CHAPTER 2

LITERATURE REVIEW

In this chapter, explains about the fundamental used and also about each stages of the design application for this final year project. This project consists of three stages which are transducer and signal conditioning circuit where, data acquisition and conversion with PIC 16F876A microcontroller and finally the output display. The flow of basic design stages is shown in Figure 2.0 below.

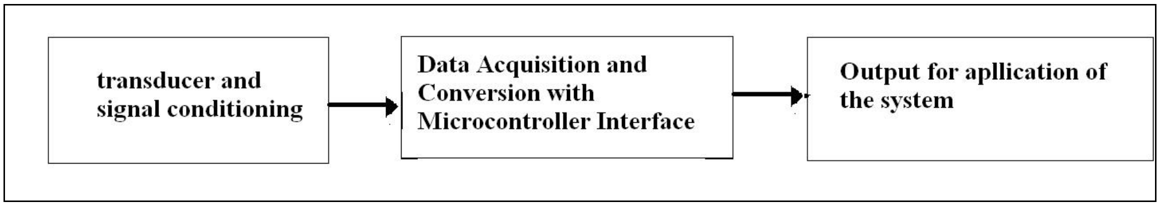


Figure 2.0: Flow of basic design stages

General measurement system design application will be applied in this design. In the nut shell, heat depends on temperature which it will be explained later in subtopic 2.1. Temperature constant or thermal coefficient can be defined as the change in resistance of a semiconductor per unit change in temperature, over a specific temperature range. [14] It can be used to design the circuit to see the potential of Barium Tantalum Strontium Titanate (BTST) thin film sensor.

2.1 FUNDAMENTAL THEORY AND EQUATION

Thermal conductivity usually can be related to heat transfer and it is the fundamental of this project. There are three mechanisms of heat transfer whereby energy can be transported from one region to the other under influence of temperature different. First is by transmission in form of radiation; the second is the process of convection, in which a bulk or motion of the material effects the transport; and the final process is the thermal conduction, when the energy is transported through a medium. These processes of the heat transfer are often very important in wide variety of scientific, industrial and also consumer applications. [1]

It is a convenient to speak of the thermal conductivity of various types of material because usually it's taken to be the empirical constant of proportionality in the linear relationship between a measured heat transport per unit area and also the temperature difference over prescribed distance in the material. The thermal conductivity is a property of the material, since it can often depend on larger number of materials; it's the method of the manufacture, and even the character of its surface. Conversely, this distinction between homogeneous and inhomogeneous material is often ignored and lead to more than a little confusion, especially where inter comparisons among measurements are concerned. As the fact, in most practical situations all the three heat transfer mechanisms are present greatly complicates the process of measurement of the thermal conductivity. [2]

The equation for thermal conduction relates the heat on the flux in a material to the temperature gradient by equation **(2.0)**

$$Q = -\lambda \nabla T \quad \textbf{……… (2.0)}$$

It is impossible to measure the local heat flux and gradient; thus all the experimental techniques must make use of the integrated form of the equation, subjected to certain condition at the boundaries of sample. All experiments are designed, so that the mathematical problem of the ideal model is reduced to integral of the one dimensional version of equation **(2.0)**, which yields, in general:

$$Q_a = G\lambda\Delta T \text{ .... } \mathbf{(2.1)}$$

in which G is a constant for a given apparatus and depends on the geometric arrangement of boundaries of the sample. Typically arrangement of the apparatus which have been employed in conjunction with equation **(2.1)**, are flat sample. Usually, the technique that is use for equation **(2.1)**, are known as steady-state techniques and they operate by measuring the temperature difference, ΔT that is generated by application of measured heat input, Q_a at one of the boundaries. The absolute determination of the thermal conductivity, λ, of the sample contained the quantity, G.

However, in practice, it is impossible to arrange an exactly one-dimensional heat flow in any finite sample so that great efforts have to be devoted to approach these circumstances and there are must always be correction to the equation **(2.1)** to account for the departures from ideal condition. Therefore, in the following chapter, for sensor characteristic, the resistance of Barium Tantalum Strontium Titanate (BTST) thin film sensor produce due to the change of temperature during testing will take account.

