Designing of Zinc Oxide Thin Film Electrode based Continuous Impedance Monitoring System

A thesis submitted in partial fulfillment of requirement for degree of

Bachelor of Technology in Biomedical Engineering

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CERTIFICATE

This is to certify that the thesis entitled "**Designing of Zinc Oxide Thin Film Electrode based Continuous Impedance Monitoring System**" submitted by **MS. SHIVI JAIN** and **MR. SATYAJIT DAS** in partial fulfillment of the requirements for the degree of **Bachelor of Technology in Biomedical Engineering** embodies the bonafide work done by her in the final year of her degree under the supervision of the undersigned. The thesis or any part of it has not been submitted earlier to any other University / Institute for the award of any Degree or Diploma.

Place: Rourkela

Date: 12th may 2014

Dr. Kunal Pal

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ABSTRACT

The study describes the analysis of d-glucose solutionby a Zinc Oxide (ZnO) thin film biosensor. The ZnO thin film sensor was developed by the RF sputtering method over a glass substrate. Two adjacent electrodes were used to measure the impedances of the various concentrations of d-glucose. A in-house developed contiuous monitoring system was also used to study the impedances of the same and it was also tested for its continuous monitoring capability of the impedances of the d-glucose concentrations.

Keywords: Thin film, Zinc oxide electrodes, impedance analyzer, D-glucose

CHAPTER 1

INTRODUCTION

The analysis and detection of biological analytes has always played an important role in the improvement of diagnosis and monitoring of various diseases and health in general [1]. Hence, the development of innovative low cost monitoring platforms will play a major role in achieving the goal of point-of-care technology [2]. Thus, there is an urgent need for the development and improvement of monitoring devices at meagre costs. Keeping this in mind, over the years, there has been a sudden increase in the monitoring and impedance measurement of the biological analytes using various impedance measurement devices. Nowadays, the costs of various impedance measurement devices are being constantly reduced due to innovations in the field. Besides the above, the impedance measurement additionally allows both the quantitative and qualitative analyses of the analytes.

Zinc oxide (ZnO) can be considered as a versatile material with a very wide range of properties that includes acousto-optical, electro-optical, luminescence characteristics among various other similar properties [3]. In recent years, it has truly emerged as one of the most sought after materials for fabrication of any kind of electrode system used for impedance measurement of biological analytes. The excellent electrical properties of ZnO coupled with its biocompatibility nature may be some of the major reasons for the same [4]. ZnO has also been time and again reported to be non-toxic [5]. Further, fabrication of ZnO sensors is relatively easy.

In the present study, ZnO thin film biosensor was designed. Various concentrations of D-glucose were taken as the analytic solutions. Characterization of the electrode-analyte system was thoroughly done using impedance analysis. Finally taking the required information from the above process, an innovative impedance monitoring system was successfully developed and tested for its efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 Sensors

A sensor is an analytical device which measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. A biological sensor consists of a suitable transducer that transform the signal from the interaction of analyte with the element which is of biological value into electrical signal which can be measured easily. Various characteristics of biosensor makes it more valuable asset in biomedical industry [6]. The most important characteristic is its selectivity i.e. it will detect the certain bio-chemical and does not react with the other contaminates. Signal stability is another important characteristic of a sensor that performs continuous monitoring and influences the precision of sensor. Basically signal stability measures the drift in continuous monitoring conditions. Sensitivity of a sensor measures the minimum amount of analyte that can be measured by the sensor. Response time is the minimum time required to analyze the assay. Regeneration time is another feature that defines the time required to return the sensor to working state after interaction with the sample. From above discussion we can say we want to construct a sensor which has high sensitivity, not effected by concentrations of other analytes present in the mixture and is unaffected by measured property.

2.2 Biosensors

Biosensors are receiving a lot of attention due to their selectivity, sensitivity and portability. So, there is a focus in the biomedical industry to develop a sensor that can measure a biochemical of significance. There are various kinds of biosensors like electrochemical, optical, electronic, piezoelectric, gravimetric and pyro-electric. Electrochemical and piezoelectric biosensors are regarded very suitable till date. Electrochemical biosensor includes immobilization of certain chemicals on suitable matrix. Biosensors are used to measure the concentration of biological analytes and various properties like osmolality, glucose level and oxygen level.

2.3 Thin Film sensor

Recently, use of a biocompatible thin film as suitable matrix for enzyme immobilization has proved to be very useful. They are usually called as thin film sensor. A thin film sensor includes arrangement of thin multilayers which produces an electric current when they are subjected to a stimuli like stress, or mechanical field. Apart from this other major advantages of thin films are large surface area to volume ratio, better quality and efficiency, low power consumption and low

consumption of materials. By using thin films we can also vary material properties in a wide range and it is easy to pattern in micrometer range. Such type of biosensors can be develop in low cost, small in size and easy to carry.

2.4 Detectable Bio chemicals

Some of the detectable biochemical are Cholesterol, Uric acid, Blood glucose, Hydrogen peroxide (H_2O_2), NO_2 gas, Hemoglobin and 4-Nonyl Phenol [5, 7, 8]. Uric acid is an end product of purine metabolism in human body and its high concentration in human body can cause a number of serious disorders. ZnO films doped with iron (Fe) are used to detect the amount of uric acid in human body. ZnO films are also used to detect blood glucose level.

ZnO has a very high isoelectric point of about 9.5. Hence, it immobilizes low isoelectric DNA proteins or glucose. Glucose immobilized on the surface of ZnO film is very stable with highly catalytic activity during the measurements.

2.5 Mechanism of Glucose oxidation on metal oxide

Glucose biosensors based on the equation shown below:-

The activity of enzymes is affected by various physical parameters like pH, temperature etc. To solve this problem we can use enzyme free sensors which also end to improve electro-catalytic activity and selectivity towards oxidation glucose [9].

2.6 Nucleation and growth of thin films

Ideal conditions to obtain a film includes atom by atom deposition of the material on the substrate. There should be a sufficient time interval between the two successive deposition of atoms and layers. The deposited atoms occupy the minimum potential energy configuration w.r.t the substrate and subsequently on previously deposited layer. However, the above conditions are practically hard to obtain. Hence, the films obtained are meta-stable films.

