SENSING AND CAPTURING THE GASEOUS STATE OF CARBON THROUGH NOVEL BIO CATALYTIC RESISTIVE SENSOR

M.S. Sudhir Narayana[1], T. Fabio Mughilan[2], G. Samar Simha Reddy[3], N. Vignesh[4]

Abstract

The presence of toxic and harmful gases utterly dangers human health and environmental wellbeing. Selective detection of these gases is immediately required to meet the demands of the society. A promising and presently thriving area for monitoring volatile organic compounds (VOCs) and combustible gas items from the evolution of detection strategies blended with a novel, green, bio-inspired miracle leaf extracts that has been synthesised using Soxhlet Apparatus has been taken forward here. The synthesised leaf extracts were coated with three different copper coil and it was investigated for the detection of carbon dioxide at ambient temperature using laboratory made sensor setup. Three different plant extracts was coated in three different copper coil using dip coating. The sensing characteristics were monitored and compared by measuring the change in electrical resistivity on exposure to two different environmental conditions – in the presence and absence of Carbon dioxide. It is observed that the electrical response in terms of resistance of prepared miracle plant extracts towards carbon dioxide vapour has been scaled up after the passage of carbon dioxide gas. To the best of our knowledge, no study has been conducted on the synthesized miracle leaf extracts as a catalyst in line with sensing field towards carbon dioxide capture.

1. INTRODUCTION

A variety of toxic and harmful gases generated during human activities (chemical production, interior decoration, food industry, medical treatment, transportation, etc.) have severely negative impacts on air quality and human health. Nowadays, gas detection tools include infrared absorbers, ion mobility spectrometers, gas chromatographs, etc. However, these methods suffer from their time-consuming and complex operation, and their expensive analytical techniques, which make it difficult to meet the ever-growing demand. Therefore, it is imperative to develop the next generation of detection techniques for toxic and harmful gases so as to protect humans from the potential health risk. Gas sensors are advantageous over traditional detection methods because of their convenient operation, low cost, small size, low detection limit, etc. which can convert the concentration signals of the target gases into visual signals to achieve fast and accurate gas detection for early warning. For these reasons, exploring and developing high-performance gas sensors has aroused extensive interest from scientists in recent years.

To date, many types of gas sensors with different transduction forms have been developed, e.g., catalytic combustion gas sensor, electro-chemical gas sensor, quartz crystal microbalance (QCM) gas sensor, thermal conductivity gas sensor, infrared absorption gas sensor and resistive gas sensor. Catalytic combustion the resistance value of the temperature change as the output signal. Electro- chemical gas sensors seek to determine the gas concentration through the conversion of electrical signals after the target gas has been oxidized/reduced. Thermal conductivity gas sensors can convert signals related to the type and concentration of the gas into electrical signals. Infrared absorption gas sensors measure the gas concentration via the specific infrared absorption spectra of different target gases, enabling qualitative and quantitative detection simultaneously. QCM gas sensors are a kind of sensitive monitoring instrument with a selective adsorption film coated on the surface of the crystal. Resistive gas sensors can effectively transform the gas change around the gas-sensing medium into resistance signals, thus achieving the goal of gas sensing. An ideal gas sensor must have high responsivity, good selectivity, fast response/recovery, great stability/repeatability, and low costs for practical application. Hence, six-axes spider-web diagrams for evaluating the gas-sensing properties of various sensors are shown in Figure 1.