2.2 TRANSDUCER AND SIGNAL CONDITIONING PART

Barium Tantalum Strontium Titanate (BTST) thin film is a Barium Strontium Titanate (BST) thin film which is doped with tantalum oxide. The development of the Barium Tantalum Strontium Titanate (BTST) materials shows that the pyroelectricty character sensing capability of the material elements is demonstrated in the form of heat which will be related to the change of temperature. Pyroelectricity is the ability of certain materials to generate an electrical potential when they are heated or cooled. As a result of this change in temperature, positive and negative charges move to opposite ends through migration (as example; the material becomes polarized) and hence, an electrical potential is established. Pyroelectricity can be visualized as one side of a triangle, where each corner represents energy state in the crystal namely as kinetic, electrical and thermal energy. [3]

The side between electrical and thermal corners represents the pyroelectric effect and produces no kinetic energy. The side between kinetic and electrical corners represents the piezoelectric effect and produces no heat. Although artificial pyroelectric materials have been engineered, the effect was first discovered in minerals such as quartz and tourmaline and other ionic crystals. The pyroelectric effect is also present in both bone and tendon. The name is derived from the Greek *pyr* for fire, and electricity. Pyroelectric charge in minerals develops on the opposite faces of asymmetric crystals. The direction in which the propagation of the charge tends toward is usually constant throughout a pyroelectric material, but in some materials this direction can be changed by a nearby electric field. These materials are said to exhibit ferroelectricity. All pyroelectric materials are also piezoelectric, the two properties are being closely related. Very small changes in temperature can produce an electric potential due to a materials' pyroelectricity. [3]

Barium Strontium Titanate (BST) thin films have been deposited by sputtering on SiO2 structures using five different host substrates such as magnesium oxide, strontium titanate, sapphire, silicon, and vycor glass. These substrates were chosen to provide a systematic change in thermal strain while maintaining the same film microstructure. All films have a weakly textured microstructure. The impact of thermal strain on dielectric constant of sputtered Barium Tantalum Strontium Titanate (BTST) thin film by temperature dependent dielectric measurements from 100–500 K determined that decreasing thermal expansion coefficient of the host substrate as example a larger tensile thermal strain which is reduced the film dielectric permittivity.[4] Therefore, from the sensor characteristics, Barium Strontium Titanate (BST) thin film can be resistance and also as capacitor. But, in this project, for Barium Tantalum Strontium Titanate (BTST) thin film have resistance element as an electrical potential that is produced due to material's pyroelectricity.[5] Therefore, Barium Tantalum Strontium Titanate (BTST) thin film sensor can be categorize as electrical transducer or sensor. This sensor also can be classified as passive electrical transducer. An electrical sensor must have following parameter which will be explained in Table 2.0. [6]

Table 2.0: Electrical Transducer Parameters

PARAMETER	EXPLANATION
LINEARITY	The relationship between physical parameter and the resulting electrical signal must be linear.
SENSITIVITY	Define the electrical output per unit change in physical parameter. High sensitivity is generally desirable for a transducer.
DYNAMIC RANGE	The operating range of transducer should be wide, to permit it's used under a wide range of measurement conditions.
REPEATABILITY	The input/output relationship for a transducer should be predictable over a long period of time. This is ensures reliability of operation.
PHYSICAL SIZE	Must have minimal weight and volume

The fabrication steps for BTST sensor are shown in the flowchart in Figure 2.1. The following subtopic will explained all fabrication steps for this sensor. [7]