2.7 Formation of Nuclei

This phenonmenon includes impinging of atomns/ions on substrate. The atoms may not uniformly deposit on the substrate. However, the atoms try to occupy the position in which they have minimum energy and maximum stability.

The atoms/ions deposit on glass substrate at certain sites, thus forming nuclei of clusters.

2.8 Thermodynamics of nucleation

We should take care of few points for carrying out nucleation. The surface should be smooth and defect free. This process can be treated from the Gibb's energy conditions. Various factors on which nucleation rate depends are vapor pressure of gases and solid phases, the temperature of corresponding states, free energies of these phases, free surface energies, adsorption rate of atoms on the substrate and dissolution rate of molecules during deposition. In addition to these factors few more factors that may affect /alter nucleation rate are migration of the adsorbed species (atoms) over the surface, joining of two atoms to form clusters, temperature of the substrate and adhesive force between atoms and substrate.

2.9 Thin film growth process

The condensation of vapor atoms/molecules on a neutral, inert or active solid generally takes place from a supersaturated condition of vapors. It is either homogeneous (substrate is of same atoms as vapors) or heterogeneous (substrate is of different material than vapor atom). In either case a series of steps occurs. Starting with accommodation of the impinging atoms, then binding on the substrate surface, thereafter surface diffusion of atoms and cluster formation. These

clusters grow into islands and then coalescence of islands occurs. Finally, continuous films grow on the surface.

2.10 Thin film deposition by sputtering process

Sputtering process is analogous to generation of drops out of a liquid surface by an impinging primary drop. Technically it is a process where atoms are ejected from a solid target material due to bombardment of the target by non-reactive (inert) energetic particles (ions). The process involves various steps to obtain a thin film sensor [10]. A sputter system consists of a chamber with a sputtering target and a substrate over which film is generated. An inert gas (Ar) is fed into the vacuum chamber in the sputter system at low pressure. A plasma is created by applying a voltage across the electrodes. The plasma consists of neutral argon atoms and roughly equal numbers of ions and free electrons. Therefore, plasma is a conducting medium. The cathode is target and anode is grounded and the substrate is mounted on the anode. When the voltage is applied the positive ions in the plasma drifts to the negatively biased target and sputter the target atoms. These atoms are then free to travel through the plasma as a vapor and deposited on the surface of the substrate.

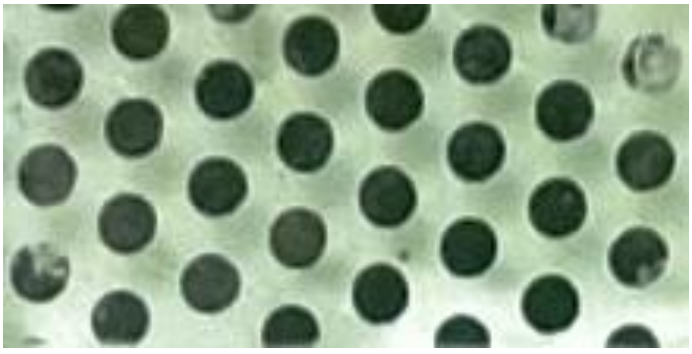


Figure 1 : ZnO electrode array

CHAPTER 3

MATERIALS AND METHODS

3.1 Sputtering

Strongly textured ZnO film was prepared using RF sputtering (radio frequency sputtering) method. Zinc oxide was used as it is a promising material due to the wide band gap of 3.37eV at room temperature and high excitation binding energy of 60meV which allow it to use in UV region with harsh condition.

