperature sensor circuit

4.2.4 Multiplexer circuit design

The centre piece of the multiplexer circuit is an AD8180 IC which is a high speed 2 to 1 integrated analog multiplexer. It has a switching time of 10 ns (Analog Devices, 2000). The switching happens upon the change of the logic input level at its SELECT input. The connection diagram is shown in figure 4.5. When SELECT input is logic LOW the common output Aout equals the analog input IN1 from thermocouple temperature sensor, otherwise Aout equals analog input IN2 from pressure sensor. The designed circuit of the analog multiplexer module is indicated in figure 4.6 and V_{cc} voltage used to power the multiplexer was +5 V

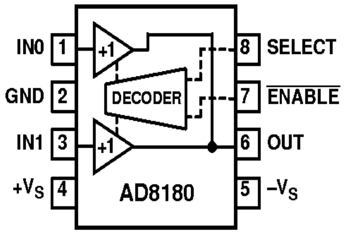


Fig. 4.5: Analog multiplexer AD8180 connection diagram (Analog Devices, 2000).

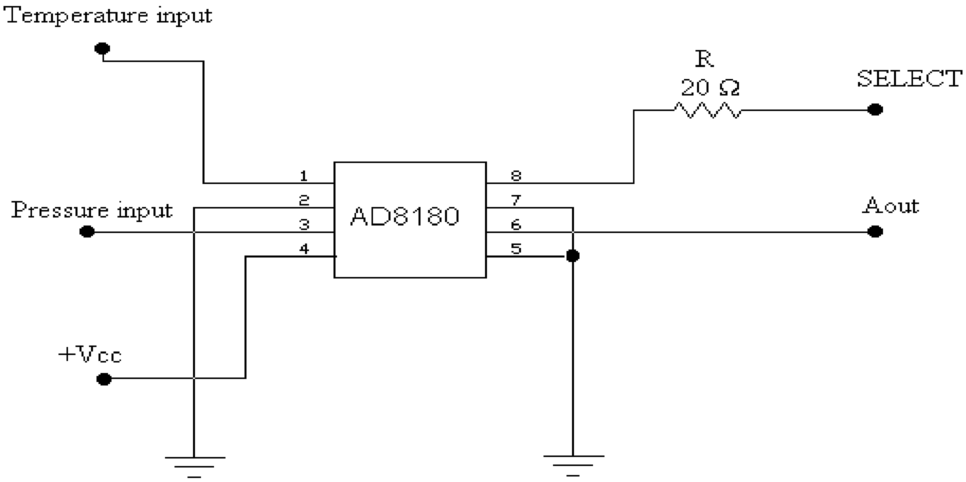


Fig. 4.6: Analog multiplexer AD8180 designed circuit.

The computer held the SELECT input signal LOW to select thermocouple input for 20 milliseconds and then HIGH for 20 milliseconds afterwards to select pressure sensor voltage into the digitizing unit. The Enable signal was permanently tied to the ground rail to ensure the multiplexer is active throughout its operations. Taking enable input HIGH, the multiplexer would be disabled and the output would be switched to HIGH impedance state.

4.2.5 Circuit and components on PCB

The ADC0804, thermocouple amplifier AD595CQ, multiplexer AD8180, input buffer 74LS244 ICs and pressure sensor circuits were etched on printed circuit board (PCB) using chemical etching. The integrated circuit of all the chips was designed using Multisim software from National Instruments using a computer before printing on the PCB board. Usually air is trapped between wires on a breadboard. This acts as a dielectric material between wires carrying current, hence introduce capacitance which affect the accuracy of the designed electronic system. Etching the circuit components on a PCB eliminates the air between the wires, hence minimizes the capacitance observed on the breadboard.

4.3 Software design

The software driver, which was used to access the temperature and pressure data from the parallel port interface, was designed using LabVIEW programming language from National Instrument. The front panel was designed on the LabVIEW environment using the numeric and Boolean indicators and controls before the block diagram that controls the execution of the LabVIEW program. The indicators and controls that appeared as blue icons, are meant for integers and yellow for double precision numeric that were joined by wires inform of lines. The green icons and dotted lines indicated Boolean codes that were used to indicate conditions that were to be fulfilled by program subroutines in order for execution to take place and proper choices to be made. Section 4.3.1 describes the codes that were used to access data specifically from the parallel port in LabVIEW programming.

4.3.1 Accessing parallel port in LabVIEW programming

Enhanced parallel ports are bidirectional and can be used as both input and output ports. In LabVIEW programming, the following codes were used to communicate with the parallel port and so the external pressure and temperature sensors. The code in figure 4.7 was used to read the data from the parallel port while that in figure 4.8 was used to write data to the parallel port.

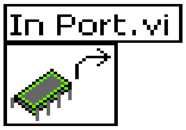


Fig. 4.7: LabVIEW code used to read data from the parallel port.

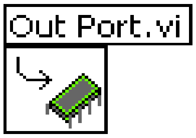


Fig. 4.8: LabVIEW code used to write data to the parallel port.

The two codes are located in All functions palettes >Advanced>Port I/O in the block diagram of the LabVIEW environment. However, to use the parallel port as a bidirectional data bus, bit 5 in the control register at base address +2 was set high. This was achieved by writing a decimal number 32 to the control register as shown in figure 4.9. The blue lines indicate an integer value wired to the outport.vi function.

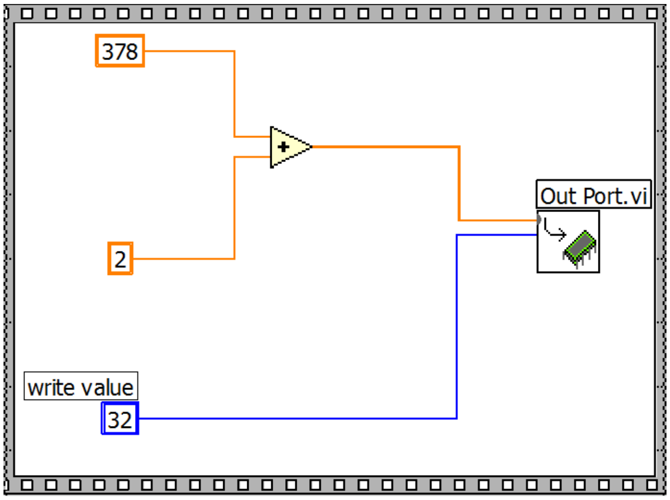
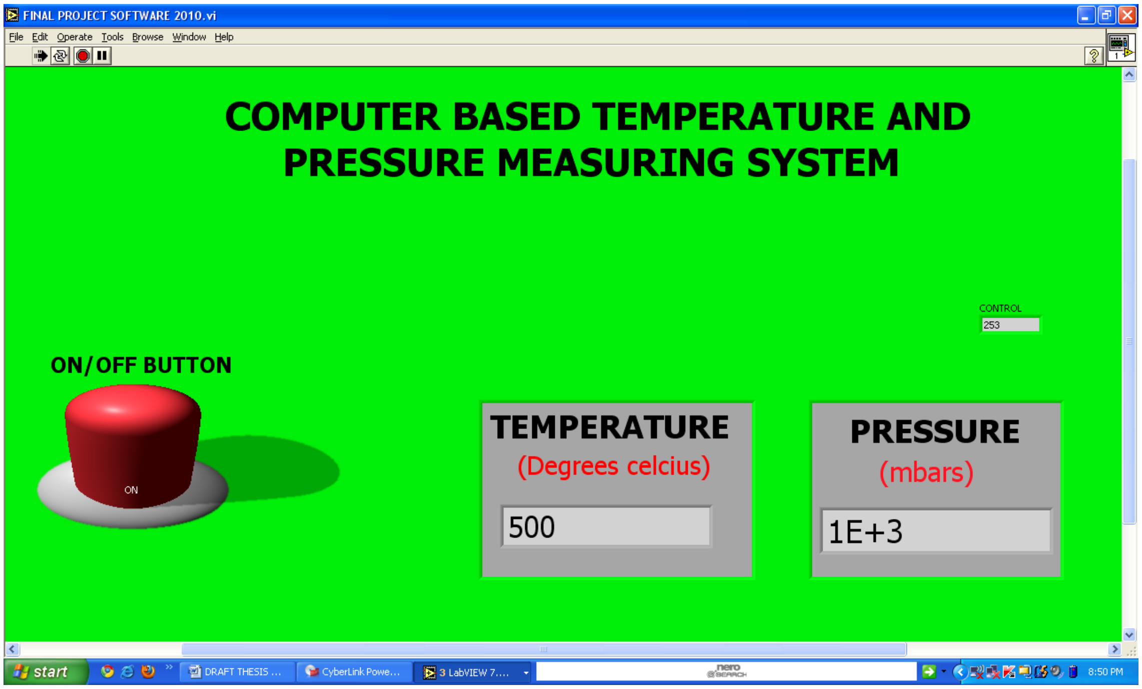