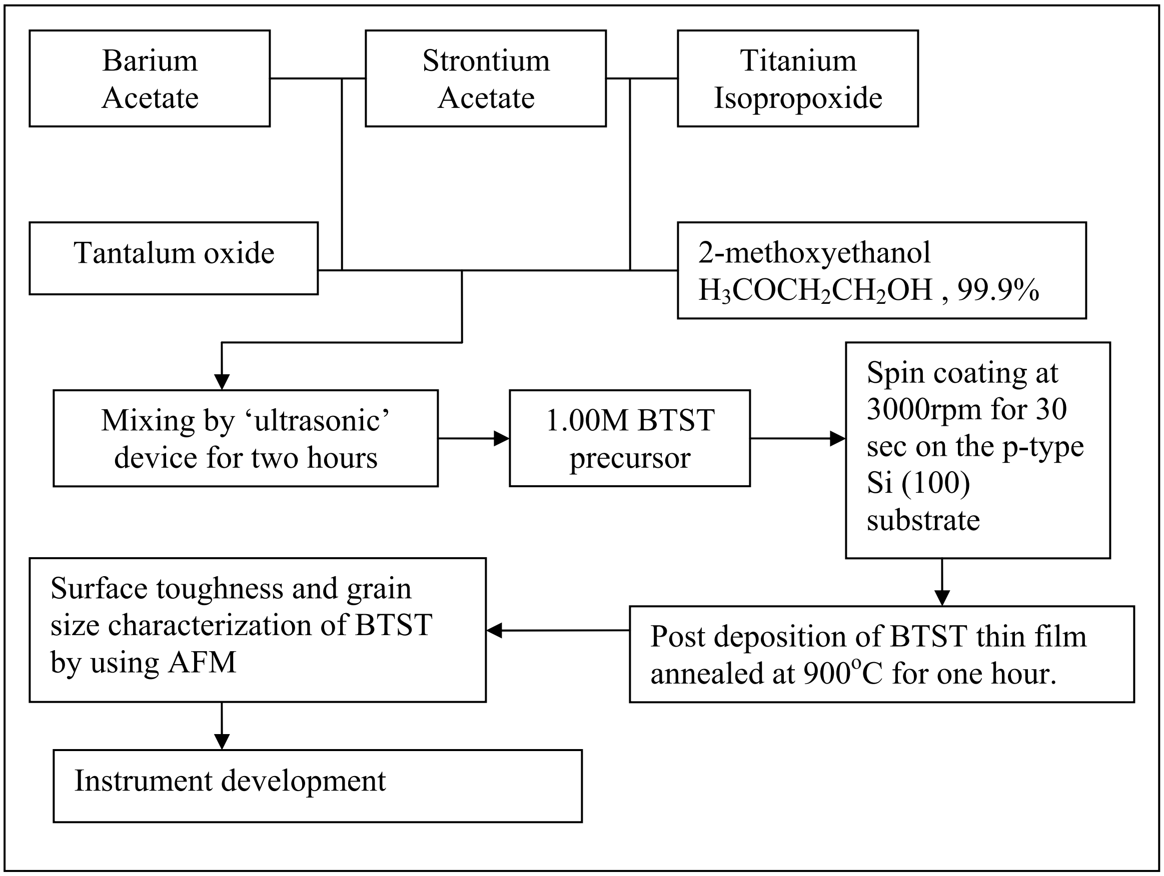


Figure 2.1: Flow of sensor general fabrication process

2.2.1 Solution

The material or the solution must first to be prepared to produce BTST sensor. Generally, there are two types of material solutions that are used for producing this sensor which are solid and liquid solution. The solid solutions that are used are Barium Acetate (0.16 gram) and Strontium Acetate (0.131 gram) and then doped with Tantalum Oxide producing BTST (0.06g) with the concentration of 10%. After that, mix the Titanium iso-propoxide (0.355gram) with 2-methoxeythanol (1.25ml) as a reactance and it used to dissolve the doped material. The solution that is produce is also called as 'Sol-gel'. Mixing all solution by using 'Ultrasonic machine' in Figure 2.3 for two hours but for better results longer time is needed. Ultrasonic machine is used for mixing the solution by using ultrasonic wave.

Then, two hour or more, filter the solution to get only the clear solution from the mixing solution.

Figure 2.2: Solutions that are used to producing BTST sensor

Figure 2.3: Ultrasonic machine.

2.2.2 Fabrication process

CSD (Chemical Solution Deposition) method is the method that was used to fabricate this BTST sensor. This method is used because it is simple, inexpensive means of film deposition, compatible with semiconductor process, direct mixing with stock solution MOD (Metal Organic Decomposition)and also precise stoichiometric control. Beside that, the factors of low processing temperature, chemical homogeity, and the ability to form uniform film over, large area and thickness in range of 0.1 microns. The steps are shown below in the Figure 2.4: Flow chart of CSD process.

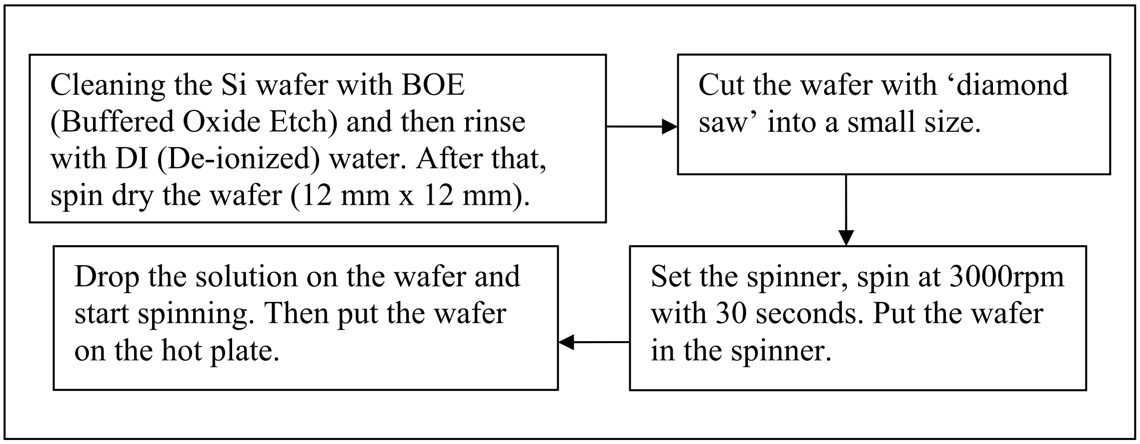


Figure 2.4: Flow chart of deposition process

2.2.3 Annealing/sintering

Annealing is a thermal process in which different atoms chemically bond with each other to form a metal alloy. Meanwhile, sintering is a method heating the material (below its melting point) until its particles adhere to each other. Thus, sintering is also an annealing process. The steps are shown in Figure 2.5.