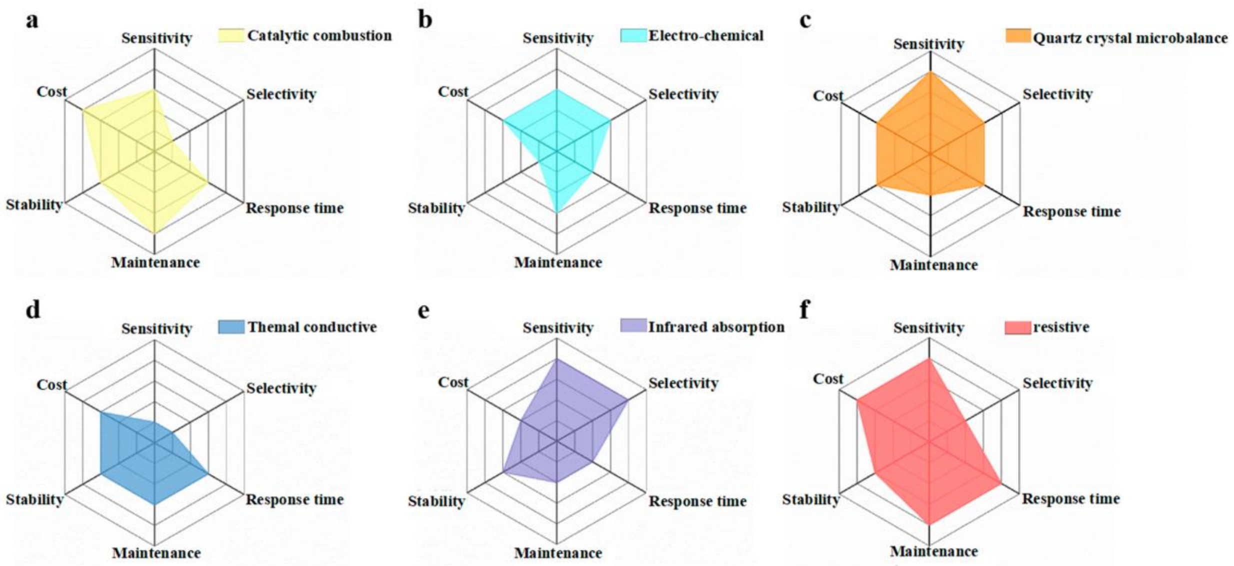


Figure 1

Compared with other gas sensors, the resistive gas sensor exhibits attractive advantages, including higher sensitivity, outstanding stability, flexibility (easy to operate and easy to utilize/integrate into portable devices), low power consumption, and lower operation cost, operation cost, highlighting its great potential in gas detection, such as for environmental safety and health monitoring. However the poor gas selectivity and high operating temperature of resistive gas sensors hinder their commercial application. To develop high-performance resistive gas sensors, it is important to understand their gas-sensing mechanism as well as choosing suitable gas-sensing mate.

2. Goals

Phase I

- To synthesize the plant extracts using distillation route by using Soxhlet apparatus.
- To characterize the plant extract in terms of size, shape, surface morphology and surface area by
  performing XRD, SEM, TEM and BET Surface area experiments.
- To coat the prepared plant extracts in copper coil using dip coating technique.
- Developing a sensor chamber in which the series connected coated copper coil will be examined for
  resistance in the absence and presence of carbon dioxide gas at ambient temperature conditions.

Phase II

- Preparation of nanomaterial's from the secondary source of pollution and it will be examined for characterization studies followed by its application as a catalyst in the form of coating material in the field of resistive sensor systems for the capture of carbon dioxide gas.
- Fusion of the above nanomaterial's with the plant extracts at suitable proportions with a way forward having a footage with characterization studies and creation of new foot print in the field of resistive catalytic sensor systems.
- Further mechanisms will be developed in terms of energy storage. The future work is aimed at converting the CO2 gas in to suitable energy using special process.

3. System Architecture and Design

Plant extracts were prepared using Soxhlet apparatus having a capacity of 500 ml round bottom flask. As shown in the below figure (Figure No. 2a, 2b, 2c, 2d). Here water was used as a solvent. The plant leaves were placed in the thimble region. The upper part of the thimble region was connected to the condenser. The water solvent was heated to a temperature of 100 degree Celsius. The water vapour was formed and it moved upward and finally it reached the condenser unit where the vapour was converted to liquid droplets and the liquid droplets was collected in the thimble region where the water droplets was in contact with leaves and finally the liquid extracts was collected in the round bottom flask as it reached through the siphon tube. The operation time took about 4 hours for the three extracts.