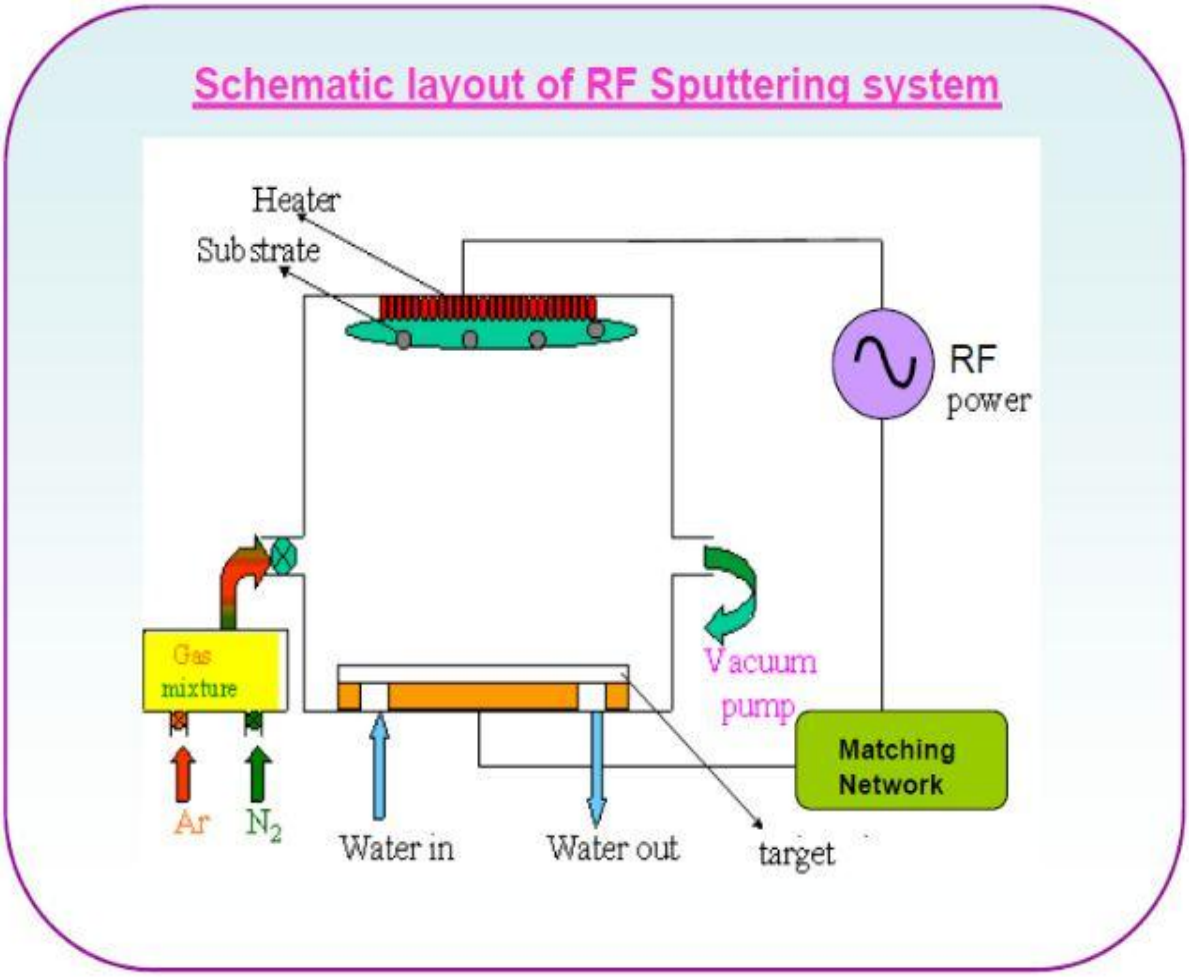


Figure 2 : Schematic Diagram Of RF sputtering machine

There are various sputtering techniques like dc plasma sputtering, RF sputtering, ion sputtering, and pulsed dc sputtering and reactive sputtering used in deposition of thin film. We have used radio frequency sputtering as it is suitable for all types of target. In this method a high frequency

of 13-14 MHz is used. Radio frequency voltage is capacitively coupled to the plasma through the insulating target is neutralized by electrons bombardment over each cycle. A high frequency ensures continuous production of plasma. Since, the electrons have lighter mass and hence, have higher mobility. More electrons are collected at electrode resulting in negative charges, maintaining a potential which is negative w.r.t. plasma voltage. The net voltage drop at both electrodes would be equal and sputtering occurs at both electrodes (substrate and target) throughout the RF cycle. The sputtering rate is high and can work at low pressure in case of RF Sputtering.

Figure 3 : RF sputtering machine

3.2 Fabrication:

By RF sputtering method we obtained a sensor (glass slide over which thin layer of zinc oxide was deposited). In order to accommodate in an impedance analyzing circuit, we need to do wiring of the sensor. For this we attached the sensor by means of a double sided tape in the middle of a box. Thereafter, drilled two holes in opposite faces. Through them two wires are inserted and connected to the biosensor with help of silver paste. Silver paste keeps the wire attached to silver dots on the sensor and provides least resistance. The other ends of the wires are connected to the sensor with banana clips and wires are extended from this to connect to the impedance circuit. The setup is bit sensitive, hence needed to be handled carefully.

3.3 Electrical Characterization

For the electrical characterization, 50 µl of different concentrations of d-glucose solutions were taken to be measured by a impedance analyzer machine (3532-50 LCR HiTester, HIOKI, Japan) . This time the frequency was set between 100 Hz and 1 MHz and a drop of the d-glucose concentration was put between te two electrodes to be analyzed. The voltage given as input for the analysis was kept constant at 1 V. The data received from the machine was stored in an excel file. The excel file later helped in the plotting of various characteristic plots such as the nyquist plot, bode plot, ac conductivity etc.

3.4 IV Characteristics

Impedance measurement of a thin film sensor can provide information about the deposition of electrolyte on the sensor [11]. The basic concept of the impedance method is to use high-frequency vibrations to monitor the local area of a structure for changes in structural impedance

that would indicate damage or incipient damage. Here, we had made an impedance analyzer circuit by assembly the components. The impedance of the sensor was measured using the arrangement at different concentrations of the solution like 0% w/w i.e. distilled water, 0.5% w/w dextrose in distilled water and 2% w/w dextrose in distilled water. The data at each concentration was collected. We have measured voltage at different frequencies for each concentration. The frequency range taken is 50Hz to 10 KHz and voltage taken is 1V peak to peak. Thereafter, we have kept frequency constant and recorded the results at varying voltage. The above method used is low cost impedance measurement technique and is very efficient in health monitoring.

3.5 Designing of impedance monitoring system

Using IC 8038 an impedance monitoring system was developed. IC 8038 is a signal generator with the following specifications:-

• Low Distortion - 1% (Sine Wave Output)

• Low Frequency Drift with Temperature - 250ppm/oC

• Wide Frequency Range - 0.001Hz to 300kHz

• High Linearity - 0.1% (Triangle Wave Output)

• Variable Duty Cycle - 2% to 98%

• High Level Outputs - TTL to 28V

• Simultaneous Sine, Square, and Triangle Wave Outputs

• Easy to Use - Just some of External Components Required

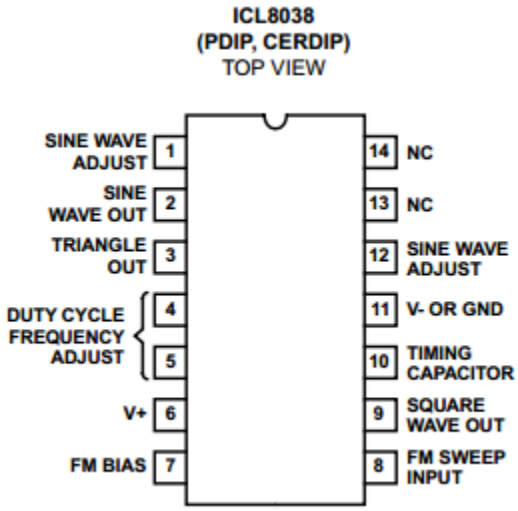


Figure 4: Pinout Diagram of IC 8038

We used a sinusoidal waveform with an amplitude of 2 Vp and a constant frequency of 10 kHz. Output of the signal generator was then put into a voltage buffer. Output of this voltage buffer was then put into an inverting amplifier which was OPAMP based. Input resistance of this amplifier was chosen as 100 kΩ.We used an Arduino UNO microcontroller to obtain the voltage across the setup. The Arduino UNO microcontroller used :-