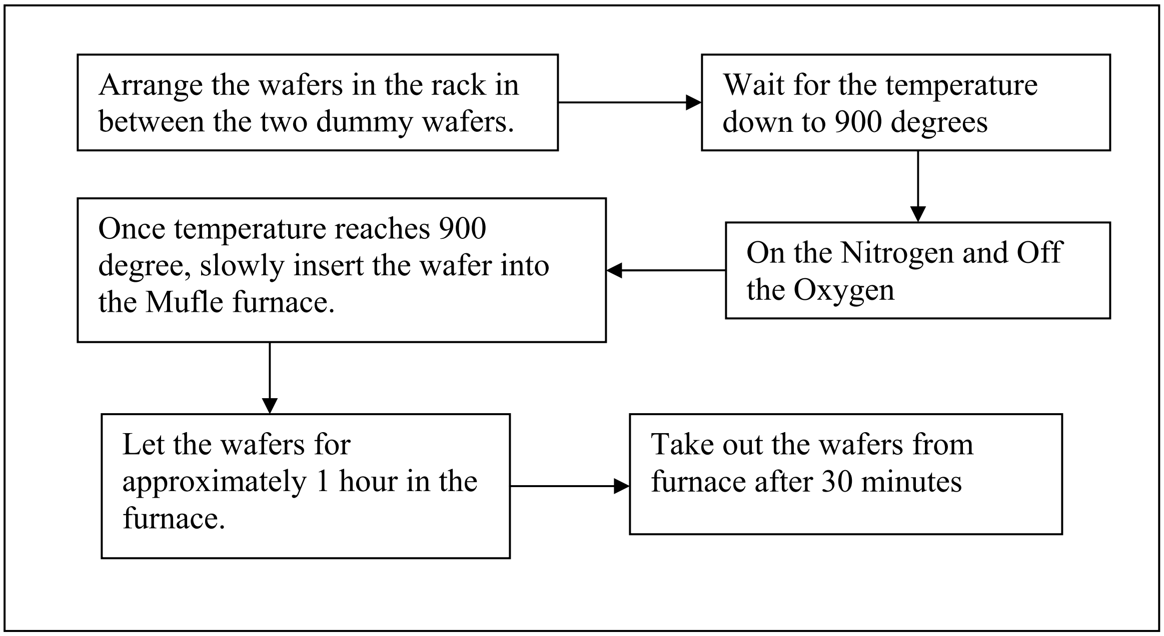


Figure 2.5: Annealing process

2.2.4 Characterization

Characterization is one of the steps to test the structure and also the junction gauge of the sensor. By using AFM (Atomic Force Microscopic) machine in Figure 2.6, it used to test the surface roughness and also the grain size. Usually, AMBIOS XP-1 will be used to test the thickness of the sensor.

