

Design and Development of Humidity Sensor Based on Alumina and Zirconium Dioxide

SaiTeja Chopparapu, Beatrice Seventline J, S. Sam Joseph Joy, Sanikommu Akash Reddy



Abstract: Humidity calculation is one of the most significant issues in different applications such as automated system, irrigation, instrumentation, climatology and GPS. The design and fabrication of Humidity sensor are mostly used for industries and laboratory applications. This work highlights the fabrication of humidity sensor based on alumina (Al_2O_3) used as substrate and Zirconium Dioxide (ZrO_2) as active or sensing material to detect both moisture and air temperature in the environment. The objective was to fabricate a humidity sensor of compact size with better sensitivity and spatial resolution at low cost. In this project, AUTOCAD software was used for designing and was developed a miniaturized thin film sensor over a ceramic substrate and deposition of active sensing material was done through RF sputtering process. The fabricated humidity sensor has been characterized under different humidity conditions and the results showed a faster response.

Keywords: AUTOCAD, LabVIEW, RF Sputtering, Thermal Evaporation.

I. INTRODUCTION

Measurement and control of humidity is critical in various industrial, irrigation and medical applications. It is used in the medical sector during pharmaceutical approaches. In industry, it is used for various manufacturing processes such as semiconductor manufacturing and chemical gas purification. It is also very important in people's daily lives. [7] Humidity sensor is nothing but a device which detects or measure the water vapor in the environment. In 1450, Nicolas Crafts developed first humidity measurement device namely hygrometer. It is used to determine the change of humidity in environment. Different types of hygrometer were developed after so many years of development, such as psychrometer and Lithium chloride ($LiCl$) dew point sensors. These are the classical techniques of measuring the humidity. There are many limitations to these devices including large size, slow response detection and low accuracy. Comparatively these miniaturized humidity sensors have many advantages such as small sizes, low power consumption, fast response and ease of manufacturing. [2]

Nowadays, day-to-day sensor manufacturing techniques have been enhanced driven by immediate post-process, lower power consumption and low-cost hybrid electronics, signal conditioning methods and advances in innovation scaling. Miniaturization of sensing element gadgets offers various benefits like low physical phenomenon, batch fabrication and simple packaging/integration alongside the corresponding price reductions. [1]

The main objective of this work was to design a humidity sensor using alumina (Al_2O_3) as a substrate and to detect moisture and air temperature in the environment using Zirconium Dioxide (ZrO_2).

II. ELECTRODE DESIGN AND PATTERN

MEMS system are very popular because of their benefits, such as minute size, low manufacturing cost and less power consumption. IDE (Inter Digitated Electrode) electrode using micro fabrication technology are designed and fabricated for the humidity sensor. IDE electrode has many benefits.[5]

It can build the contact area between the electrode and detecting material, which can improve the sensitivity of humidity sensor. It has simple structure, which can be reduces the fabrication cost and complexity. In this work, the electrode pattern was done using the AUTOCAD software. The design was made with a scale factor of 1:0.5 ratios in terms of millimeters (mm) and used for making the mask.

Substrate Size	19*19 mm
Connecting pad	3*3 mm
Gap width	0.5 mm
Finger width	0.5 mm
Gap between two connecting pads	11 mm
Interdigitated Electrode size	16 mm

Table 1-Measurement Parameters of Humidity Sensor

Previously the IDE material was gold and chromium at first. Gold was utilized in micro-fabrication and was bounded for electrical connection. In some cases, gold was sputtered during the reactive ion etching (RIE) step for etching zirconium dioxide, which was utilized as an active sensing material. As gold was expensive, manufacturing cost increases so, aluminum was used as the material of IDE. In this proposed work silver conductive epoxy was utilized to bond wire on Al pad. The IDE was coated on top of Al_2O_3 substrate by using thermal evaporation technique

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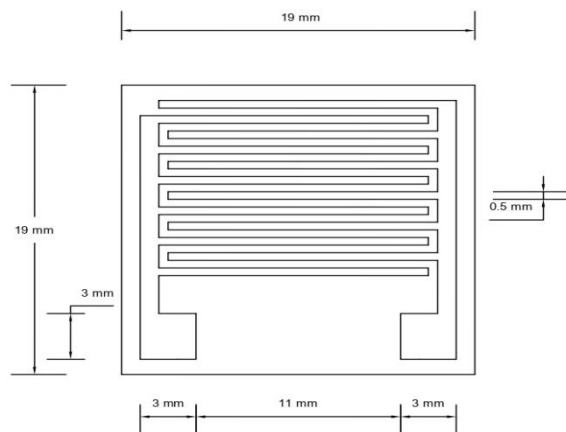