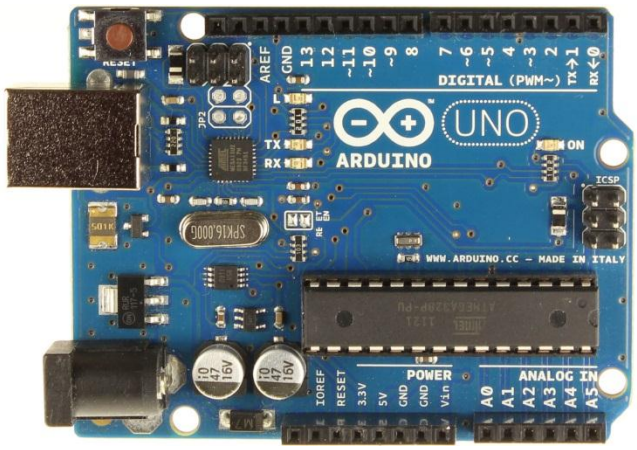


Figure 5 : Arduino UNO microcontroller

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Development of ZnO thin films

Over a glass substrate, a ZnO thin film layer was successfully deposited. A commonly available Al mask was selected for the thin film electrode array development. Electrodes of 1mm diameter and separation were fabricated. The electrode array is shown in the figure below. The array as can be seen below was fabricated in such a way that each electrode was equidistant from every other electrode. Hence, a hexagonal structure with an electrode at the centre of the hexagon was chosen. Electrodes were kept at all the 6 points of the hexagon while the other parts were left transparent.

Figure 6 : ZnO Electrode Setup

4.2. Electrical characterization

From the data obtained from the impedance analyzer, all the characteristic graphs were successfully plotted. The results of all the three concentrations were mapped onto a single characteristic gap so as to compare the results among them. At first to determine the electrical equivalent circuit, the nyquist plot was successfully plotted [12]. The nyquist plot of all the three concentrations gave us similar results with a semicircular region at higher frequency range and a

spike in the lower frequency range. Distilled water had the highest resistance among the three concentrations with the highest bulk resistance value. The resistance offered by a particular solution could be inferred by the real axis intercept of the semicircular region. This intercept of all the three concentrations appeared in the mid frequency regions or in the lower frequency regions. 2% dextrose solution's intercept occurred at somewhat higher frequency range compared to the other two solutions and also gave the lowest impedance. After the modelling of the nyquist plot, fitting was done to the graphs that gave us the equivalent electrical circuit for the setup. The fitting was found to be (RQ)(Q) with R standing for bulk resistance and Q for the constant phase element . The bulk resistance and the CPE were found to be in parallel and represented the semicircular region while the spike could easily be explained by only a constant phase element. The constant phase element cannot be considered as either a resistance element or a capacitive element. It is actually a cross between the two and exhibits characteristics of both the capacitor as well as that of a resistor. The fitting and the subsequent analysis of the graphs were done by the Z Simp Win software to which the experimental data of the nyquist plot of all the three concentrations were exported to from Origin software. The fitting of the graph proved that there were similarities between the experimental data and the equivalent circuit that we arrived at after fitting [13]. The error percentages of the fitting were all within the required limits, hence showing the accuracy of the experiment.

