CHAPTER - 3

EXPERIMENTAL SET-UP AND FABRICATION ASPECTS

This chapter presents the details of experimental set-up to detect the quantity of carbon monoxide (CO) in the engine emissions, which include the fabrication aspects of biosensor with SU-8/CB (Carbon Black) cantilevers, functionalised with Iron porphyrin.

The fabrication of biosensor requires sophisticated test facilities. Enormous efforts are made in this regard for infrastructure. Initial plans for test facilities both at my parent institution and nearby S.V.University, Tirupathi did not materialise due to lack of adequate infrastructural facilities. Further, creation of such facilities requires heavy financial support. Efforts even at IIT, Madras and Central University, Hyderabad did not yield any result on the ground that their existing facilities do not accommodate this area of research work.

Subsequently, efforts are made through Internet about ways and means, related to Bio-Sensors and have come across a site, connected with this research work related to Bio-Sensors in the Department of Center of Excellence in Nanoelectronics, at IIT, Bombay, whose projects are funded by Indian Nano Users Programme (INUP), Ministry of MCIT, Government of India. With a ray of hope, as per the advice of our research guides, proposal was sent to the Chair Person, Centre of Excellence in Nanoelectronics, IIT, Bombay. This request was sympathetically considered and received a call for discussions on the proposal in March 2010 at IIT, Bombay. The committee consisting of Prof V.R.Rao, Chair Person and others agreed to accommodate this area of research at IIT, Bombay at free of cost after thorough discussions. This paved way for an access to IIT, Bombay and to carry the
experimental investigations for about one year from 2010 to 2011. The activities, the vision and the objectives of this centre are furnished for favour of information.

**Activities of Center for Excellence in Nanoelectronics, IIT, Bombay**

Indian Nanoelectronics Users Program (INUP) is an initiative to create and spread the expertise of nanoelectronics in India, jointly run by the Centres of Excellence in Nanoelectronics (CEN) at the Indian Institute of Technology, Bombay (IITB) and Indian Institute of Science, Bangalore (IISc), with financial support from the Department of Information Technology (DIT), the Ministry of Communication and Information Technology (MCIT), Government of India.

**Vision of Center for Excellence in Nanoelectronics, IIT, Bombay**

To facilitate and support the generation of expertise and knowledge in nanoelectronics through participation and utilization of the facilities established at the Centers of Excellence in Nanoelectronics at IISc and IITB by external users.

**Objectives of Center for Excellence in Nanoelectronics, IIT, Bombay**

- To open up the R&D infrastructure set-up at the Centres of Excellence in Nanoelectronics to Indian researchers from outside of IISc and IITB.
- To impart hands-on training in Nanoelectronics to researchers from other institutions in the country and assist in the initiation of research in Nanoelectronics by enabling the execution of the work of the external users at these centers.
- To collaborate with research teams at other Indian centers and develop joint academic and research programs in Nanoelectronics.
- To provide a platform for researchers in Nanoelectronics to come together and benefit from complementary expertise.
To conduct regular workshops for the wider dissemination of knowledge in the area of Nanoelectronics.

The Department of CEN have permitted to utilise most of the components required for experimental set-up. Some of the components are fabricated in the laboratory. The experimental set-up and the detailed fabrication process is presented.

3.1 Experimental Set-up.

The experimental set-up for the measurement of carbon monoxide is shown in the Fig (3.1), with required equipment such as carbon monoxide and nitrogen cylinders, Flow Controllers, Gas Mixing Chamber, Sensor Device, Gas Sampling Pump and Electronic Readout. The sensor device and mixing chamber are fabricated in the laboratory. The sensor device consists of cantilever, Flow Cell (packaging) and a Printed Circuit Board (PCB). The Electronic Readout is an output measuring instrument which consists of Wheatstone Bridge and Texas Instrument Board (TI Board). The experiments are conducted in Fume Hood as the carbon monoxide is a poisonous gas. All the equipment, instruments and the materials needed for the experimentation are supplied by the Centre of Excellence in Nanoelectronics (CEN), IIT, Bombay. The salient features of these equipment / instruments are presented here under.
Nitrogen and Carbon Monoxide Cylinders

Nitrogen gas is selected as the carrier gas since its molecular weight is nearer to carbon monoxide i.e 28 so as to facilitate both gases to be mixed thoroughly. If the molecular weight of carrier gas and CO are not equal, there will an improper mixing.