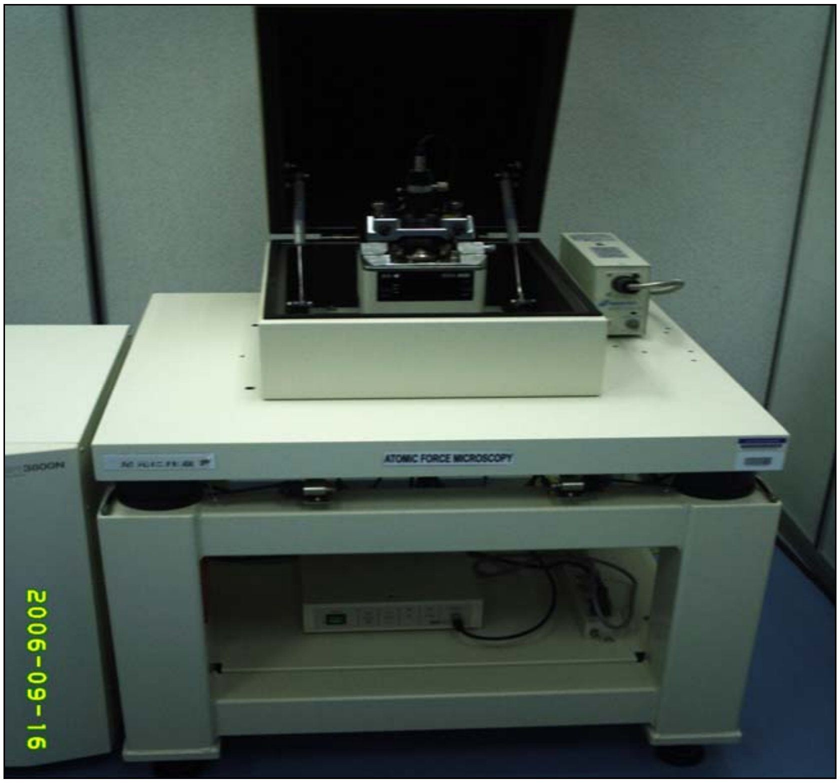


Figure 2.6: Atomic Force Microscopic (AFM) machine

2.2.5 Metallization

In metallization process, a layer of metal is deposited on the wafer surface to provide electrical contact with the devices. Metallization process requires Physical Vapour Deposition Module (PVM) as shown in Figure 2.7. This module uses vapourization techniques.

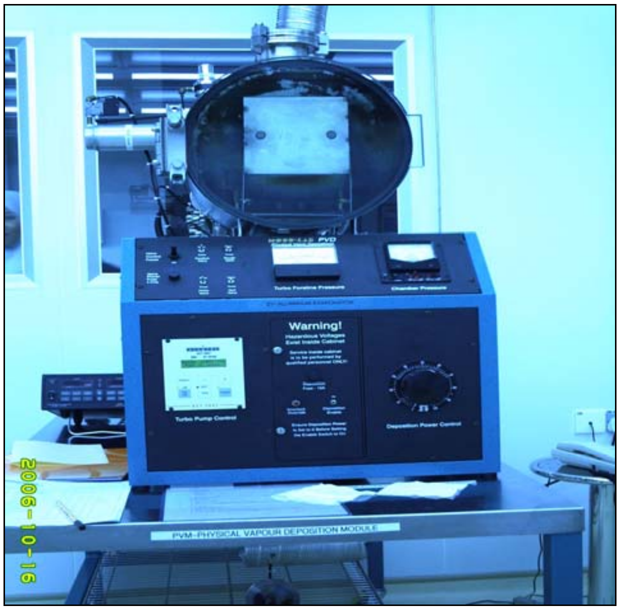


Figure 2.7: Physical Vapour Deposition Module(PVM)

2.2.6 Packaging

For packaging, the sensor was packaged by putting the sensor on a glass slide; connected with thin wire from metal contact at the sensor to the connector. Figure 2.8 and Figure 2.9 show before and after packaging done for the sensor.