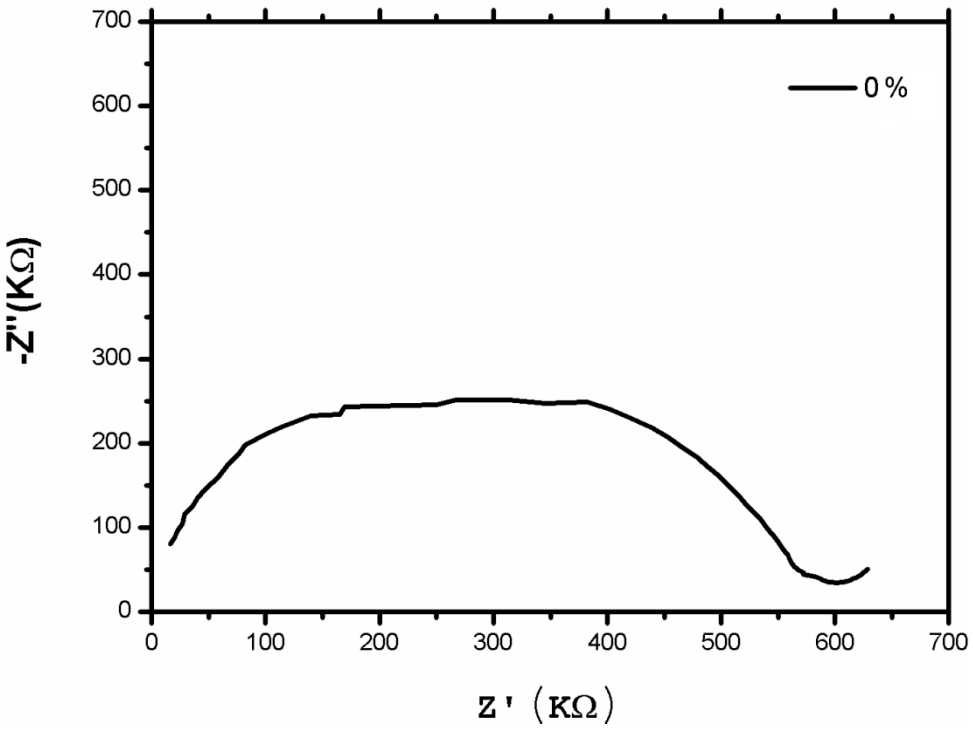


Figure 7 : Nyquist plot of pure water solution

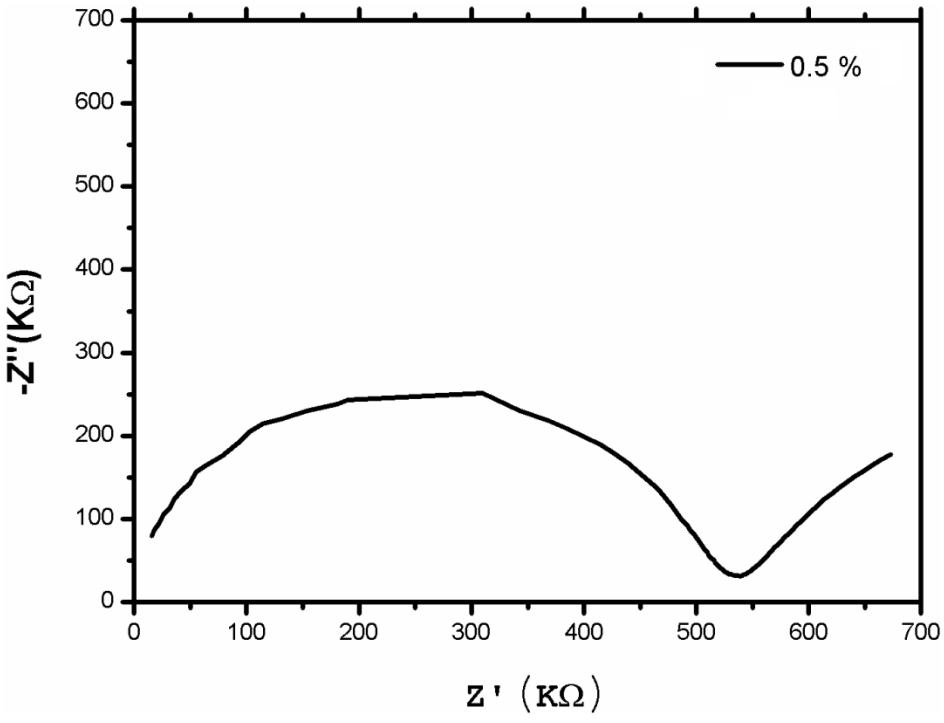


Figure 8 : Nyquist plot of 0.5% d-glucose solution

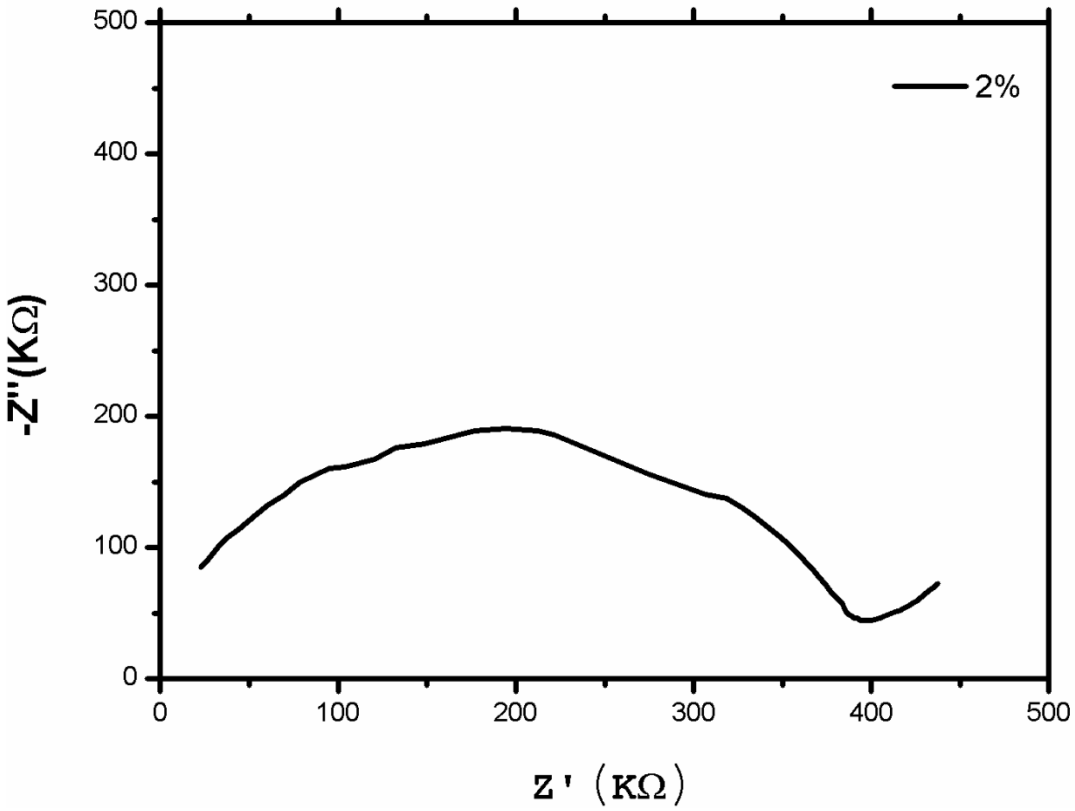


Figure 9 : Nyquist plot of 2 % d-glucose solution

The AC conductivity plot also showed similar characteristics to that of the nyquist plot. The conductivity of the pure water solution was the lowest as was expected earlier and that of the 2% glucose solution was the highest [14]. The conductivity profile of the three solutions contained two different parts- d.c. conductivity and a.c. conductivity. The d.c. conductivity could be calculated in two ways i.e. either by extrapolating the graphs onto the y axis or by using the formula:-

$\sigma_0 = (1/R_b)^* (l/A)$

where l stood for the distance between two electrodes and A the area of a single electrode. The d.c. conductivity profile also followed similar suit to that of the a.c. profile with water

providing the lowest conductivity followed closely by 0.5% d-glucose solution and 2% d-glucose solution having the highest d.c. as well as a.c. conductivity.

The tan delta graphs of the three concentrations were also plotted from the experimental data from the impedance analyzer machine.

The Tan δ plot displayed that there was a general shift in the peaks towards the higher frequency range as the d-glucose concentration was increased. Peak value of the distilled water water as well as that of the 0.5% D-glucose solution were found to lie between the frequency ranges of 2 kHz and 4 kHz while that of 2 % D-glucose solution was found to have a peak at about 10 kHz. As the concentration increased from that of pure distilled water to 2%d-glucose solution, there was a simultaneous decrease in the amplitudes of the tan δ profile for all the three concentrations. These combined effects showed that the stability of the system increased with the subsequent increase in the concentration of the d-glucose solutions.