Flow Controllers

The flow controllers are flow measurement devices also as shown in Fig (3.2). These are connected to Gas Mixing Chamber. They are used to control the flow of N₂ and CO gases, and the flow is varied from 7 SCCM (Standard Cubic Centi Meter) to 70 SCCM range in steps of 10,20,30,40,50,60,70 and 0 to 1000 SCCM (0 to 1 Lts) in steps of 100,200,300,400,500,600,700,800,900 to conduct experiments for different concentrations.
Gas Mixing Chamber

The Gas Mixing Chamber is fabricated using a plastic rectangle box with three openings. First and second openings are used for the inlet of nitrogen gas and carbon monoxide gas respectively. The third opening is used for the outlet of the mixed gas that goes to Sensor Device. It further acts as a storage chamber for the mixed gases.

Sensor Device

The Sensor Device is made out of SU-8/CB cantilever coated with Iron Porphyrin, Flow Cell and PCB. It is an important aspect of this thesis. The detailed fabrication process of SU-8/CB cantilevers and the Sensor Device assembly is presented in section (3.2).

Flow Cell

The SU-8/CB cantilever is fixed on the Printed Circuit Board (PCB) as shown in the Fig (3.3). A hallow cylindrical flow cell made out of Teflon cylindrical rod, is made into two halves. The lower half (Base) of the cylinder is fixed to the PCB enclosing the cantilever as shown in Fig (3.4). This assembly is replaceable for different experiments. The upper half of the cylinder (Lid) has a provision for inlet
from Gas Mixing Chamber and outlet to gas sampling pump to pull the gases. The assembly of upper half of the cylinder is used as a permanent arrangement in all experiments. These two halves of the flow cell are assembled with force fit as shown in Fig (3.5), which facilitates for easy replacement of sensor devices.

Fig (3.3) Cantilever fixed on PCB

Fig (3.4) Flow Cell base fixed on PCB and Lid

Fig (3.5) Upper half and lower half of the flow cell in assembled condition
Gas Sampling Pump.

It is a Micro Diaphragm Pump (series NMP 05L) as shown in Fig (3.6). It is used to suck the CO and N₂ mixture from the Gas Mixing Chamber passing through sensor device. It is supplied by Innovative Technology World Wide KNF Neuberger. The pumps works on a simple principle – of an elastic diaphragm, fixed on its edge, moves up and down by means of an eccentric at its center. In this way the fluid is transferred using automatic valves. These pumps are suited for use in portable and stand-alone equipment as they are DC driven using 6 volts battery.

![Image of Micro diaphragm pump series NMP 05L](image)

Fig (3.6) Micro diaphragm pump series NMP 05L

Read out (Output)

Different types of read out methods are available to record the cantilever deflection (Output). They are optical, piezoresistive, piezoelectric, electrostatic, tunneling, and thermal, as discussed in Chapter-1. In this research work, Piezoresistive read out method has been adopted. Its basic principle and functions are explained in this chapter. Piezoresistive MicroElectro Mechanical (MEMS) cantilevers exhibit changes in base resistance by a few parts per million while deflected. Hence, highly sensitive resistance change (ΔR) measurement system is therefore necessary [126,127].
The block diagram of change in resistance measurement system is shown in Fig (3.7). This measurement system consists of Wheatstone Bridge and TI board for recording the output. It is operated by 9 volts battery.