Figure 2a **Figure 2b** **Figure 2c**

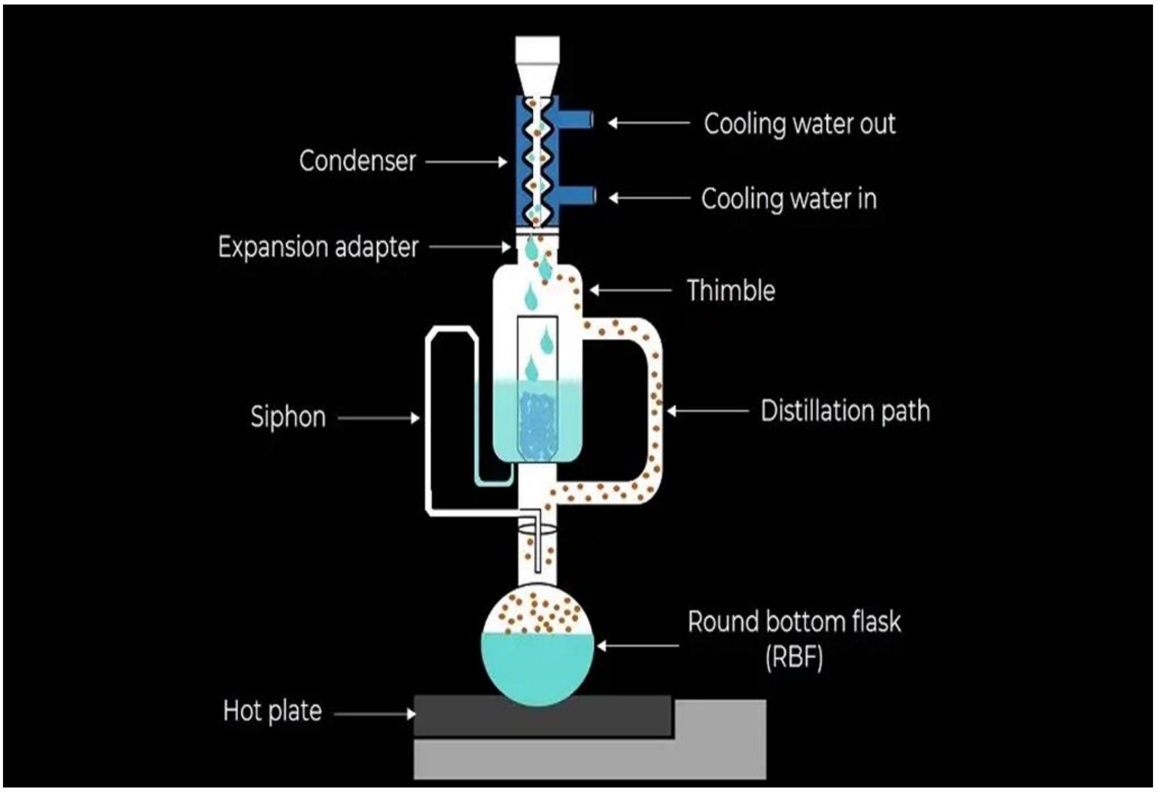


Figure 2 d

Copper coils of three in numbers having fourteen turns were made and they were dip coated by immersing in three different plant extracts (Sample 1, Sample 2, and Sample 3) for four hours as shown in the figures (Figure 3a, 3b, & 3c) below. Further it was dried using air blower.