The IV Characteristics of the electrode analyte electrochemical cells displayed that the voltage was linearly increasing with respect to the increase in current at a particular frequency. The properties were expressed best at 10khz frequency though the voltage vs. current plots did not vary much with respect to the change in frequency.

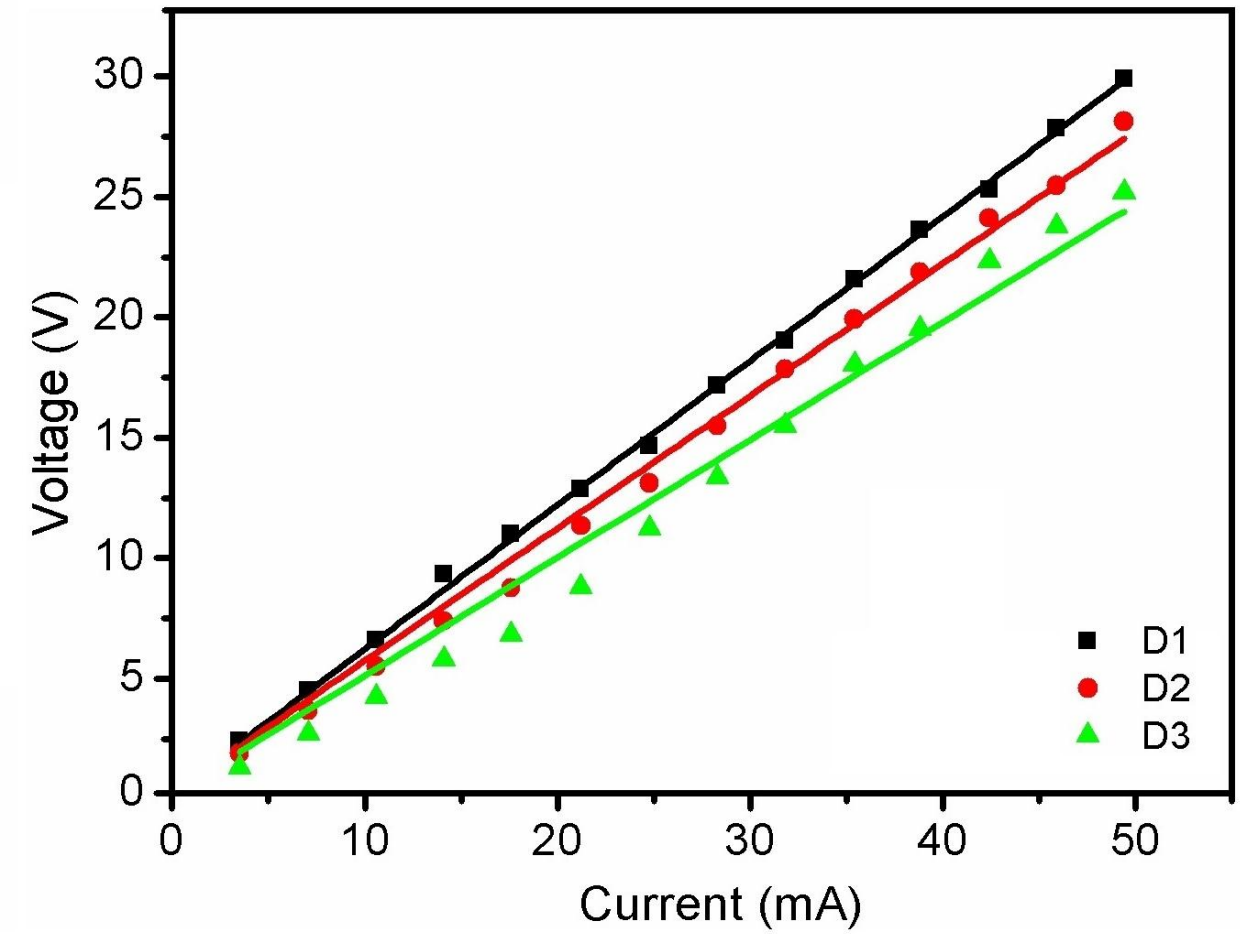
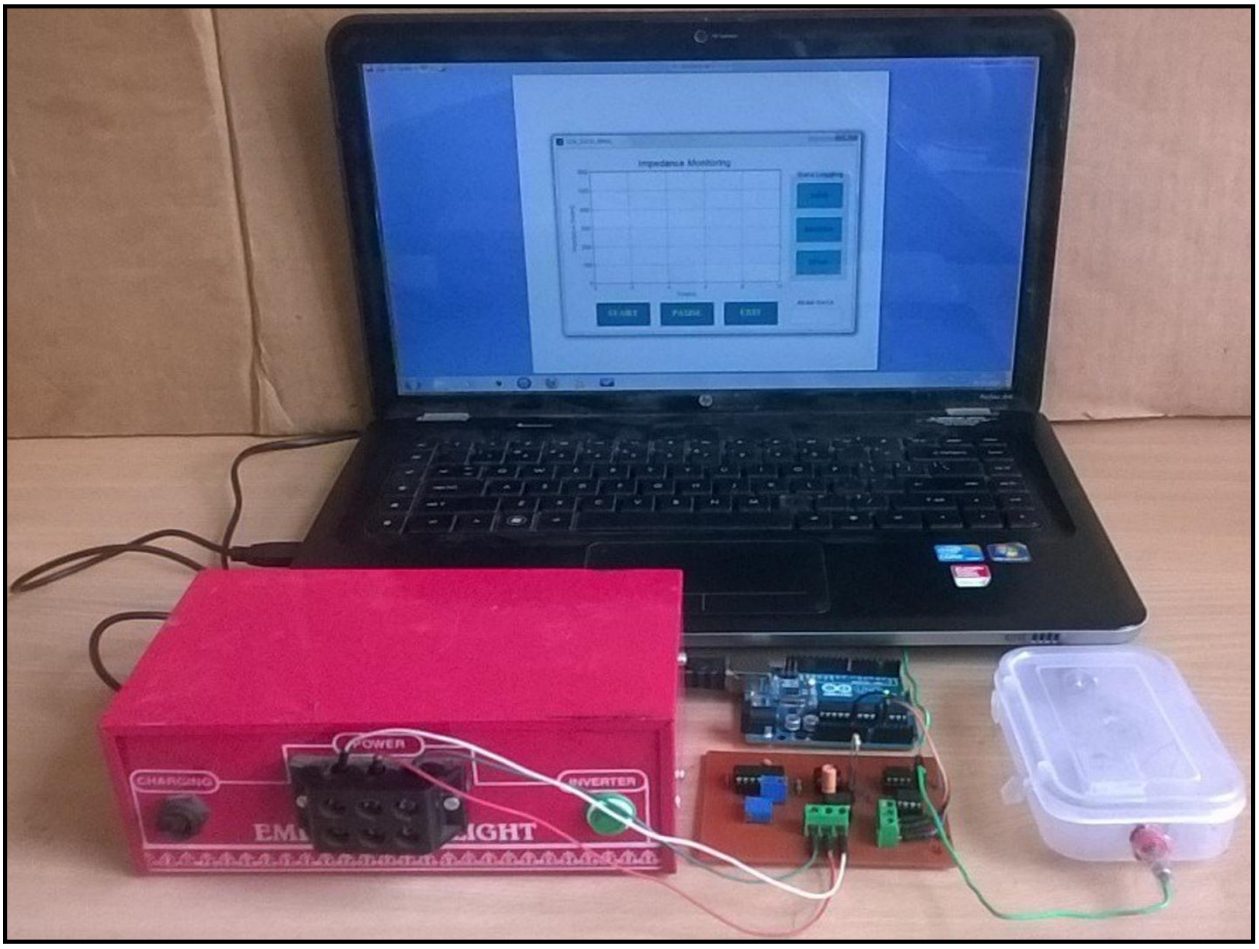