![Diagram of change in resistance measurement system.](image1)

Fig (3.7) Diagram of change in resistance measurement system.

![Wheatstone Bridge](image2)

Fig (3.8) Wheatstone Bridge

The wheatstone Bridge as shown in Fig (3.8) comprises of four arms of which one arm is a sensor device with cantilever (R2) and two arms (R1 and R3) are of the known resistance and the remaining fourth arm (R4) is a variable resistor. Initially the bridge is balanced by matching R4 with the three remaining resistors R2 (cantilever), R1 and R3 such that output voltage of the bridge is zero. As the mixture of CO and N2 flows over the cantilever (R2), the resistance of the cantilever changes due to the adsorption of CO. This change in resistance is measured by means of the Wheatstone Bridge in terms of voltage. Sensitivity (S) calculation of the current system is based on the change in output voltage ($\Delta V$) for the corresponding resistance.
change ($\Delta R$) in one of the arms of the bridge. In the current case, the same can be
applied with respect to voltage and resistance changes given as,

$$S_{\Delta R}^V = \frac{\Delta V}{V} \cdot \frac{\Delta R}{R}$$  \hspace{1cm} (3.1)

The *Texas Instrument Board (TI Board)* model ADS1232REF is a 24-bit, delta-sigma analog-to-digital converter (ADC). It contains all the circuits and user interface elements as shown in Fig (3.9). Graphical PC software is also provided for histogram display, data logging, and device control as shown in Fig (3.10). It is used in recording the output of the Wheatstone Bridge. The important features of TI board are:

- ADS1232 ADC
- Connections for load cells or other voltage sources
- Low-side excitation switch on the load cell header connector
- Ample EMI/RFI suppression between the ADC and rest of design
- Eight-digit starburst LCD readout
- USB connection for firmware updates and remote control
- Designed for very low power consumption
- Battery (9V) or wall power

Fig (3.9) ADS1232REF controls and connectors
Fig (3.10) ADS1232REF Software display

The photograph shown in Fig (3.11) and Fig (3.12) shows the complete experimental set-up.
Fig (3.12) Photograph during experiment.

All the components needed for experimental set-up are presented above except the sensor device. This device is fabricated in the laboratory at the Centre of Excellence in Nonoelectronics (CEN), IIT, Bombay, which has supplied all the materials needed for fabrication. The detailed fabrication process is presented in the next section.

3.2 Fabrication of Sensor Device

The fabrication of the sensor device involves the following steps:

Step-1: Fabrication of SU-8 / CB Cantilevers.

Step-2: Depositing Porphyrin coating on the cantilever.

Step-3: Fixing Cantilever on the Printed Circuit Board (PCB).

Step-4: Connecting the PCB with Cantilever by Silver Epoxy.

Step-5: Fixing Flow Cell on the PCB enclosing Cantilever.

A few salient futures of SU-8/CB (Carbon Black) cantilevers are as follows. Different types of materials are used in fabrication of cantilevers like Silicon Oxide, Silicon Nitride, Poly Silicon and Polymers (SU-8). In this research work the
cantilevers are made of SU-8, a negative epoxy-based photo-resist polymer. It is developed by IBM for the micro technology industry in the early 1990s. It is a polymer, that can be spin-coated to thicknesses ranging from 1 μm to 1 mm and the final structures can be defined by UV lithography or e-beam lithography. The low Young’s modulus and high mechanical strength of SU-8 makes it a highly suitable material for fabrication of cantilever-based sensors\[116,140\]. The properties of SU-8 are given in Appendix-II. This polymer has lower Young’s Modulus (4.02GPa) as compared to silicon oxide, silicon nitrides and polysilicon, which are conventionally used to make cantilever. With lower Young’s modulus leads to lower stiffness, hence these cantilevers deflect more to a given applied stress and generate more strain. The SU-8 cantilevers with lower stiffness posses great advantage over the conventionally used cantilevers. These cantilevers are sensitive in detecting the pollutant even at a very low vapour pressure and can measure small trace of these molecules. With more strain for a given stress, these cantilevers are more sensitive. The change of resistance with strain is partly due to geometrical changes in the deformed body and partly due to physical changes within the material itself. Together these two effects are described by the strain gauge factor (GF). The gauge factor GF (strain sensitivity) is given by