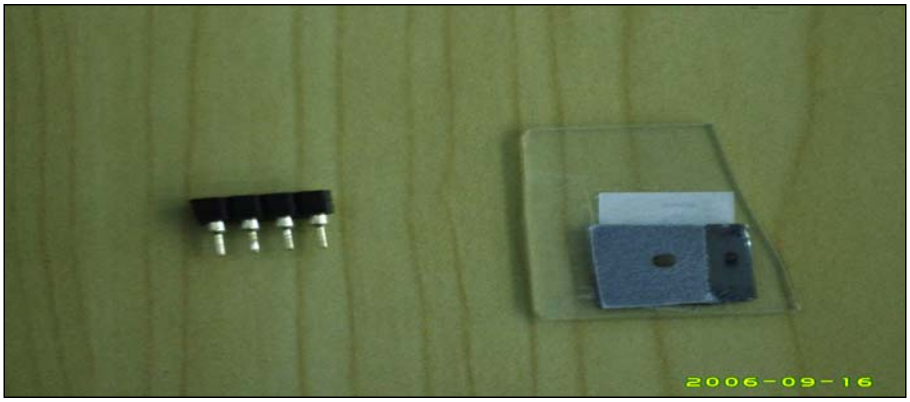


Figure 2.8: Sensor before packaging

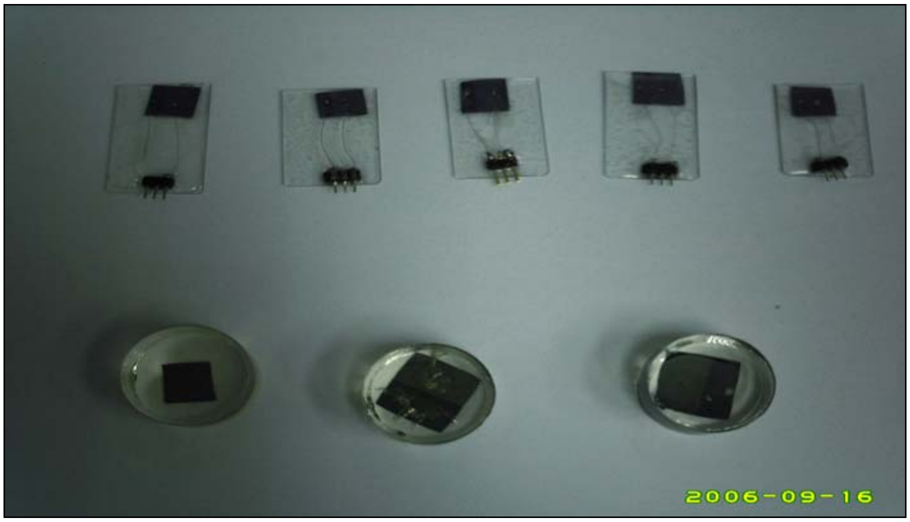


Figure 2.9: Sensor after packaging

2.2.7 Electrical Properties

For electrical properties, as in the BTST sensor characteristic, this sensor is a multi mode sensor which can sense light, optical, infra red, ultra sonic wave, temperature and also heat. Therefore, for this project, heat property is chosen as an electrical property to develop new product which is “Heat Indicator”. This indicator will be indicated the heat of the room whether it’s hot or cool.

2.3 DATA ACQUISITION AND CONVERSION.

For data acquisition and conversion, PIC 16F876A was used. The programming for PIC 16F876A is based on PIC16F786A instruction set. The rest of the programming language will be discussed and explained in Chapter 3: METHODOLOGY. Figure 2.10 shows the PIC 16F876A microcontroller board. In the mean time, in Figure 2.11, shows the PIC 16F876A microcontroller block diagram and Table 2.1 is pinout listing.[8]. PIC 16F876A microcontroller was been used because of the features that microcontroller have itself such as low power, high speed CMOS FLASH/EEPROM Technology, Build in 10-bit multi-channel Analog-to-Digital converter, Power-on Reset (POR), Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation, Programmable code protection and many more.

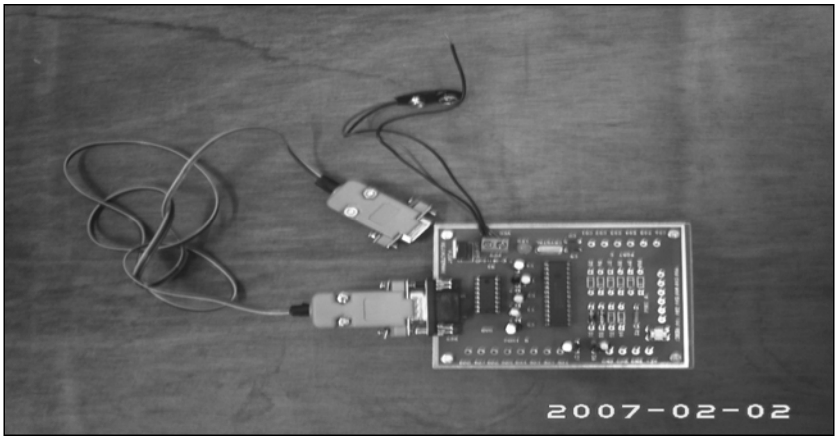
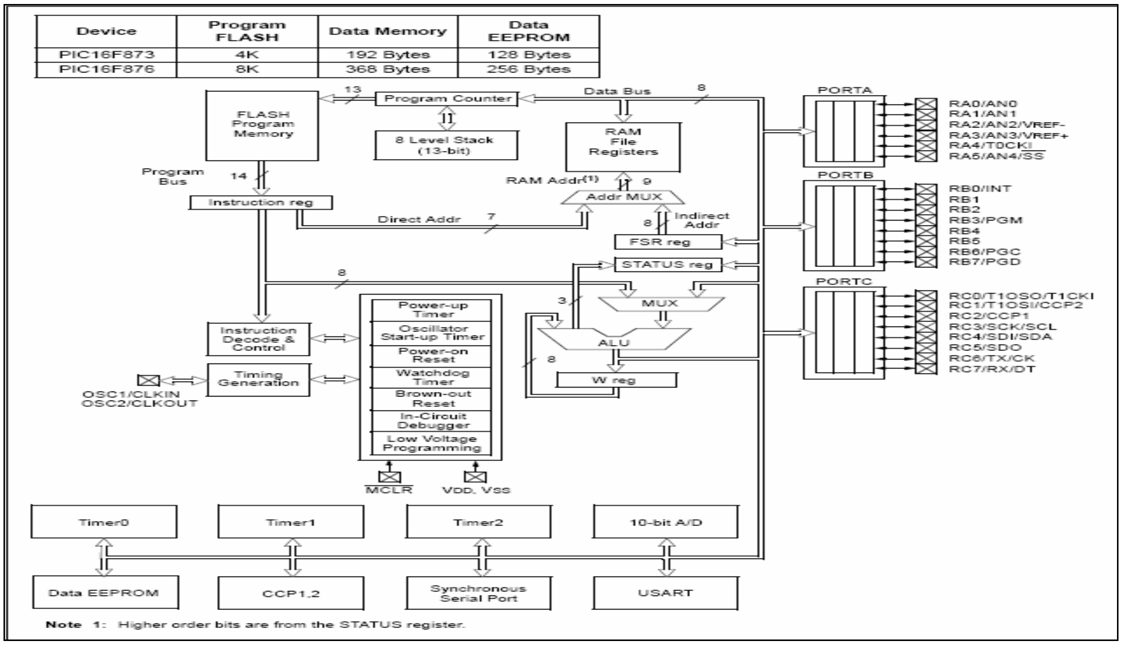