Fig. 4.9: A section of LabVIEW code used to make bit 5 of the parallel port high.

4.3.2 Front panel of the software driver

The graphical user interface (GUI) depicted in figure 4.10 was designed using numeric indicators in LabVIEW programming. It displayed chamber temperature and pressure to the user during deposition of thin films in thin film deposition system. An ON/OFF button was also included in the front panel to assist the user stop and start the acquisition of data from the designed interfaced board attached to the pressure and temperature sensors through the computer parallel port. The GUI displayed the temperature data in ^{o}C while pressure in mbar.



COMPUTER BASED TEMPERATURE AND PRESSURE MEASURING SYSTEM

CONTROL 253

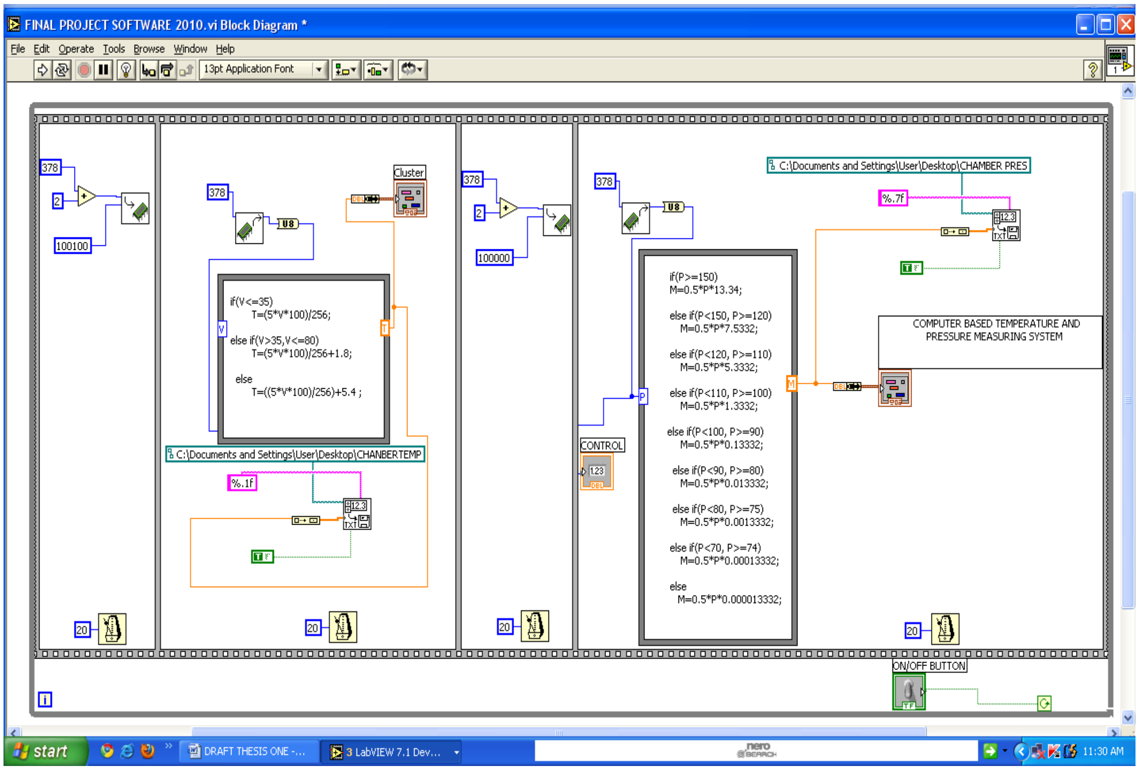
TEMPERATURE (Degrees celcius) 500

PRESSURE (mbars) 1E+3

Fig. 4.10: The GUI of the software driver for the designed electronic measuring system.

4.3.3 Block diagram of the software driver

The LabVIEW codes that were used to access temperature and pressure data from the parallel port interface are shown in figure 4.11. These codes accessed and manipulated the values of these parameters and stored them in a computer memory for retrieval by the user after the deposition process. The codes appeared as icons on the block diagram as opposed to text based codes that are composed of several lines of text in text based programming. Appendix IV indicates an equation included in the software codes to manipulate temperature data from the thermocouple type K sensor. Appendix VIII indicates the flowchart for the designed LabVIEW software that controlled the designed pressure and temperature measuring system.



```
if(V<=35)
      T=(5*V*100)/256;

else if(V>35,V<=80)
      T=(5*V*100)/256+1.8;

 else
      T=((5*V*100)/256)+5.4 ;
```

```
if(P>=150)
M=0.5*P*13.34;

else if(P<150, P>=120)
  M=0.5*P*7.5332;

else if(P<120, P>=110)
  M=0.5*P*5.3332;

else if(P<110, P>=100)
  M=0.5*P*1.3332;

else if(P<100, P>=90)
  M=0.5*P*0.13332;

 else if(P<90, P>=80)
  M=0.5*P*0.013332;

 else if(P<80, P>=75)
  M=0.5*P*0.0013332;

else if(P<70, P>=74)
  M=0.5*P*0.00013332;

else
 M=0.5*P*0.000013332;
```

Fig. 4.11: LabVIEW codes that controlled the designed electronic measuring system.

4.4 Integration of software and hardware design

The ADC0804 converter processed the analog voltage inputs from pressure and temperature sensors after amplification and filtering, and digitally encoded them. Once digitized the bit representation of voltages were sent through the parallel port via the input buffer and were fetched by the software driver developed using LabVIEW programming language to the computer memory for processing. The voltage range from 0 V to 5 V was represented by the 8 bit binary codes ranging from 00000000 to 11111111. The 0 V correspond to 00000000 and 5 V to 11111111. The voltages between these values relayed the corresponding 8 bit representation as described in table 4.1. Figure 4.12 indicates the interfaced thermocouple and pressure sensor to the computer for temperature and pressure measurement.