Fig 1. AUTOCAD Design of Sensor

III. RF SPUTTERING

RF sputtering is a basic PVD (Physical Vapor Deposition) technique which is used for deposition of metals and oxides over a substrate. In this work, this technique was used for deposition of active sensing material (Zirconium Dioxide) on top of the Al_2O_3 at 13.5 MHz frequency.

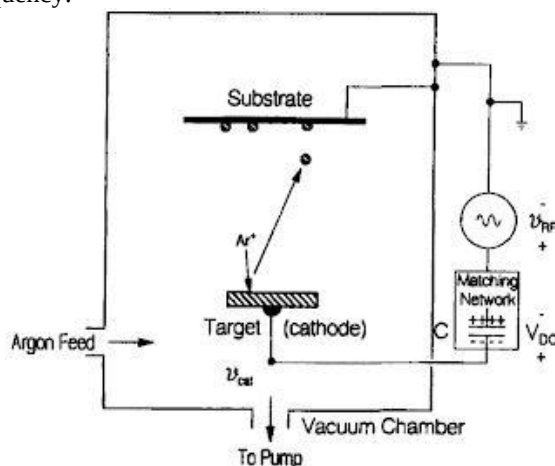


Fig 2. RF Sputtering

3.1 REASON FOR USING RF SPUTTERING

It significantly decreases the development of charge in particular area on the outside of the objective material that prompts the sparks that make the circular segment which causes various quality control issues. It also decreases the production of "Race track erosion" over the surface of the target material. There is no any disappearing result, once the substrate to be coated becomes insulated and acquires charge.

IV. STAINLESS STEEL MASK CUTTING

Stainless steel mask was used in thermal evaporation to obtain the sensor pattern on the Al_2O_3 substrate. The mask was placed over the alumina substrate. The set of samples with the mask was kept inside the evaporating chamber and required conditions are made to perform metal deposition.

Preprocessing of sheet metal wire cut:

- Selecting thinnest sheet metal possible, considering the cutting technology in mind.
- Sheet metal should be both thin and rugged to cut easily and use.
- 0.2 mm thick sheet metal was selected for the application.

To perform sheet metal cutting using the wire cut technology. Certain steps should be carried out to as a preparation for precious cutting.

- Sheet metal cut in 2cm X 2cm pieces.
- Sheets were stacked.
- Braising was performed to hold there at one place, preventing them from moving from its place.
- Power drill should be done to start the cutting area since the model was a closed one.

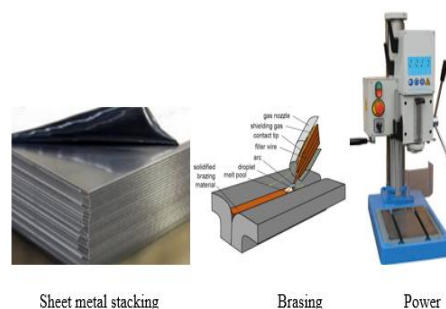


Fig.3 Pre-Process carried out before Wire Cutting Method

CAD diagram was made and converted into G-code graph as shown in Fig4 by the machine itself. The G-code is given as the input to the cutting machinery. Once the cutting starts the entire setup immerses itself into DI-water to progress with the cutting operation

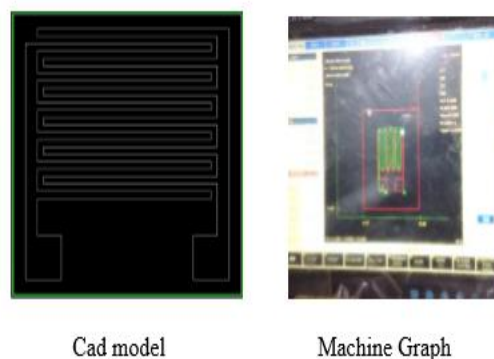


Fig.4 Methods involved in Operation

Cutting has been performed as per the pre-processes and trends to obtain thin mask suitable for thermal evaporation process. Fig.5 shows the obtained steel mask after the cutting has been over.