Figure 2.10: PIC 16F876A microcontroller board

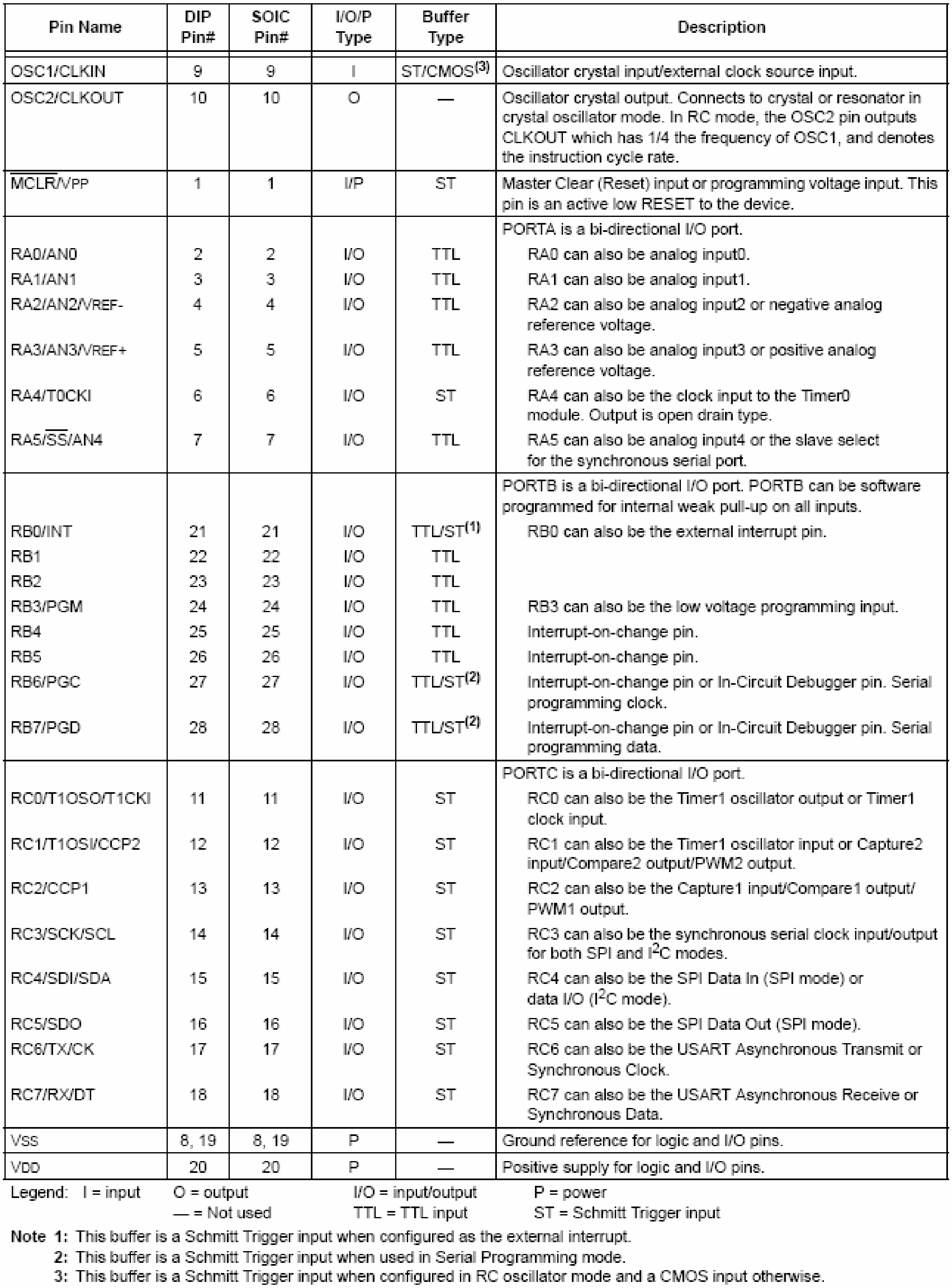


Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes

Note 1: Higher order bits are from the STATUS register.