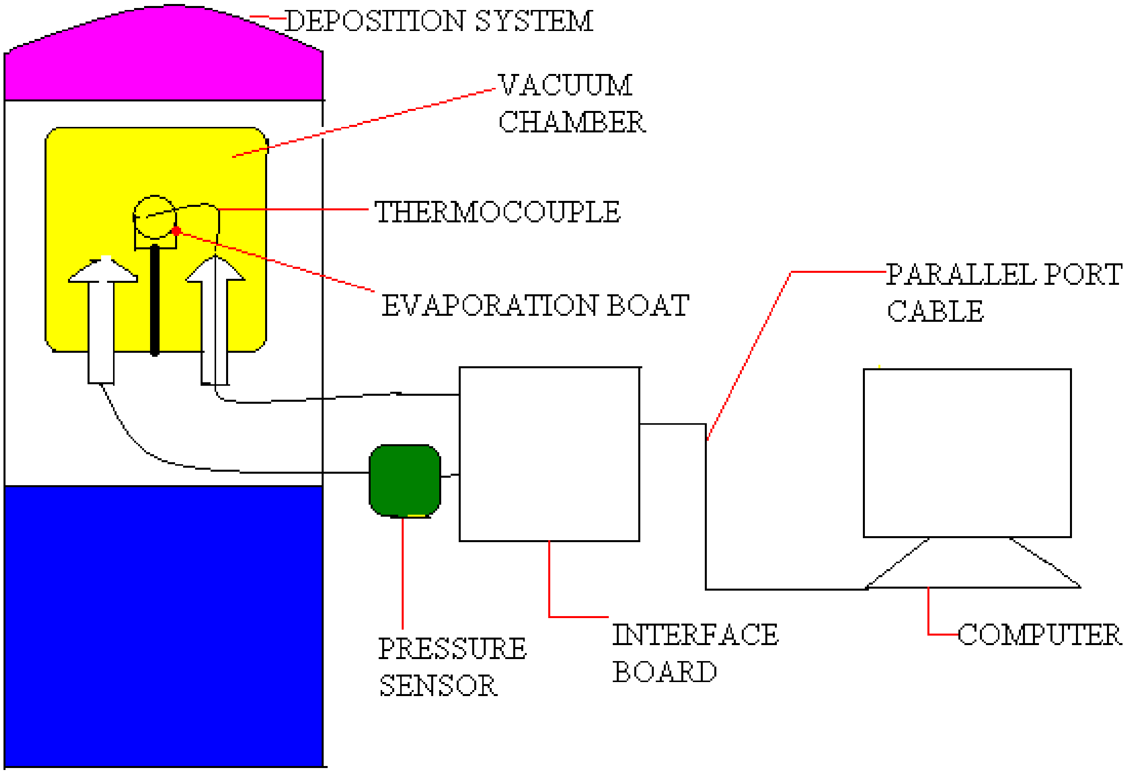


Fig. 4.12: Schematic of electronic temperature and pressure measuring system.

Thermocouple and pressure sensors were connected to the chamber using flanges which were drilled at their centers to provide for narrow openings leading to the chamber. Once the sensors were fixed, the space between the sensor and the opening was sealed using super glue to make the chamber air tight. The diagram in appendix VII depict how the pressure sensor MP20C-01-F2 from Mindman Company was fixed to the vacuum chamber in Edward auto 306 magnetron sputtering system through a flange with a hole drilled between it. The vacuum pipe connector, made of hardened plastic, was fixed through the hole and connected to the sensor. Figure 4.13 indicates the block diagram of the designed electronic temperature and pressure measuring system.

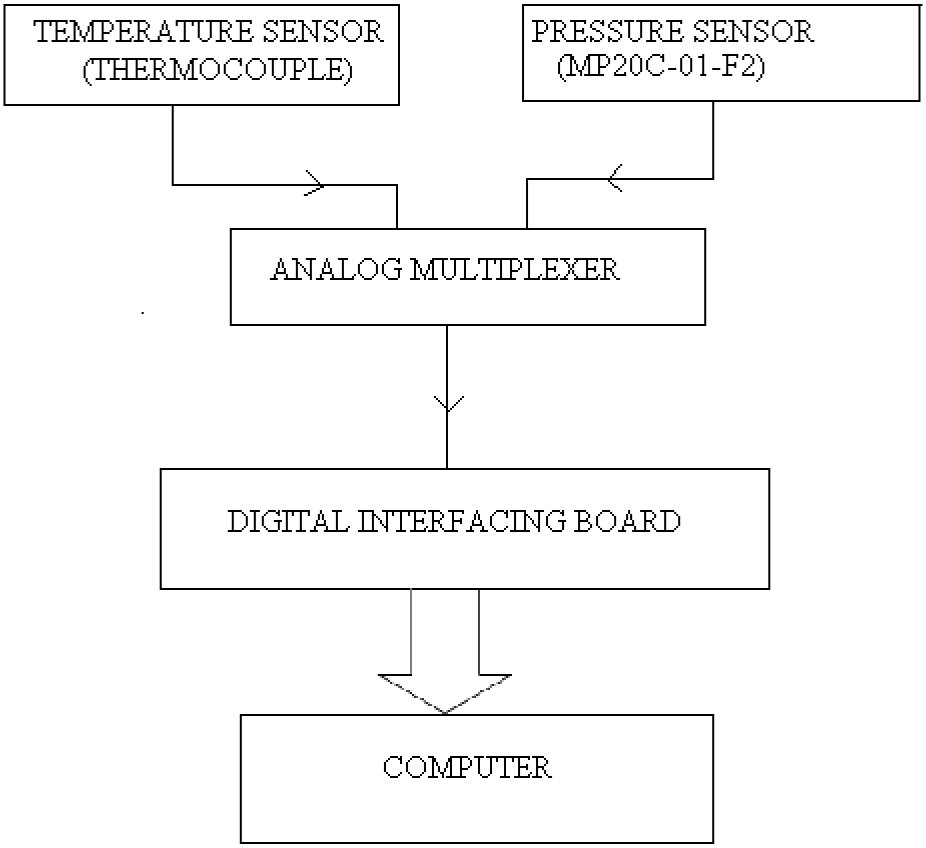


Fig. 4.13: Block diagram of electronic temperature and pressure measuring system.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Introduction

The electronic pressure and temperature measuring system was successfully designed and its functionality tested in Edward auto 306 magnetron sputtering system indicated in appendix I. The designed system was used to measure process parameters; temperature and pressure. The chamber pressure was measured when Edward auto 306 magnetron sputtering system was both pumping up and down and the chamber temperature was measured when SnSe thin film samples were deposited by evaporation technique. To validate the designed electronic pressure and temperature measuring system, SnSe and AlO_xN_y thin films were deposited on glass substrates using evaporation and sputtering techniques, respectively, while measuring process parameters using the designed system. Their electrical properties were determined using the four point probe and results agreed with those from earlier researchers (Mariappan *et al.* 2010, Borges *et al*. 2010 and Komatsu *et al.* 2010). Finally, the digital interface board was also designed with two digital inputs and work as expected.

5.2 Temperature measurement in Edward auto 306 magnetron sputtering system

SnSe thin films were deposited on glass substrate in the ratio 1:1 in Edward auto 306 magnetron sputtering system using evaporation technique. During the deposition process, the temperature at which the samples started to evaporate was measured. Two thermocouple type K sensors, fixed in the chamber were used simultaneously to measure the evaporation temperature of the samples. One of the sensors was interfaced to the computer and the other to the standard thermocouple display. The evaporation temperatures measured by the designed electronic pressure and temperature measuring system and those from the standard thermocouple display are shown in table 5.1.

Table 5.1: Evaporation temperature of SnSe thin films prepared by evaporation technique in Edward auto 306 sputtering system.

Sample (Thin films of SnSe)	**Temperature measured by designed electronic system (^{o}C)**	**Temperature measured by standard thermocouple (^{o}C)**
A	426	425
B	427	428
C	428	429
D	431	430
E	424	423
F	425	425

It was observed that the designed electronic system had a temperature error of ± 1 ^{o}C which is within acceptable range.

5.3 Measurement range of the thermocouple type K temperature sensor

The measurement range of the interfaced thermocouple type K temperature sensor was tested in a Lindberg/Blue electric furnace where it was placed in the furnace with the help of a glass tube and the furnace temperature varied. The variation of temperature was measured by the interfaced thermocouple and its values stored in an excel file in a computer memory and retrieved after the experiment. The corresponding voltage outputs after amplification was also measured at the output of the AD595CQ amplifier and before feeding to the ADC0804. Table 5.2 indicates the voltage (mV) from the thermocouple type K after amplification and before feeding to the computer and the corresponding temperature (^oC) read on the computer by the designed electronic temperature and pressure measuring system.