\[ GF = \frac{\Delta R}{\Delta \sigma} = 1 + 2\nu + \frac{\Delta \rho / \rho_o}{\Delta \varepsilon} \]  

where \( R_o \) is the initial resistance, \( \Delta R = R - R_o \) is the resistance change resulting from the strain change \( \Delta \varepsilon \), \( \nu \) is the Poisson’s ratio, and \( \rho_o \) and \( \Delta \rho \) are the electrical resistivity and the change of resistivity resulting from \( \Delta \varepsilon \), respectively.

Since the change in resistance of the piezoresistive material is directly proportional to the strain undergone by it and the relationship is given as
\[ \Delta R = \varphi \sigma \]  \hspace{1cm} (3.3)

Where \( \varphi \) is the gauge factor (GF), \( \sigma \) is surface stress (N/m) and \( \Delta R \) (Ohm) is the change in resistance.

The piezoresistive layer material used in the fabrication is a nanocomposite, based on a dispersion of Carbon Black (CB) nanoparticles in SU-8, a non-conductive, negative-tone photoresist. The SU-8/carbon black nanocomposite is obtained by homogeneously mixing the carbon black powder in the photosensitive SU-8 resin. The lower Young’s modulus of SU-8 compared to Si and the higher strain sensitivity of SU8/carbon black nanocomposite provide these devices the required sensitivity to detect CO down to the ppm sensitivity. As per the technical data (Appendix-II) the SU-8 can withstand to a temperature of 170°C. The fabrication process of SU-8 / CB Cantilevers is presented below.

3.2.1 Fabrication of SU-8 / CB Cantilevers

The SU-8 integrated with SU-8/Carbon Black piezoresistive material cantilevers are fabricated in the Laboratory, Center for Excellence in Nanoelectronics (CEN), IIT, Bombay. The department has developed a procedure for the fabrication of the cantilevers and the same procedure is adopted. The step by step procedure is given below.

Step 1: Surface cleaning.

The fabrication of the SU-8/Carbon Black(CB) Cantilevers begin with the surface cleaning for removing contamination on the silicon wafers such as, native oxide and any residual impurities and particles by following the procedure (RCA cleaning) developed by the Werner Kern.. The step by step RCA cleaning (Radio Corporation of America) process is given below.
• Substrate is cleaned in 2% HF in H$_2$O and then in DI water. Removal of metallic and organic impurities is done by using H$_2$SO$_4$. Then H$_2$SO$_4$:H$_2$O$_2$ in composition 3:1 to 4:1 is used at 90°C for organic contamination and particle removal.

• Standard Cleaning- I Step: NH$_4$OH+H$_2$O$_2$+H$_2$O in composition 1:1:5 to 1:2:7 at 70-80°C removes organic contamination and particles by oxidation. 180ml of DI water and 20ml of NH$_4$OH is taken and heated to 70±5°C for about 5min. This is to increase the chemical reaction rate. This is removed from hot plate and 50 ml H$_2$O$_2$ (30%) is added. Solution will bubble vigorously after 1-2 min, indicating that it is ready for use. The silicon wafer is soaked in the solution and kept for heating for 6-8 min. It is removed and allowed to cool for 8-10 min. The wafers are rinsed 3 times in 3 DI water beakers. A 30 sec HF Dip is then given. Again the wafers are rinsed 3 times in 3 DI water beakers [fresh DI water is used in each step].