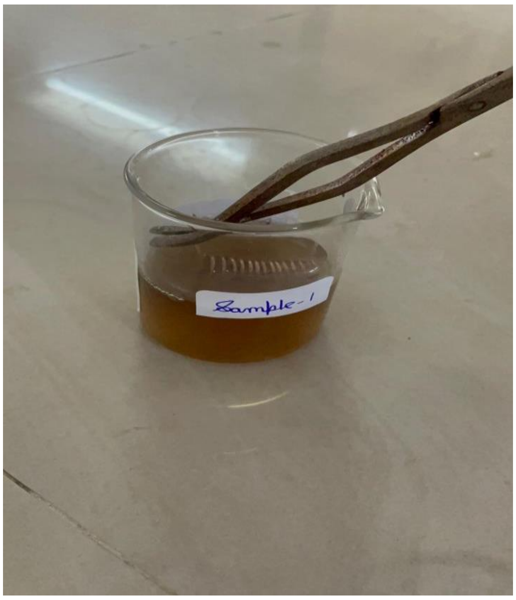


Figure 3a

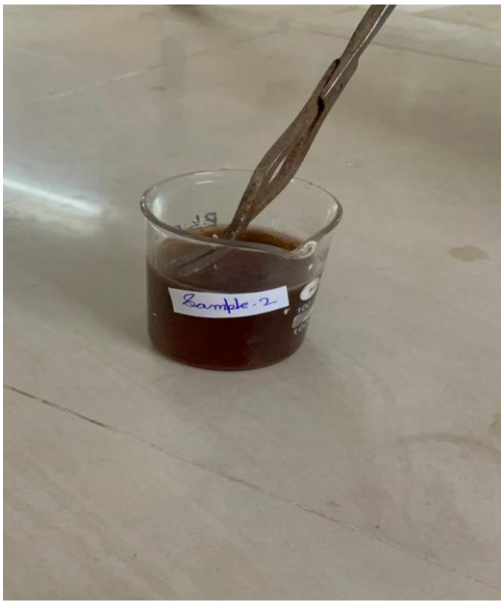


Figure 3b

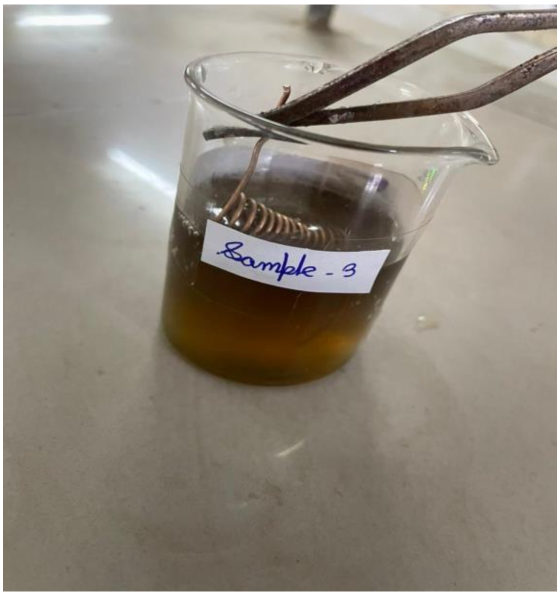


Figure 3c

The coated coils was connected to the wires and it was assembled in series inside the chamber as shown in the figure (Figure 4a & Figure 4b) below. Further the coils was connected independently to the power source and the resistance of the coil was measured before the passage of gas.

The resistance values for Coil 1, Coil 2 & Coil 3 are given below before the passage of Carbon dioxide gas:

Coil coated with first plant extract (Sample 1) – 32-35 Ω

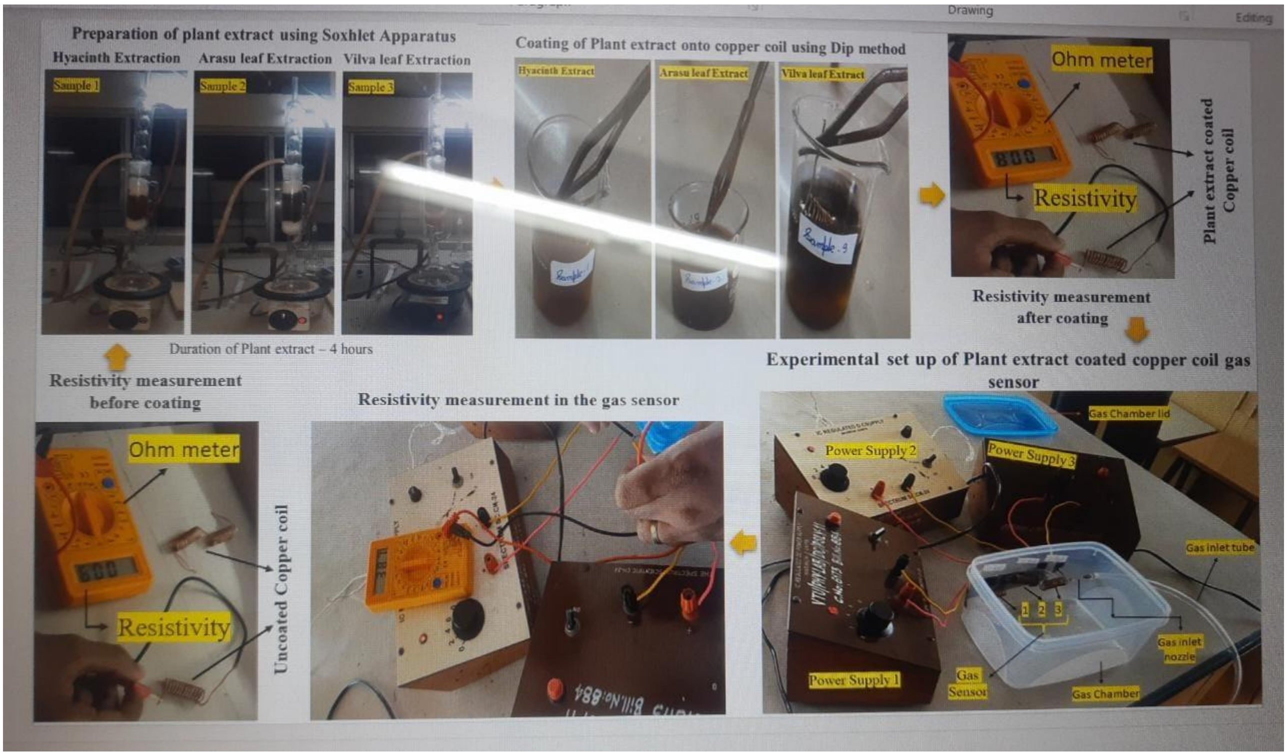
Coil coated with Second plant extract (Sample 2) – 42-45 Ω

Coil coated with Third plant extract (Sample 3) – 37 – 41 Ω

3.1 Hardware

Component/Device	Use
Power supply	This is used for power supply purpose
Resistive coils	These coils are wound for sensor fabrication purpose
Swtich	Used for on/off purpose
Soxhlet	Used for extraction of three different plant extracts
Multimeter	Used for measuring the voltage and current
Glass wares	Used during preparation of extracts – Round bottom flasks, measuring jar.
High Temperature Owen	Used for drying the leaves.

Graphical Abstract



4. Addressing Challenges

The greatest challenges is detection of CO_2 gas in this first phase we have identified suitable extract for gas sensing and our prototype senses the CO_2 gas and the plan for the next phase is that not only sensing this CO_2 will be converted in to suitable energy using some special process.

5. Performance Evaluation and Testing Results

Sensing Mechanism of Resistive Gas Sensor

The gas sensing mechanism of the developed sensor, is predominantly based on the changes in their resistance after they are exposed to the carbon dioxide gases due to the chemical interaction between interfaces. There are two main sensing mechanisms, which are the surface charge layer model and the grain boundary barrier model.

For the sensor that has been developed surface charge layer model played a dominant role.

In the CO_2 atmosphere, a certain amount of carbon dioxide molecules has been adsorbed on the surface of the sensing material. The adsorbed carbon dioxide molecules extract electrons from the conduction band and trap the electrons on their surface as ions, forming different surface energy levels. As a result, a space charger layer or electron depletion layer was formed. In a target carbon dioxide gas atmosphere, the donor or acceptor gaseous electrons are adsorbed onto the surface coated with plant extracts and exchange electrons resulting in a change in the conductivity of the sensing material.