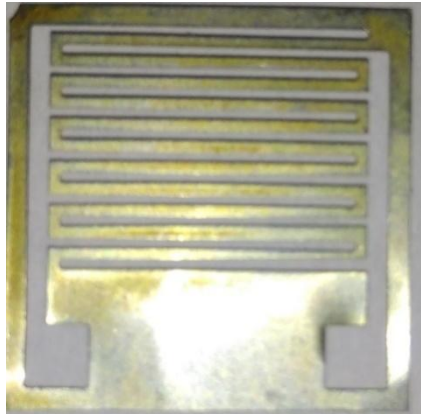


Fig.5 Stainless Steel Mask

The chance of good cut was restricted to the amount of precision in cutting and stacking of the sheet metals. Minor miss alignment in the surface or bend in the surface will lead to wrong cuts and the sample will not be useful. Hence only 5 out of 10 samples were seem to be proper from the cutting process.

V. THERMAL EVAPORATION

Thermal evaporation was basic thin film evaporation technique used to evaporate metals and oxide. It has unique operating procedure to follow with required conditions to perform metal deposition. The sample are placed inside the chamber, small amount of aluminum is weighted and kept in the heating element.

A high vacuum was created in the chamber with a process flow according to the operative manual. When the required conditions are set, primary and secondary current of the chamber element was varied that heats up the aluminum to a gas state, due to high vacuum the metal particle evaporates straight towards the destination samples. Once it was coated the primary voltage was minimized, the chamber was let to revert to initial condition, hence thermal evaporation was carried out.

5.1 CHAMBER PREPARATIONS

1. Thermal evaporation chamber was keenly examined for contaminants or any residual metals on the previous use.
2. The chamber was cleaned to prevent contamination.
3. The hardware peripherals of the chamber are also wiped with acetone. Emery sheet was used if required to scrap of old metals contaminants from the walls and peripherals.
4. The entire chamber was covered internally using silver foil to preserve the chamber clean for a prolonged time, this is done to prevent frequent cleaning of the entire chamber, and instead the foil is alone replaced.
5. The target material was cleaned weighted and kept in the heating element, with the sample on the sample holder.
6. Then the machine was started for metal evaporation.

5.2 THERMAL EVAPORATION CHAMBER

Thermal evaporation chamber is shown in Fig.6, with basic parts that are illustrated

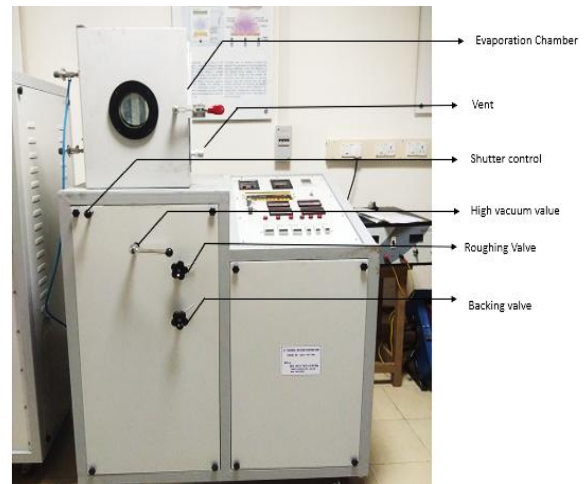


Fig.6 Thermal Evaporation Chamber

Evaporation Chamber:

Evaporation chamber was the environment which enables us to perform the metal evaporation, the chamber consists of heating boat element, sample holder, thickness monitor, vacuum valves and vent.

Vent:

Vent was the access point to release the pressure of chamber, once the metal evaporation is carried out.

Shutter control:

Shutter control was used to start and stop the amount of metal deposition on the substrate; this was opened and closed using a push-pull knob.

High vacuum valve:

High vacuum valve was used to make the pressure much lesser to 3×10^{-5} bar, making suitable conditions to perform the metal evaporation.

Roughing valve:

Roughing valve connects the vacuum access setup to the evaporating chamber in maintaining chamber vacuum.

Backing valve:

Backing valve creates vacuum inside the pump level. It serves as re-suitable conditions to operate the diffusion pump and high vacuum pump.