• Standard Cleaning – II Step: HCl+H$_2$O$_2$+H$_2$O composition 1:1:6 to 1:2:8 at 70 - 80°C, removes metal contamination by forming a soluble complex. 150ml of DI water and 25ml of HCl is taken and this solution is heated to 70±5°C for about 8 min. This is to increase the chemical reaction rate. The solution is removed from hot plate and 50 ml H$_2$O$_2$ (30%) is added. Solution will bubble vigorously after 1-2 min, indicating that it is ready for use. The silicon wafer is soaked in the solution and kept for heating for 6-8 min. It is removed and allowed to cool for 6-8 min. The wafers are rinsed 3 times in 3 DI water beakers.
• At the end of each cleaning process, the surface is dipped in buffered HF solution. A 30 sec HF dip is allowed for this purpose. Again the wafers are rinsed 3 times in 3 DI water beakers [fresh DI water is used in each step]. The wafer cleaning process is over. The wafers submerged in DI water are taken to the laminar bench and allowed to dry in the drier.

The next step is to develop a sacrificial layer of SiO$_2$ on the silicon wafer through Oxidation process which is explained below.

**Step 2: Oxidation Process.**

There are two types of oxidation processes for Si wafers namely Wet and Dry Oxidation. The schematic diagram for these processes is shown in the Fig (3.13).

![Fig (3.13) Chamber for oxidation process](image)

In dry oxidation, the chamber is heated uniformly up to a temperature of 1000 °C, and the atmosphere is made inert with nitrogen gas. The chamber is connected to a two-valve pipe, through which either oxygen or nitrogen may be passed. Much higher pressure is maintained inside the chamber than the pressure outside the chamber, so
that the contents of the chamber are pushed out when it is not necessary. When the temperature reaches 1000 °C, the nitrogen gas is removed and oxygen/oxygen + hydrogen are passed for dry/wet oxidation. The wafers are then loaded in a quartz container into the chamber. After the required thickness is obtained, the oxygen/hydrogen valves are closed and nitrogen is passed into the chamber. For every 15 minutes of dry oxidation the thickness obtained is 45 nm.

In case of wet oxidation, the chamber, after being heated upto 1000 °C, is cooled back to around 200-300 °C and then the wafers are unloaded. This method produces an oxide layer of thickness 100 nm. The chemical reaction during oxidation is given in Fig (3.14) and is self explanatory. The photograph of the oxidation system used at IIT, Bombay is shown in Fig (3.15)

![Fig (3.14). Basic reaction in oxidation of silicon Wafer](image-url)
Out of these two processes, dry oxidation process is followed for the present investigation and SiO$_2$ is developed upto 500 nm. In the next step of the fabrication process, *Micro Electro Mechanical Systems (MEMS) technology* is used to develop SU-8 Cantilever structure on the silicon dioxide wafer.

**Step 3: Development of SU-8 /Carbon Black (CB) Cantilevers.**

The fabrication technique capable of making nanostructures requires the fabrication of nano-objects combined with surface micromachining. There are two main categories namely Top-down and Bottom-up processes. **Top-down** processing is based on the optical lithography and etching batch type processing of semiconductor industry, which gives high volumes and high productivity on silicon wafers with thickness ranging from 1 µm to 1mm, where as **Bottom-up** processing is based on non- lithographical method. Growth or self assembly processing that can provide feature size much smaller than the resolution offered by the lithography. Silicon nanowires (SiNWs) and carbon nanotubes (CNTs) are typical nano-structures that can be realized by bottom-up techniques with cross sections smaller than 50nm. In the fabrication of SU-8 cantilevers, the top down process is adopted and the cantilevers are developed by using Photolithography process which is explained below.
Photolithography is a process of transferring geometric shapes on a mask to the surface of a silicon wafer. The purpose of mask is to allow UV light to pass through the required geometrical shape. Photoresist material (SU-8) is applied to the surface of the wafer by ‘spin coating’. This is a process where a required thickness of the photoresist is obtained by spinning a wafer at a certain speed. The thickness is inversely proportional to the spin speed.