Table 5.2: Voltage (mV) output and the corresponding temperature (^oC)

Voltage (mV)	Temperature (^oC)
201	20
299	30
400	40
501	52
605	61
808	79
1015	99
1217	121
1421	139
1619	161
1818	179
2015	199
2214	220
2414	239

Table 5.2 continued

Voltage (mV)	Temperature (^{o}C)
2615	261
2817	280
3020	301
3227	320
3435	339
3620	360
3848	379
4056	401
4265	422
4475	440
4686	459
4898	480
5107	500
5318	520
5526	539
5740	559
5949	579
6162	601
6370	629
6580	640
6792	661

Table 5.2 continued

Voltage (mV)	Temperature (^{o}C)
6999	680
7207	701
7413	720
7619	739
7722	750
7824	761
8030	780
8233	800
8435	821
8637	841
8837	860
9036	881
9233	900
9430	921
9626	941
9822	960
10015	981
10209	1000
10400	1020
10592	1041
10782	1061

Table 5.2 continued

Voltage (mV)	Temperature (^{o}C)
10970	1080
11159	1100
11346	1120
11531	1140
11755	1162
11899	1181
12079	1200
12259	1221
12437	1242
12525	1251

From table 5.2, it was observed that, the designed electronic pressure and temperature measuring system had a temperature measurement range of 0 ^{o}C to 1251 ^{o}C. The amplified thermocouple voltage outputs (mV) and the corresponding temperatures were plotted. Their relationship is indicated in figure 5.1.

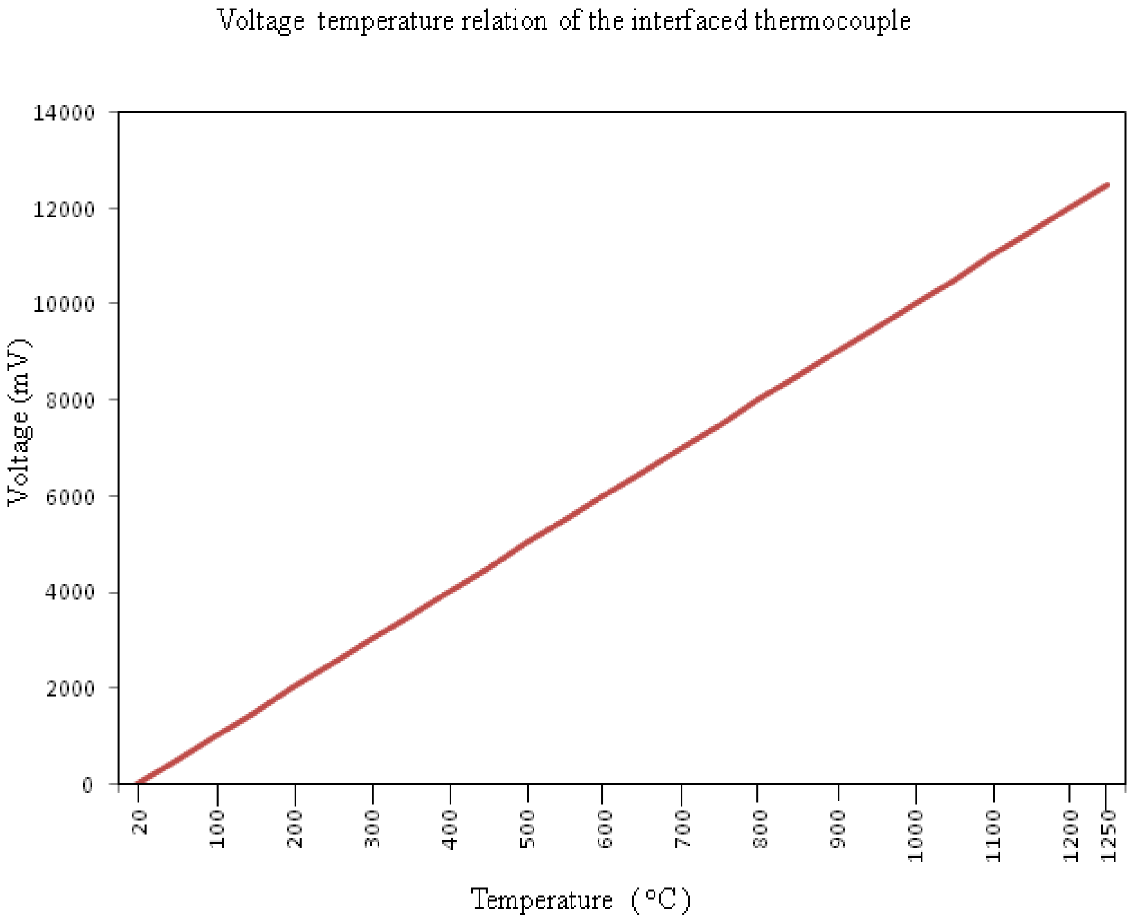


Fig. 5.1: Relationship between voltage output and the corresponding temperature sensed by the interfaced thermocouple type K.

The output of the interfaced thermocouple sensor was linear as indicated in figure 5.1. When heat energy was applied to a thermocouple wire, a voltage proportional to the sensed temperature was induced into the wire. Due to the Seebeck effect, the induced thermocouple voltage is made up of two components, the Peltier voltage and the Thomson voltage. The Peltier voltage is proportional to the temperature of each junction while the Thomson voltage is proportional to the square of the temperature difference between the two junctions. It is the Thomson voltage that accounts for non linearity in thermocouple response as indicated by equation 3.4 and not observed at temperatures below 1500 °C.

5.4 Validating temperature measurement by the designed system

5.4.1 Crystallization temperature of SnSe determined using the designed system

Thin films of SnSe deposited in the ratio 1:1 were heated in a Lindberg/Blue tube furnace while their resistivity measured using four point probe interfaced to the computer and temperature measured using both the designed electronic pressure and temperature measuring system and the standard thermocouple type K before interfacing. The graph in figure 5.2 indicates the variation of resistivity with temperature measured using the designed electronic temperature and pressure system.

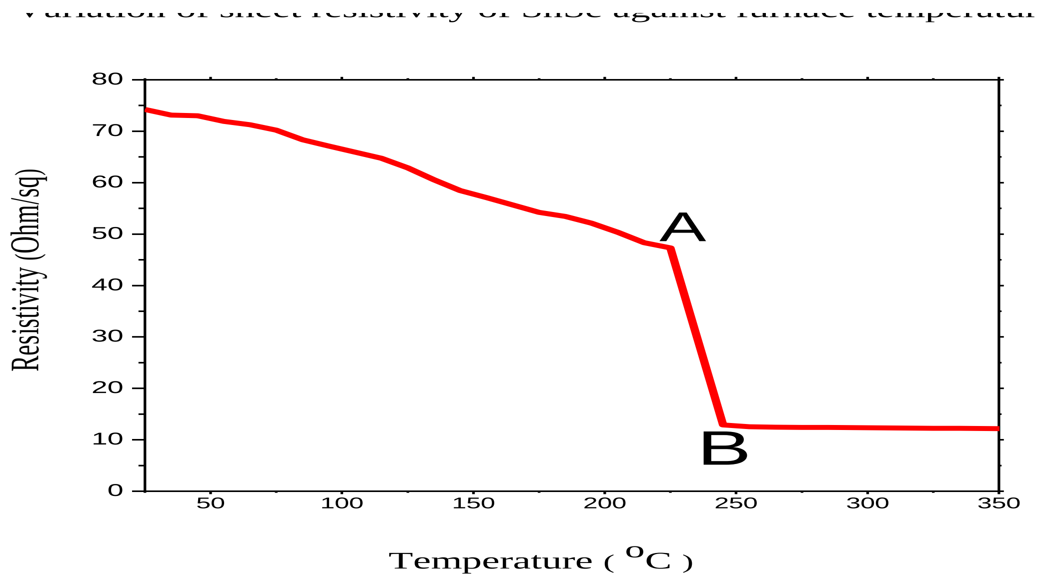


Fig. 5.2: The curve of resistivity against temperature measured by designed electronic temperature and pressure system for SnSe thin films.