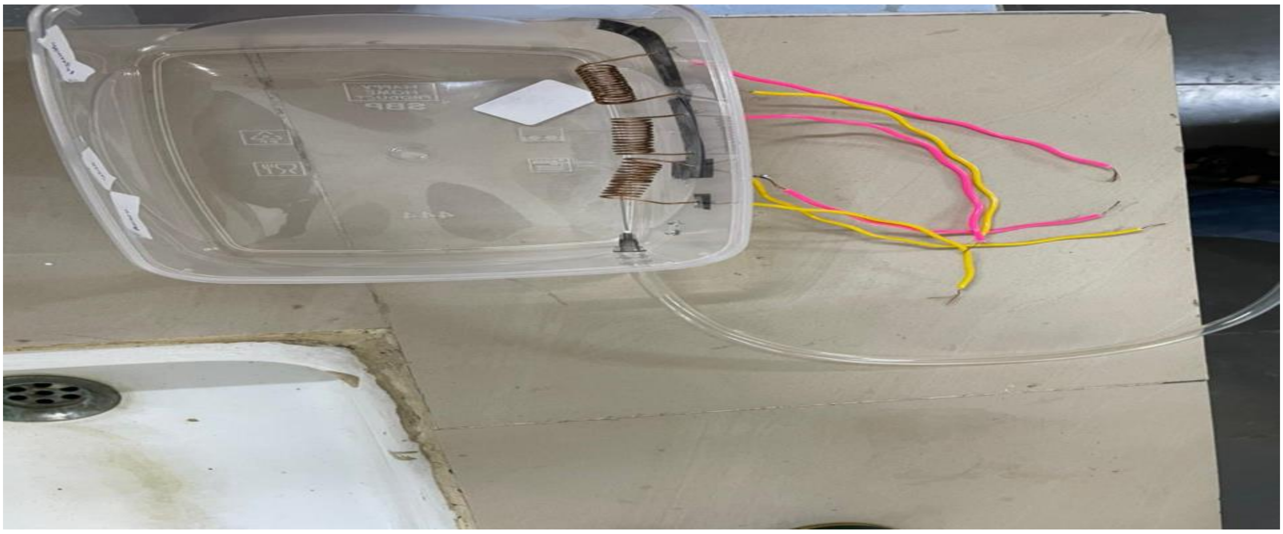


Figure 4a

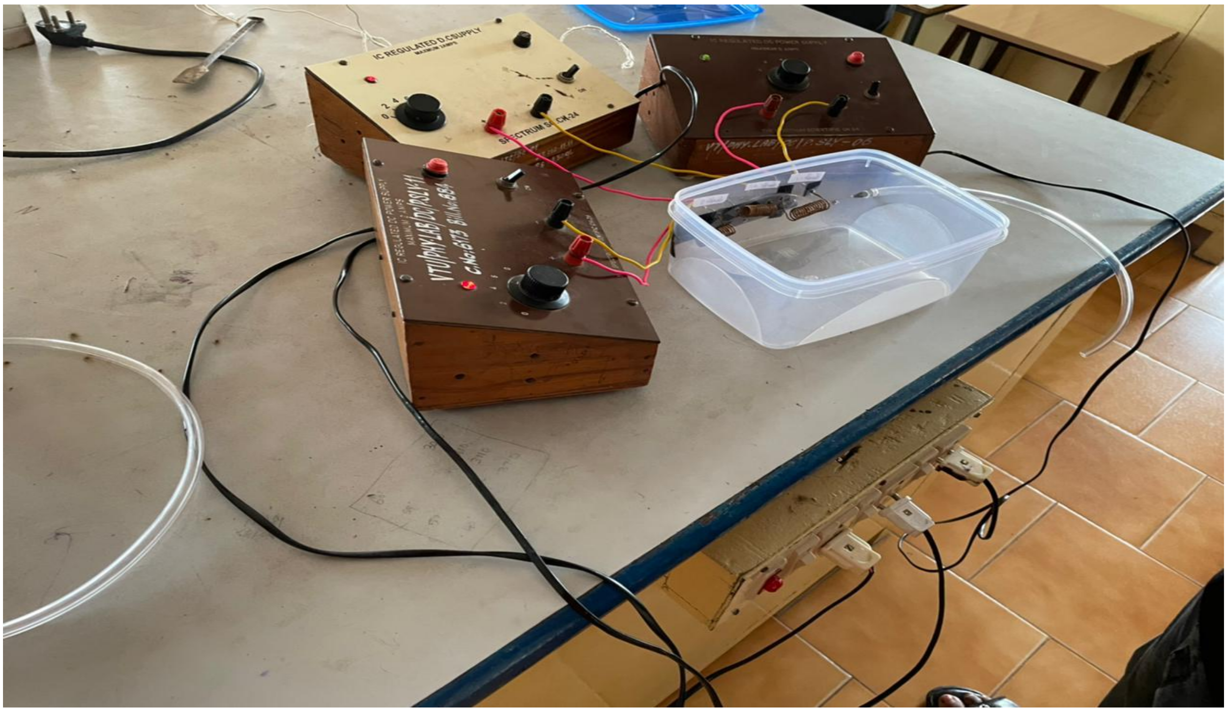


Figure 4b

In the same note the resistance of the coated coils were measured after the passage of carbon dioxide gas as shown in the figure 5 and it was observed that there was an increase in resistance for all the three samples. Meanwhile the carbon dioxide gas was prepared in our laboratory as shown in figure 6 by fusing sodium bicarbonate and acetic acid which resulted in the formation of carbon dioxide gas that was collected in the balloon. The collected carbon dioxide in the balloon is allowed to pass through the tube by inserting it which has been connected to the chamber. The other end of the tube is connected to the syringe which helps in the uniform exit of carbon dioxide gas.

Coil coated with first plant extract (Sample 1) – 37 – 39.3 Ω

Coil coated with Second plant extract (Sample 2) – 46 – 56.3 Ω

Coil coated with Third plant extract (Sample 3) – 45-50 Ω

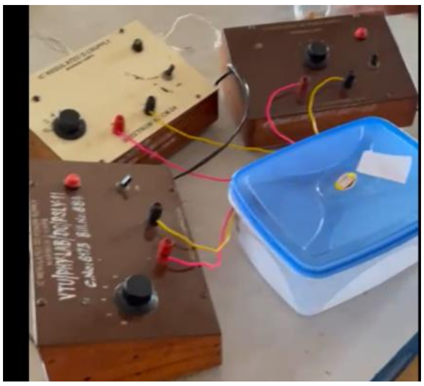


Figure 5

Figure 6

6. Concluding Remarks and Avenues for Future Work

The proposed sensor configuration can be used for the detection of CO2 gas The system is designed to meet the maximum absorption in the near surface.

Future Work