Figure 10 : IV Characteristics of the samples at 10 kHz

4.3 Impedance monitoring system

A in-house developed impedance monitoring system was developed to measure the impedances of all the three concentrations at a constant frequency which was chosen to be 10 kHz. At 10 kHz, the impedances of the analytes examined had sufficiently different impedances. Hence, 10 kHz was selected as the desired frequency. The voltage drop across the setup was monitored using an Arduino UNO microcontroller connected to a laptop [15]. The system was monitored for a duration of 5 mins during which it did not show much deviation from the stable value. The results were plotted on the laptop and were also stored in a text file for the entire duration.



Program for the above setup is mentioned in Appendix A

Figure 11 : Impedance Monitoring Setup

The impedance values obtained at 10 kHz were similar to those obtained during electrical characterization of the setup. The impedance of distilled water was monitored for 5 minutes and the monitoring showed that there was not much variation in the impedance value over the entire duration and the impedance remained more or less similar for the entire 5 minutes which has been shown by the following figure .

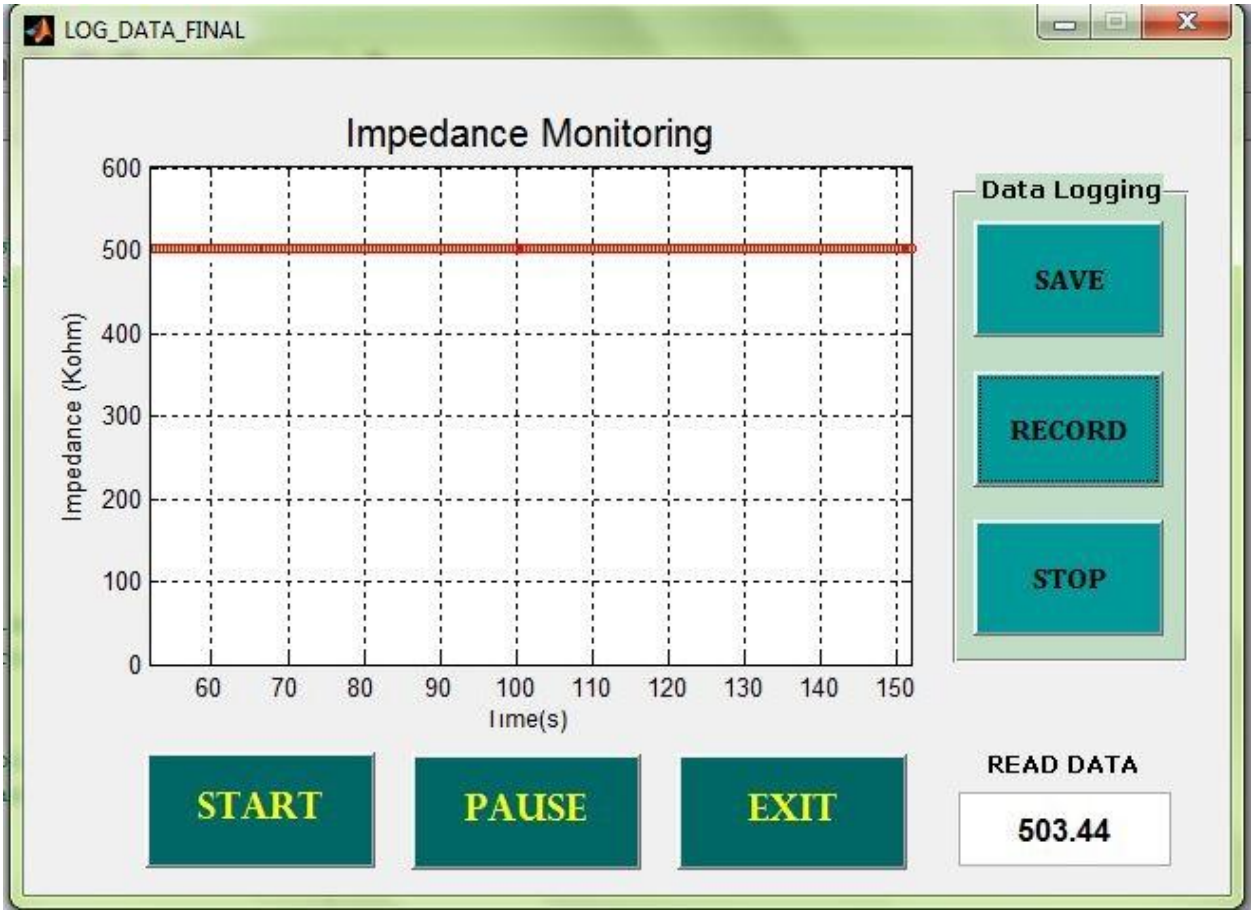


Figure 12 : Impedance monitoring of 0.5 % d-glucose solution

CHAPTER 5

CONCLUSION

The current study discusses about the successful creation of a ZnO thin film based microelectrode biosensor. A RF sputtering machine was used for the creation of the same. The microelectrodes formed were equidistant from each other and were also similar in structure. A low cost impedance monitoring device was also successfully developed in the study. D-glucose solutions were prepared and their impedances were measured so as to test both the efficiency of the in house developed impedance monitoring system as well as to characterize the d-glucose solution. The results of the impedance analysis thus obtained suggested a favorable promise for the use of the ZnO thin film based biosensor to be eventually used to detect the concentration of D-glucose as well as other biological analytes.

APPENDIX A

PROGRAM CODE

```
function varargout = LOG_DATA_FINAL(varargin)
% LOG_DATA_FINAL M-file for LOG_DATA_FINAL.fig
%      LOG_DATA_FINAL, by itself, creates a new LOG_DATA_FINAL or raises the existing
%      singleton*.
%
%      H = LOG_DATA_FINAL returns the handle to a new LOG_DATA_FINAL or the handle
to
%      the existing singleton*.
%
%      LOG_DATA_FINAL('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in LOG_DATA_FINAL.M with the given input arguments.
%
%      LOG_DATA_FINAL('Property','Value',...) creates a new LOG_DATA_FINAL or raises
the
%      existing singleton*.  Starting from the left, property value pairs are
%      applied to the GUI before LOG_DATA_FINAL_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property application
%      stop.  All inputs are passed to LOG_DATA_FINAL_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help LOG_DATA_FINAL

% Last Modified by GUIDE v2.5 05-May-2014 11:30:40

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @LOG_DATA_FINAL_OpeningFcn, ...
                   'gui_OutputFcn',  @LOG_DATA_FINAL_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
```

```
% --- Executes just before LOG_DATA_FINAL is made visible.
function LOG_DATA_FINAL_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to LOG_DATA_FINAL (see VARARGIN)

% Choose default command line output for LOG_DATA_FINAL
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes LOG_DATA_FINAL wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% --- Outputs from this function are returned to the command line.
function varargout = LOG_DATA_FINAL_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in START.