In figure 5.2, the sharp drop in resistivity between points A and B is due to the fact that SnSe is a phase change material and is changing phase from amorphous to crystalline as the temperature is increased from 228 °C to 250 °C. The exact temperature at which this transition from amorphous to crystalline material occurs was obtained by differentiating the graph of resistivity against temperature in figure 5.2 and figure 5.3 was obtained.

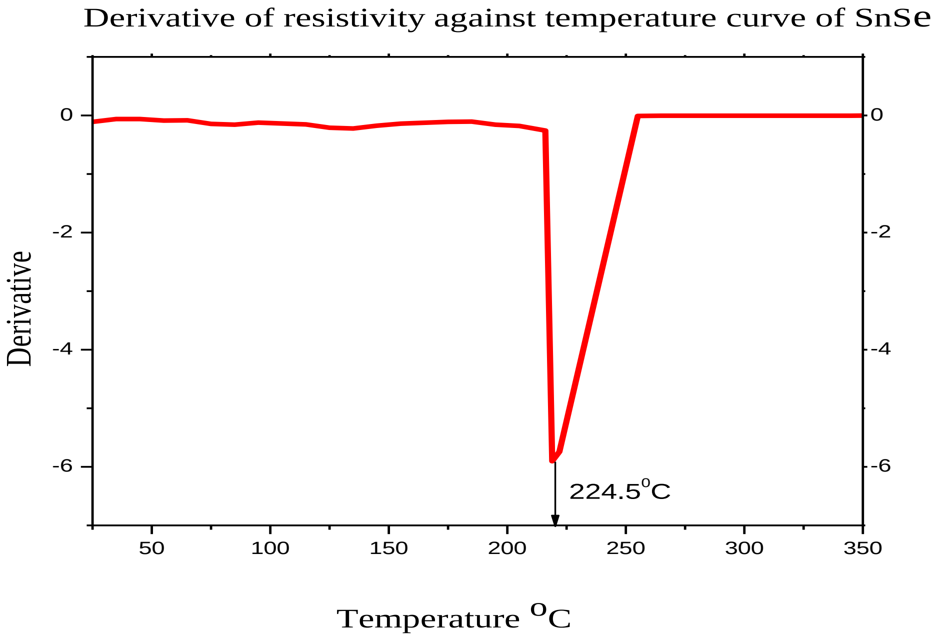


Fig.5.3: The curve of derivative against temperature measured by the designed electronic temperature and pressure system for SnSe thin films.

The lowest point of the curve gives the crystallization temperature, T_c of SnSe thin films. T_c is the temperature at which a phase change material changes phase from amorphous to crystalline. The T_c measured by designed electronic pressure and temperature measuring system was 224.5 °C

5.4.2 Crystallization temperature of SnSe determined using the standard sensor

The graph in figure 5.4 indicates the variation of resistivity with temperature measured using the standard thermocouple type K that was not interfaced to the computer.

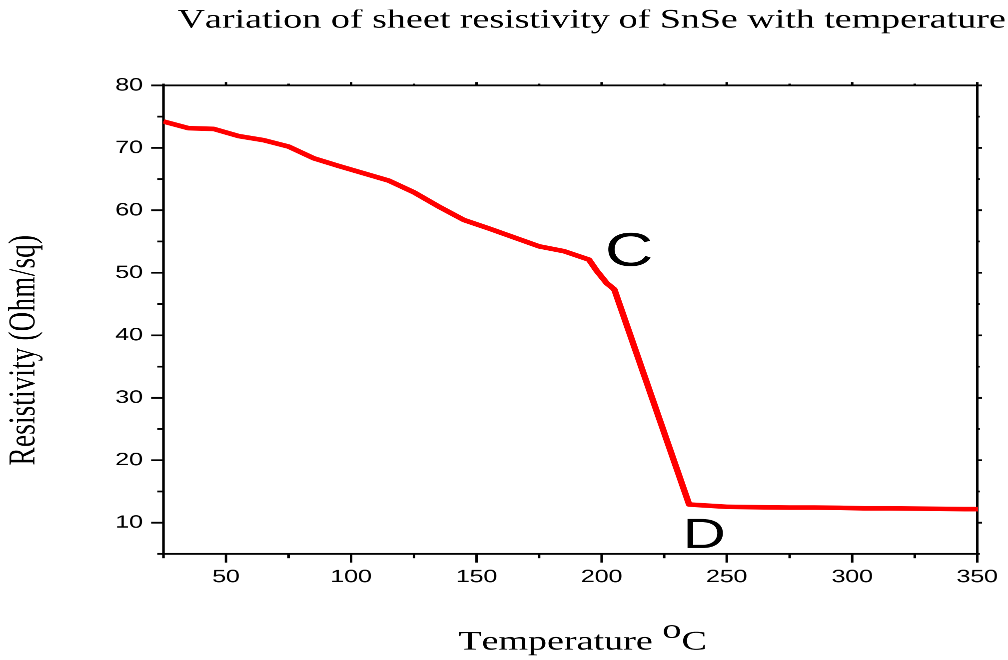


Fig.5.4: The curve of resistivity against temperature measured by the standard thermocouple type K before interfacing for SnSe thin films.

Again in figure 5.4, the sharp drop in resistivity between points C and D is also due to the fact that SnSe is a phase change material and is changing phase from amorphous to crystalline as the temperature is increased from 221 ^{o}C to 239 ^{o}C. The exact temperature at which this transition from amorphous to crystalline material occurred is obtained by differentiating the graph of resistivity against temperature in figure 5.4 and figure 5.5 was obtained.

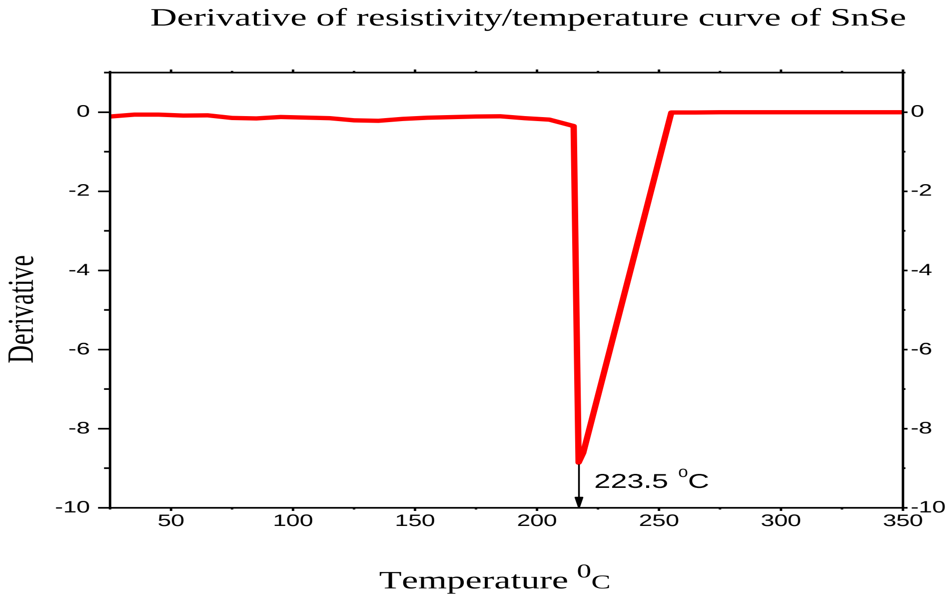


Fig.5.5: The curve of derivative against temperature measured by the standard thermocouple type K before interfacing for SnSe thin films.