Preparation of nanomaterials from the secondary source of pollution and it will be examined for characterization studies followed by its application as a catalyst in the form of coating material in the field of resistive sensor systems for the capture of carbon dioxide gas.

Fusion of the above nanomaterial's with the plant extracts at suitable proportions with a way forward having a footage with characterization studies and creation of new foot print in the field of resistive catalytic sensor systems.

Further mechanisms will be developed in terms of energy storage.

7. Availability

The below url link is provided for the proof of work carried out during the phase I.

https://1drv.ms/v/s!AoFhF78-VOSYiCTsZPk07NImuxmz

8. References

1. Ze Wang , Lei Zhu , Shiyi Sun, Jianan Wang and Wei Yan, One-Dimensional Nanomaterials in Resistive Gas Sensor: From Material Design to Application. Chemosensors, 2021,9, 1-32.

2. Ali Mirzaei, Jae-Hyoung Lee, Sanjit Manohar Majhi, Resistive gas sensors based on metal-oxide Nanowires. J. Appl. Phys.2019, 241102-1 - 241102-24.

3. Liqun Wu 1 , Ting Zhang 1 , Hongcheng Wang 1,*, Chengxin Tang 2 and Linan Zhang, A Novel Fabricating Process of Catalytic Gas Sensor Based on Droplet Generating Technology, Micromachines, 2019, 10, 1-11.

4. Yingying Jian , Wenwen Hu , Zhenhuan Zhao , Pengfei Cheng , Hossam Haick, Mingshui Yao, Weiwei Wu, Gas Sensors Based on Chemi-Resistive Hybrid Functional Nanomaterials, Nano Micro Letters, 2020, 1-43

****