Figure 2.11: PIC 16F876A microcontroller block diagram

Table 2.1: PIC16F876 pinout description



Pin Name	DIP Pin#	SOIC Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	9	9	I	ST/CMOS(3)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	10	10	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, the OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{\text{MCLR}}$/V_{PP}	1	1	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
					PORTA is a bi-directional I/O port.
RA0/AN0	2	2	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	3	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/V_{REF-}	4	4	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/V_{REF+}	5	5	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	6	I/O	ST	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/$\overline{\text{SS}}$/AN4	7	7	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
					PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	21	21	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	22	22	I/O	TTL	
RB2	23	23	I/O	TTL	
RB3/PGM	24	24	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	25	25	I/O	TTL	Interrupt-on-change pin.
RB5	26	26	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	27	27	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	28	28	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.
					PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	11	11	I/O	ST	RC0 can also be the Timer1 oscillator output or Timer1 clock input.
RC1/T1OSI/CCP2	12	12	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	13	13	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	14	14	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	16	16	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	17	17	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	18	18	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.
V_{SS}	8, 19	8, 19	P	—	Ground reference for logic and I/O pins.
V_{DD}	20	20	P	—	Positive supply for logic and I/O pins.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

2.4 OUTPUT DISPLAY

Meanwhile, for output display, LED were used to indicate whether the room is hot or cool. The circuit for this output display is simple. All the circuit design will be mentioned later in Chapter 3: Methodology. LED (Light Emitting Diode) is an electronic diode that produces light. The light is produced only when current passes through the diode in the forward direction, propelled by a forward voltage charge (see Figure 2.12). [9]

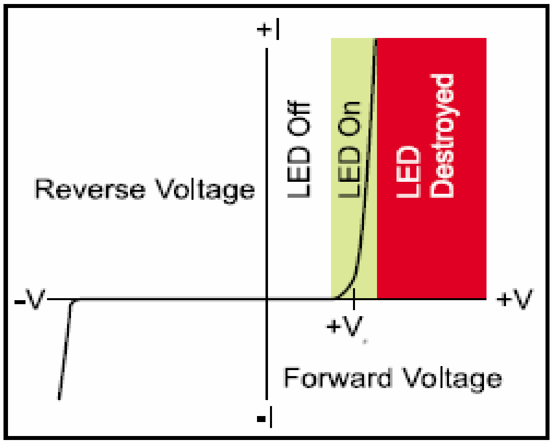


Figure 2.12: The LED conduction curve shows the safe operating area.

Before light is produced, however, the forward voltage across the diode must be higher than the internal barrier voltage of the diode. At this point, labeled +VF (Voltage Forward) on the graph in Figure 2.13, is the point at which the diode begins to conduct and produce light. It is important to notice that once the voltage across the LED reaches +VF the diode conducts current extremely well. This action is shown by the sharp rise in the forward current (+I) indicated by the near vertical line on the conduction graph. The LED attempts to clamp the voltage near +VF and can be easily destroyed by an excess of voltage. Therefore to protect the LED, a series current limiting resistor should be added, as shown in Figure 2.13.

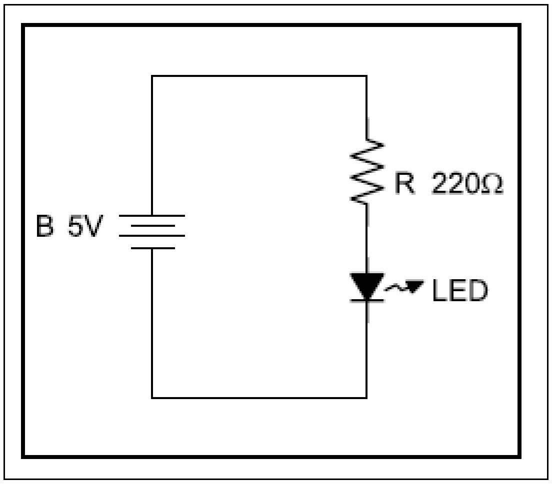


Figure 2.13: A typical LED circuit with a series current limiting resistor.

The value of the series limiting resistor must be calculated based on the maximum allowed LED current and the difference between the applied voltage and the LED's voltage drop, +VF. Like any other diode, LED passes current in the forward direction, but block current in the reverse direction (see Figure 2.12). This means is that the LED will only light up if connected with its cathode on the negative side of the circuit, and its anode on the positive side of the circuit. Thus, too much reverse voltage will also destroy LED. The cathode side of an LED is usually marked with a flange that rings the body of the diode. The cathode wire is also usually shorter that the anode wire of an LED.