The lowest point of the curve gives the crystallization temperature, T_c of SnSe thin films. For the temperatures measured by the standard thermocouple, the T_c obtained was 223.5 ^{o}C. Hence the designed electronic pressure and temperature measuring system indicated a temperature error of ± 1 ^{o}C. These results agree with those of Mariappan *et al.* (2010).

5.5 Pressure measurement

The designed electronic pressure and temperature measuring system was used to measure vacuum pressure in Edward auto 306 magnetron sputtering system when it was pumping up (venting). The pressure values were recorded simultaneously with those measured by the pirani gauge already fitted in the vacuum chamber as the machine was running. The values obtained are tabulated in table 5.3.

Table 5.3: Chamber pressure measured in Edward auto 306 sputtering system when it was venting (pumping up).

Pressure measured by designed electronic system (mbar)	**Pressure measured by Pirani gauge (mbar)**
1.0×10^{-4}	1.2×10^{-4}
1.2×10^{-3}	1.3×10^{-3}
1.0×10^{-2}	1.2×10^{-2}
2.6×10^{-2}	2.5×10^{-2}
3.6×10^{-1}	3.4×10^{-1}
8.5×10^{-1}	8.1×10^{-1}
1.3×10^{0}	1.3×10^{0}
6.0×10^{1}	6.0×10^{1}
2.0×10^{2}	2.0×10^{2}
7.0×10^{2}	7.0×10^{2}
1.0×10^{3}	1.0×10^{3}

The pirani gauge and the designed electronic temperature and pressure measuring system were also used to measure simultaneously the vacuum chamber pressure when it was pumping down. The values obtained were recorded in table 5.4.

Table 5.4: Chamber pressure measured in Edward auto 306 sputtering system when it was pumping down.

Pressure measured by designed electronic system (mbar)	**Pressure measured by Pirani gauge (mbar)**
1.0×10^{3}	1.0×10^{3}
2.2×10^{2}	2.2×10^{2}
6.0×10^{1}	6.0×10^{1}
4.4×10^{1}	4.4×10^{1}
1.2×10^{1}	1.2×10^{1}
8.5×10^{0}	8.5×10^{0}
7.5×10^{0}	7.5×10^{0}
1.2×10^{0}	1.2×10^{0}
9.0×10^{-1}	9.2×10^{-1}
3.4×10^{-1}	3.6×10^{-1}
1.5×10^{-2}	1.4×10^{-2}
2.0×10^{-2}	2.3×10^{-2}
1.5×10^{-3}	1.6×10^{-3}
1.1×10^{-3}	1.2×10^{-3}
1.3×10^{-4}	1.4×10^{-4}

The pressure sensor MP20C-01-F2 works on piezoelectric principle. When a mechanical force is applied on the sensor, a voltage is induced across the positive and negative terminals of the sensor. When Edward auto 306 magnetron sputtering system was pumping up (venting), the number of air molecules was increasing in the vacuum chamber. Therefore collision of air molecules increased within the chamber hence pressure increased as observed in table 5.3 when the air continued to be pumped in. When Edward auto 306 magnetron sputtering system was pumping down, the number of air molecules reduced in the vacuum chamber. Therefore collision of air molecules decreased within the chamber hence pressure reduced as observed in table 5.4 when the air continued to be pumped out of the chamber.

From the measurement in table 5.3 and 5.4, the designed system recorded varied pressure errors. In the pressure range 1 to $1x10^{-1}$ mbar, the error was ± $1x10^{-2}$ mbar and in the pressure range $1x10^{-2}$ to $1x10^{-3}$ mbar, an error of $1x10^{-3}$ mbar was recorded. Finally, the pressure error of $1x10^{-5}$ mbar was observed in the pressure range $1x10^{-4}$ to $1x10^{-5}$ mbar. Appendix VI indicates the conversion of pressure units.

5.6 Validating pressure sensor in the designed electronic measuring system.

To validate the pressure sensor, MP20C-01-F2, AlO_xN_y thin films were deposited on glass substrate in Edward auto 306 magnetron sputtering system using dc magnetron spattering technique. The concentration of nitrogen and oxygen reactive gases were varied for different samples as indicated in table 5.5. The sputter pressure was kept at 3.7×10^{-4} mbar measured by the designed electronic temperature and pressure system and sputter power was 200 W. The resistivity of each sample was measured using four point probe techniques and recorded in table 5.5.

Table 5.5: Resistivity of AlO_xN_y thin films

N_2 (Sccm)	O_2 (Sccm)	Film thickness (nm)	Resistivity (Ωcm)
10	0	112	3.7×10^{14}
8	2	112	9.2×10^{14}
6	4	112	2.8×10^{15}
4	6	112	1.9×10^{17}
2	8	112	9.6×10^{17}
0	10	112	7.3×10^{19}

At higher O_2 concentration (10 Sccm), Al_2O_3 which is an insulator with a band gap of 8.8 eV (Komatsu *et al.* 2010) is dominant in the film. On the other hand, at higher N_2 concentration (10 Sccm), AlN which has a band gap of 6.29 eV (Borges *et al*. 2010) is dominant in the film. AlN have lower resistivity than Al_2O_3, hence the observed results. Variation of O and N in the film composition making transformation from AlN to Al_2O_3 agrees with the results of (Borges *et al*. 2010). Therefore, for process parameter; pressure, measured by the designed electronic temperature and pressure measuring during film deposition, the AlO_xN_y thin films had the same electrical properties as those obtained by other researchers. (Borges *et al*. 2010 and Komatsu *et al.* 2010).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

A computer based instrumentation system for pressure and temperature measurement in vacuum chambers of thin film deposition systems was designed and fabricated successfully. The system was tested in Edward auto 306 magnetron sputtering system and work quite well. The designed system had temperature and pressure ranges of 0 ^{o}C to 1251 ^{o}C and 0 to 1.01 x 10^3 mbar, respectively and had the capability of storing temperature and pressure data in a computer memory during deposition. These data could be retrieved later by the user after the deposition process. LabVIEW codes designed, was used successfully to access temperature and pressure data through the designed digital board and the parallel port, processed, stored in a computer memory and displayed to the user during deposition.

The designed computer based measurement system had a temperature error of ± 1 ^{o}C. However, the designed system recorded varied pressure errors. In the pressure range 1 to $1x10^{-1}$ mbar, the error was ± $1x10^{-2}$ mbar and in the pressure range $1x10^{-2}$ to $1x10^{-3}$ mbar, an error of $1x10^{-3}$ mbar was recorded. Finally, the pressure error of $1x10^{-5}$ mbar was observed in the pressure range $1x10^{-4}$ to $1x10^{-5}$ mbar. These errors are within acceptable range. Therefore, the system is viable to be used in thin film deposition systems to automate the measurement of process parameters, temperature and pressure.

6.2 Recommendations for further work

A further research should be carried out on the designed electronic temperature and pressure measuring system to enable remote access of temperature and pressure using a GSM technology. Thin film deposition systems can also be interfaced to the GSM technology to enable the user to carry out experiments remotely. In addition, the designed digital interface board should be expanded to have more digital and analogue inputs which would make it access more physical parameters when interfaced to the computer in any other automated instrumentation. Finally, a pressure sensor that will record an error of less than $\pm 1\text{x}10^{-2}$ mbar at higher vacuum pressure should be studied with the system designed in this project.