function START_Callback(hObject, eventdata, handles)
% hObject    handle to START (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

global a r rec i;
a=0;r=0;j=1;
% delete(instrfindall)

%User Defined Properties
serialPort = 'COM20';           % define COM port #
plotTitle = 'Impedance Monitoring';  % plot title
xLabel = 'Time(s)';    % x-axis label
yLabel = 'Impedance (Kohm)';              % y-axis label
```

```
plotGrid = 'on';              % 'off' to turn off grid
min = 0.0;                    % set y-min
max = 600;                    % set y-max
scrollWidth = 100;            % display period in plot, plot entire data log if <= 0
delay = 0.01;                 % make sure sample faster than resolution

%Define Function Variables
time = 0;
data = 0;
count = 0;

%Set up Plot
plotGraph = plot(time,data,'-mo',...
            'LineWidth',1,...
            'MarkerEdgeColor','r',...
            'MarkerFaceColor',[.49 1 .63],...
            'MarkerSize',2);

title(plotTitle,'FontSize',15);
xlabel(xLabel,'FontSize',10);
ylabel(yLabel,'FontSize',10);
axis([0 10 min max]);
grid(plotGrid);

%Open Serial COM Port
s = serial(serialPort);
disp('Close Plot to End Session');
fopen(s);


% while ishandle(plotGraph) %Loop when Plot is Active
 while(a~=1)
   dat = fscanf(s,'%f'); %Read Data from Serial as Float
   set(handles.edit1,'string',dat);
% ------------------------------------------------------
          if r==1
             rec(j) = dat(1);
             j = j+1;
          end
% ------------------------------------------------------

   if(~isempty(dat) && isfloat(dat)) %Make sure Data Type is Correct
      count = count + 1;
      time(count) = toc;    %Extract Elapsed Time
      data(count) = dat(1); %Extract 1st Data Element
```

```
        %Set Axis according to Scroll Width
        if(scrollWidth > 0)
        set(plotGraph,'XData',time(time > time(count)-scrollWidth),'YData',data(time >
time(count)-scrollWidth));
        axis([time(count)-scrollWidth time(count) min max]);
        else
        set(plotGraph,'XData',time,'YData',data);
        axis([0 time(count) min max]);
        end
        %Allow MATLAB to Update Plot
        pause(delay);
    end
 end
% end

%Close Serial COM Port and Delete useless Variables
fclose(s);

clear count dat delay max min plotGraph plotGrid plotTitle s ...
        scrollWidth serialPort xLabel yLabel;

     disp('Session Terminated...');


% --- Executes on button press in PAUSE.
function PAUSE_Callback(hObject, eventdata, handles)
% hObject    handle to PAUSE (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global a;
a=1;

% --- Executes on button press in EXIT.
function EXIT_Callback(hObject, eventdata, handles)
% hObject    handle to EXIT (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
close(LOG_DATA_FINAL);
clear all;
instrreset;

% --- Executes on button press in SAVE.
function SAVE_Callback(hObject, eventdata, handles)
% hObject    handle to SAVE (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
```

```
global rec i
[filename, path] = uiputfile('*.mat')
save([path '\' filename],'rec')

% --- Executes on button press in RECORD.
function RECORD_Callback(hObject, eventdata, handles)
% hObject    handle to RECORD (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global a r
r=1;

% --- Executes on button press in STOPREC.
function STOPREC_Callback(hObject, eventdata, handles)
% hObject    handle to STOPREC (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global a r
r=0;


function edit1_Callback(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit1 as text
%        str2double(get(hObject,'String')) returns contents of edit1 as a double


% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

CHAPTER 6

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