There are two types of photoresists, Positive Photo resist (PPR) and Negative Photo Resist (NPR). The following Fig (3.16) shows the difference of the positive and negative photo resist. For positive resists, the resist is exposed to UV light wherever the underlying material has to be removed. In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material.

Negative resists behave in just the opposite manner. Exposure to the UV light causes the negative resist to become polymerized, and more difficult to dissolve. Therefore, the negative resist remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. The present investigation preferred negative resist SU-8 for the fabrication of its cantilevers.
Fig (3.16) Pattern definition in positive resist and negative resist.

There are three types of exposure schemes for Photolithography as shown in the Fig (3.17), namely Contact Printing, Proximity Printing and Projection Printing. The difference among these three processes is the position of the Mask. In the fabrication of SU-8 cantilevers Contact Printing process is used. In this process, once the mask has been accurately aligned with the pattern on the wafer's surface, the photoresist is exposed through the pattern on the mask with a high intensity ultraviolet light. The resist-coated silicon wafer is brought into physical contact with the glass photomask. The wafer is held on a vacuum chuck, and the whole assembly rises until the wafer and mask contact each other. The photoresist is exposed with UV light while the wafer is in contact position with the mask. Because of the contact between the resist and mask, very high resolution is possible in contact printing (e.g. 1-micron features in 0.5 microns of positive resist).
Fig (3.17) Types of Exposure schemes of Photolithography

Nanocomposite based polymer microcantilevers SU-8/CB solid modelling and its front view, top view and side view are shown in Fig (3.18 A & B). The cantilevers of the dimensions, 200, 40 and ~3.0 μm, length, width and thickness respectively are used in this study. The actual processes of fabrication of SU-8/CB cantilevers using Lithography is as follows.

Fig (3.18 (A)) Solid modelling of SU-8/CB cantilever
The nanocomposite polymer microcantilever fabrication processes are illustrated in Fig. (3.19). SU-8 structural layer (SU-8 2000.5, Microchem, MI) Fig.(3.19 (a)) is spin coated and pre exposure baked at 70 °C and 90 °C for optimized timings with a slow ramp up and ramp down to room temperature. To transfer the microcantilever pattern (Layer-1, Fig (3.19 (b)), the samples were exposed to UV light using Karl Suss MJB3 mask aligner and subjected to a post exposure bake cycle, development and rinsed with Iso Propyl Alcohol (IPA). A thin layer of Cr/Au (10 nm/200 nm) was deposited by sputtering, and the contact pads were patterned using Positive Photo Resist (PPR) photolithography with the corresponding mask Fig (3.19 (c)). The Cr-Au layer was wet etched in respective echants. To obtain an electrically conductive and a strain sensitive layer, SU-8/CB nanocomposite is prepared by dispersing the carbon black of 8-9 Vol.% in SU-8. The nanocomposite is spin coated and subsequently patterned using mask for layer 3 as shown in Fig (3.19(d)) by UV lithography, followed by additional ultrasonic cleaning step in IPA. This strain sensitive resistive
layer of 0.12 μm is then encapsulated by 1.8 μm of SU-8 (2002) which is spin coated and photo-lithographically patterned using mask for layer 4 as shown in Fig (3.19(e)). Finally to form an anchor Fig (3.19(f)) for the cantilevers, a 180 μm thick SU-8 is defined by spin coating and patterning of SU-8 (2100). The devices are released by wet etching the silicon dioxide layer in the Buffered Hydrofluoric (BHF) acid approximately for 30 minutes. The arrays of released SU-8 nanocomposite microcantilever chips are rinsed in DI water, isopropyl alcohol and allowed to dry. Fig (3.20) shows the SEM images of the released microcantilever devices.