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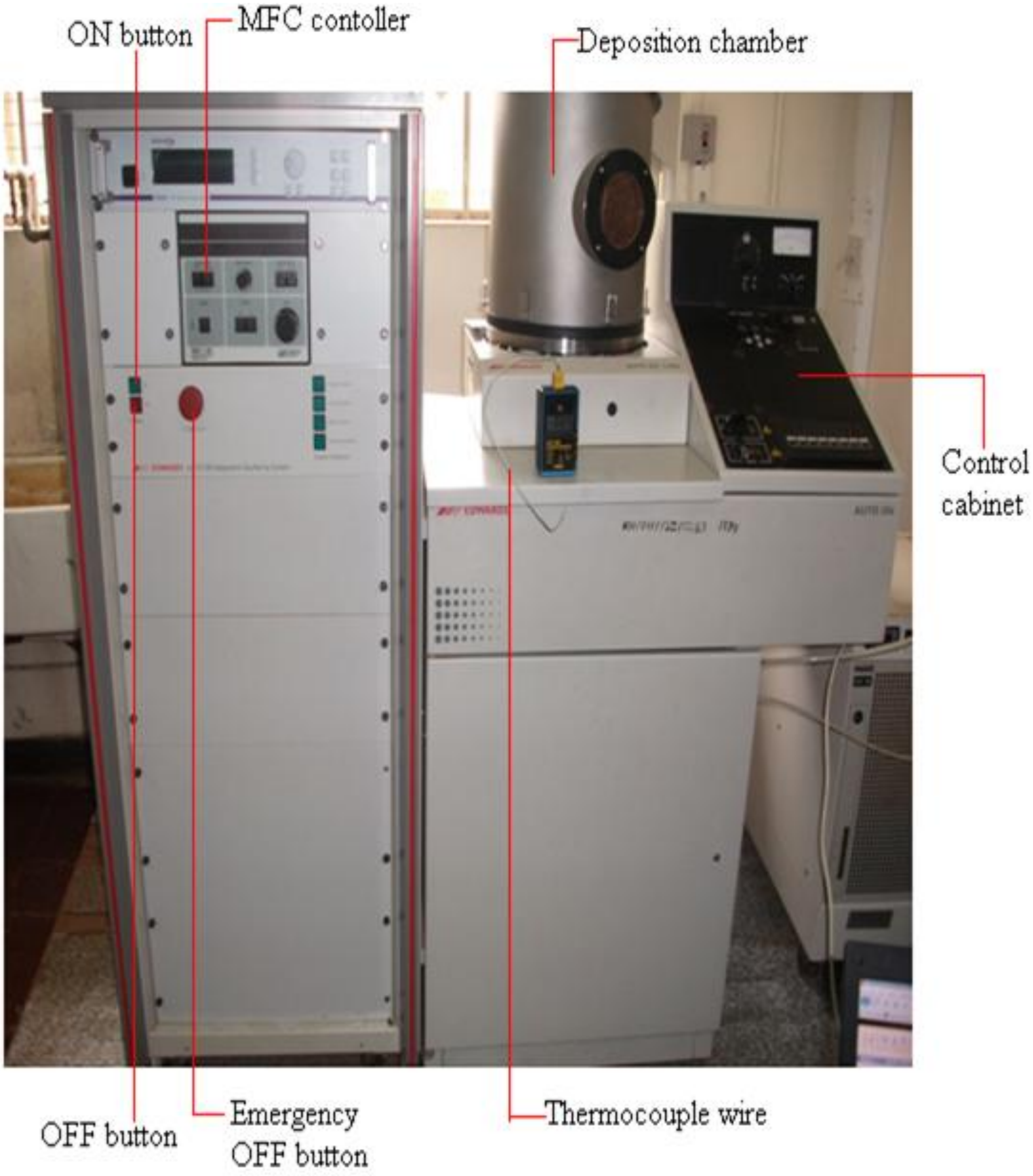
APPENDIX I

A photograph of Edward auto 360 sputtering system



Deposition Chamber: Contains DC and RF magnetrons, wafer holder and heat lamp. The door has a magnetic bearing and users should gently close the door without adding forces on it to assure good seal of the chamber. This is where the samples are deposited.

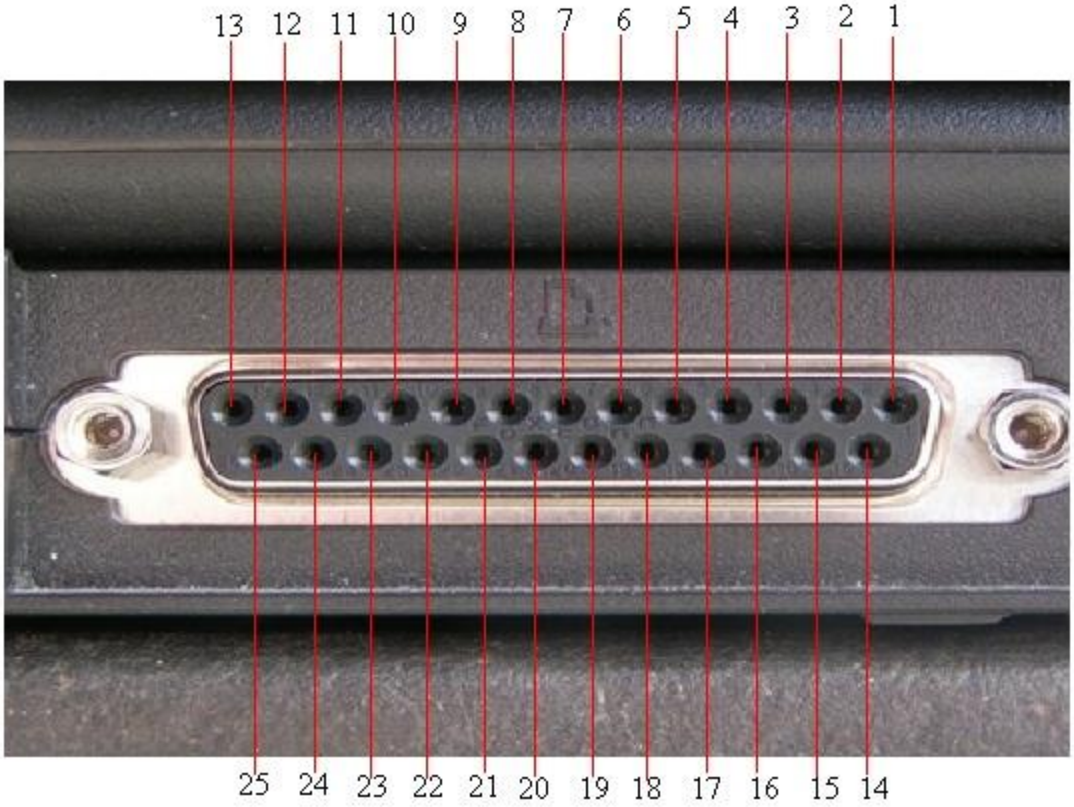
Control cabinet: Allows you to vent and pump the chamber.

Mass Flow Controller (MFC): Enable argon and oxygen by toggling the pneumatic toggle switches. The Left toggle switch is for Argon and the Right toggle switch is for oxygen and nitrogen. This opens the pneumatic valves only. Either Nitrogen or Oxygen may be selected by turning the valve below the vacuum control panel.

ON/OFF buttons: Switch on and off the power to the Edward auto 306 sputtering system and emergency off button is switched when the machine has a problem while running.

APPENDIX II

A photograph of a computer parallel port on the rear of a PC (Intel *et al*., 1996)



The specific function of each pin in the parallel port is discussed in the next section;

Pin 1 (Strobe): This pin is used by the PC to control the flow of data through the parallel port interface. Data is valid during an active low pulse on this line, hence low during a write operation and high during a read operation.

Pins 2-9 (Data lines): These are used for data transfer. In some PCs, they are used for bidirectional data transfer. Pin2 is the **LSB** while pin9 is the **MSB**.

Pin 10 (Ack): The peripheral drives this handshaking line low to indicate that the data is valid.

Pin 11 (Busy): The peripheral drives this signal high to indicate that it is not ready to receive data

Pin 12 (Paper out): Printers typically drive this signal high when papers to be printed are not present.

Pin 13 (Select): The peripheral drives this signal high when it is selected and ready for data transfer.

Pin 14 (Linefeed): During a write operation, data is valid when this signal is active high. During a read operation this signal is low when the PC is ready to receive the data.

Pin 15 (Error): The peripheral drives this signal low to indicate that there was a fault and data transfer did not occur.

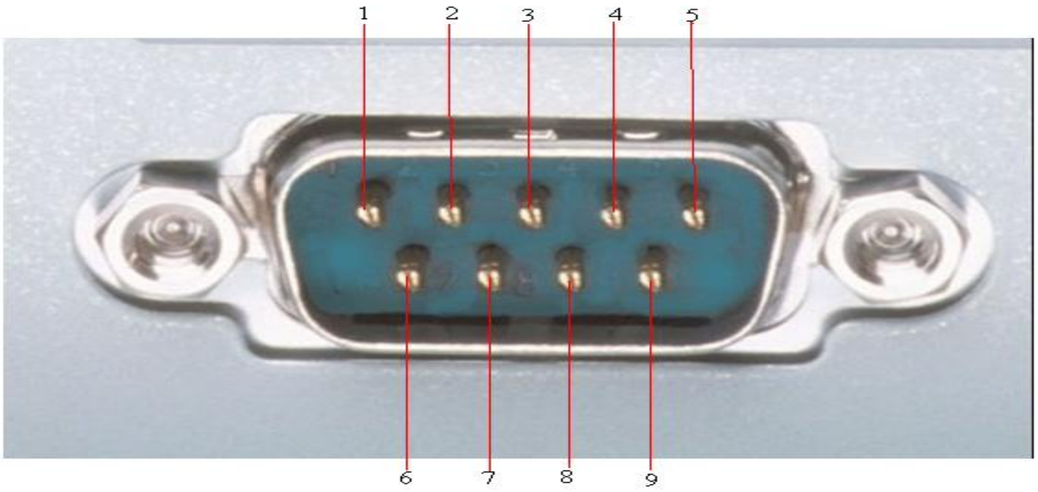
Pin 16 (Initialize): This line is held low for 50 µs to reset the printer and clear the print buffer.

Pin 17 (Select printer): The PC drives this line low to select the peripheral for data transfer.

Pin 18-25 (Gnd): These are ground signal lines.

APPENDIX III

A photograph of a computer serial port on the rear of a PC (Intel *et al*., 1996)



Pin 1 (DCD): The data carrier detect signal is send by the peripheral, usually a modem, into the PC when the modem is synchronized.

Pin 2 (RXD): The receive data signal is used by the peripheral to send data to the PC.

Pin 3 (TXD): Transmit data line is used by the PC to send data to the peripherals.

Pin 4 (DTR): Data terminal ready signal is raised by the PC when the power is switch on to indicate that it is ready for data communication.

Pin 5 (SG): Signal ground is used to provide ground to the port.

Pin 6(DRS): Data set ready signal is raised by the peripheral to indicate that it is ready to receive or send data.

Pin 7 (RTS): Request to send signal is raised by the PC when it wishes to send data.

Pin 8 (CTS): Clear to send signal is raised by the peripheral, usually a modem, in response to RTS from the PC.

Pin 9 (RI): Ring Indicator signal is set when incoming ring is detected - used for auto-answer application

APPENDIX IV

Thermocouple voltage temperature relation

The relation of themocouple output voltage to the temperature measured by thermocouple type K

$$\Delta T = \sum_{n=0}^{N} a_n v^n$$

The coefficients a_n are given for n from 0 to between 5 and 13 depending upon the metals. T and v are thermocouple temperature and output voltage respectively. N and n are integers (Klarzar *et al.*, 2009).

APPENDIX V

The bus width and bus speed for various computer interfaces (Intel, 1995)

Bus type	**Bus width**	**Bus speed**	**Data rate transfer**
ISA	16 bits	8 MHz	16 MB/s
EISA	32 bits	8 MHz	32 MB/s
VL-bus	32 bits	25 MHz	100 MB/s
VL-bus	32 bits	33 MHz	132 MB/s
PCI	32 bits	33 MHz	132 MB/s
PCI	64 bits	33 MHz	264 MB/s
PCI	64 bits	66 MHz	512 MB/s
PCI	64 bits	133 MHz	1 GB/s

APPENDIX VI

Conversion of pressure units (Prasad, 2005)

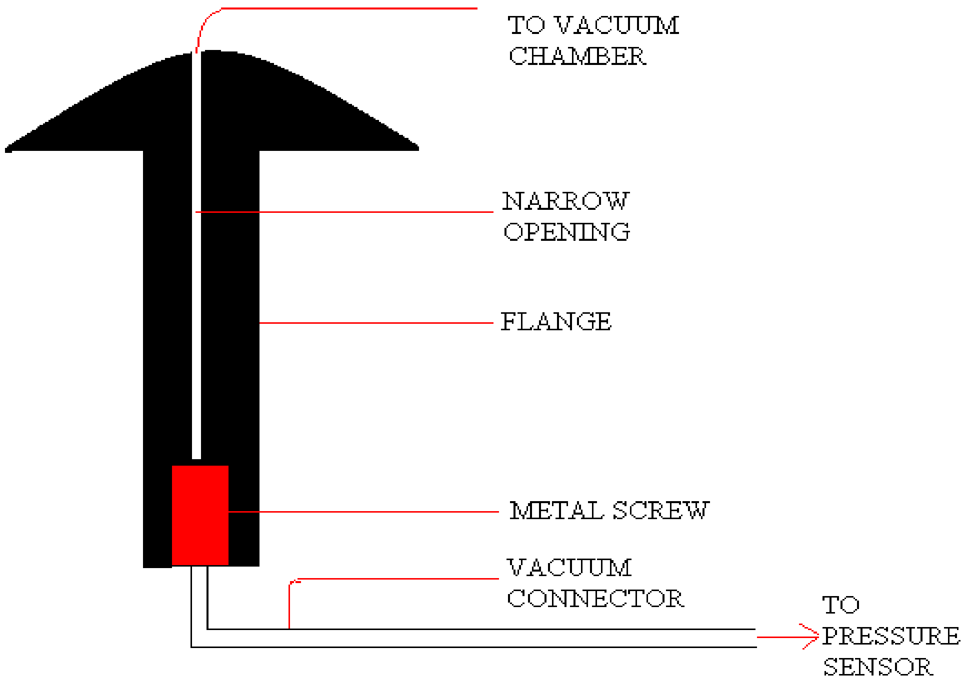
Conversion of pressure units

	pascal (Pa)	**bar (bar)**	**technical atmosphere (at)**	**atmosphere (atm)**	**torr (Torr)**	**pound-force per square inch (psi)**
1 Pa	1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	10^6 dyn/cm^2	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	1 kgf/cm^2	0.96784	735.56	14.223
1 atm	101,325	1.01325	1 .0332	1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	1 Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	1 lbf/in^2

Example reading: 1 Pa = 1 N/m^2 = 10^{-5} bar = 10.197×10^{-6} at = 9.8692×10^{-6} atm.

APPENDIX VII

Drilled flange leading to the vacuum chamber in Edward auto 306 magnetron sputtering system



APPENDIX VIII

Flowchart for the designed LabVIEW software