The microcantilever chips are characterized electromechanically to demonstrate the piezoresistive behavior. The tip of the microcantilever was deflected with a calibrated micromanipulator needle from Suss Microtech with simultaneous measurement of resistance using Keithley 4200 source measuring unit. The change in resistance (ΔR/R) as a function of deflection is given in Fig (3.21), the calculated deflection sensitivity is 1.1 ppm/nm, which is higher compared to the polymer microcantilevers with Au as the strain gauge.

The fabricated cantilevers are verified for their resistance using Keithley Model 2000 digital multi-meter. The cantilevers with an internal resistance of less than 500kΩ are selected for the development of the CO sensor.
Fig (3.19) Fabrication steps of the SU-8 / CB composite cantilevers

Fig (3.20) [From left to right] Released cantilever devices, Optical microscope Image, SEM image of cantilever devices.
Fig (3.21) The change in resistance ($\Delta R/R$) as a function of deflection

The next step in the fabrication of sensor device is functionalising the selected cantilevers with Iron Porphyrin. The Porphyrin can be coated on the cantilevers in different ways namely Drop Deposition, Spin coating, Langmuir – Blodgett, Self Assembled Monolayers (SAM), Vacuum Deposition [131].

In these experiments Drop Deposition technique is adopted as it is easy and consumes less time. The structure of Porphyrin used in these experiments as well as the deposition process is discussed below.

**Step 4: Porphyrin Deposition on Cantilevers.**

The porphyrin for this research work is supplied by the Department of Chemistry IIT, Bombay. The structure of porphyrin is shown in Fig (3.22) below.
The molecular formula 5,10,15,20-tetra(4,5-dimethoxyphenyl)-21H,23H-porphyrin iron(III)chloride for which the nomenclature is explained in the Chapter I. The Chemical Formula is: $C_{52}H_{44}ClFeN_4O_8$ and the Molecular Weight is: 944.2258 gm/mol. The porphyrin Fe(III)(TPP)Cl is dissolved in Iso Propyl Alcohol (IPA) and deposited on the cantilever using drop deposition technique.

In the *Drop Deposition Technique*, the porphyrin is coated onto the wafer or cantilever using syringe that pours the coating solution onto the surface. Usually this dispenses a substantial excess of coating solution compared to the amount that will ultimately be required. To avoid this, the cantilever is placed on the filter paper so that any excess solution will be absorbed by the filter paper. This technique is easy, low cost and consumes less time compared to other techniques. This technique is adopted for the present investigation and is shown in the Fig (3.23).
The Fe(III) porphyrin is dissolved in IPA solution (1 mg in 5 ml of solution). The selected cantilever is drop deposited with Fe(III) porphyrin solution using syringe. This enables both sides of the cantilever to be coated with the porphyrin, thus producing porphyrin attachment induced stress to generate on both surfaces. To avoid this, the back side of the cantilever is coated with gold using Nordiko sputter machine shown in Fig (3.24) to about 2 nm at a base pressure of $1.0 \times 10^{-5}$ mbar and sputter pressure of $2.6 \times 10^{-3}$ mbar to avoid the interaction of porphyrins with the CO vapours on bottom side and thus enhancing the system’s electrical detection. The cantilever is ready for fixing it on to the PCB. The next step of the fabrication of the sensor device is explained below.

![Sputtering Machine at IIT, Bombay](image-url)

The fifth step of the fabrication of the Sensor Device is fixing the cantilever onto the PCB and fixing the Flow Cell. The functionalized cantilever is mounted onto a PCB (Printed Circuit Board) using a double sided tape and electrical connections are made between the cantilever and the pre-existing contact leads on the PCB as shown in the Fig (3.25). The cantilever once mounted onto the PCB is connected with the pre-existing leads on the PCB, using conductive silver epoxy(1:1) and is heated at 80°C in the furnace for one hour to cure the silver epoxy. The cantilever is then enclosed in a flow cell made of Teflon discussed in Flow Cell and sealed with araldite as shown in Fig (3.26). Now the sensor device is ready for the experimentation.

The block diagram of experimentation and experimental procedure are presented in the next chapter.