5.3 CONTROL PANEL

The thermal evaporation and the pumps are harnessed in a panel to have a control over all the operation in the chamber. The panel consist of valve controls, gauges, displays, primary and secondary current regulators as shown in Fig.7

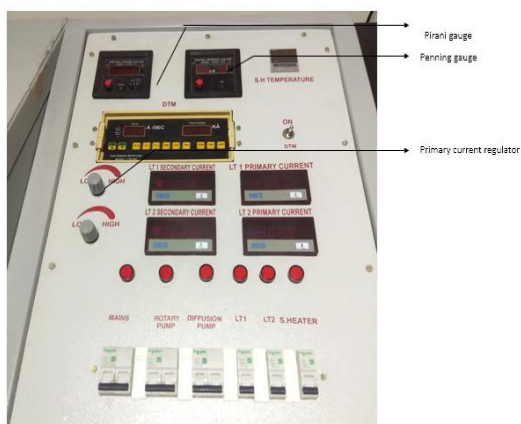


Fig.7 Control Panel

Pirani Gauge:

Pirani gauge was to monitor the pressure in roughing and backing valve.

Penning gauge:

Penning gauge was the high vacuum gauge that was used for setting minimal pressures in the chamber to monitor high vacuum conditions. It was used only after initial vacuum was created and before initial vacuum was released.

Thermal evaporation:

Thermal evaporation method operating procedure was carried out in this work. The mask was removed carefully without disturbing the structure and a gentle contact testing was made to find the resistance. The stable connection was established using silver conductive paste. The sensor was again encapsulated with a Al_2O_3 substrate in order to hold the contacts and prevent the sensor from getting damaged while testing.

VI. EXPERIMENTAL SETUP

The fabricated sensor was interfaced with LabVIEW Data Acquisition system. Trials were carried out to test the fabricated sensor, by heating in ionized water until it produces water vapor. The sensor was placed over the heated water and it was observed that there was change in resistance with respect to the humidity exposure.

For more reliable outcomes, a humidifier was purchased to create humidity artificially. This avoids temperature dependency in the previous trial of heating DI water. A chamber was made using 8mm acrylic sheet which was cut to the required dimensions using laser cutting method. The cut sheets were assembled using general purpose silicone sealant. With a door accessory to have access to inside the chamber. Acrylic sheet was chosen for feasibility as it is transparent; it is less reactive to temperature changes. It is also less reactive to chemical gases like, acetone gas, and ethanol gas etc.

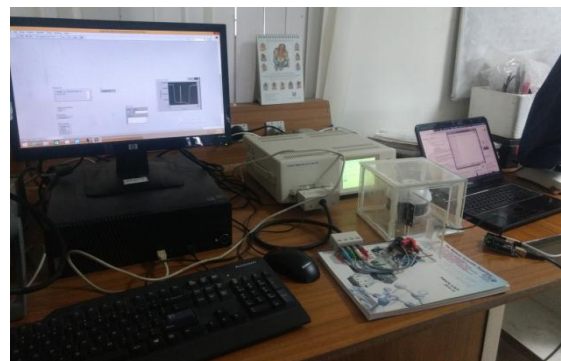


Fig.8 Experimental setup

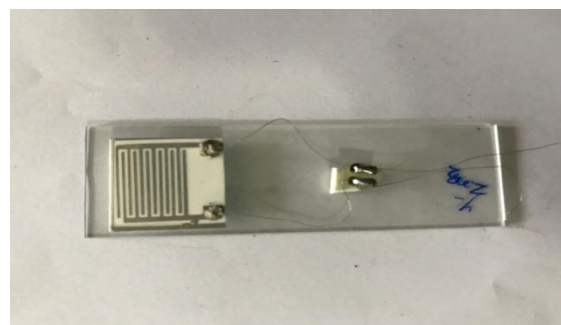
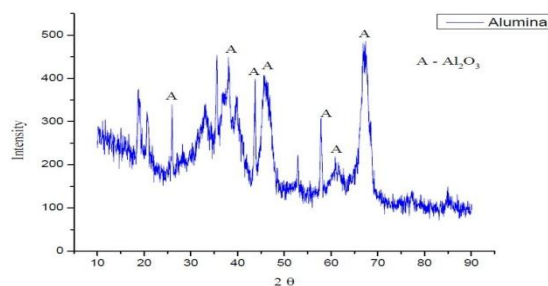


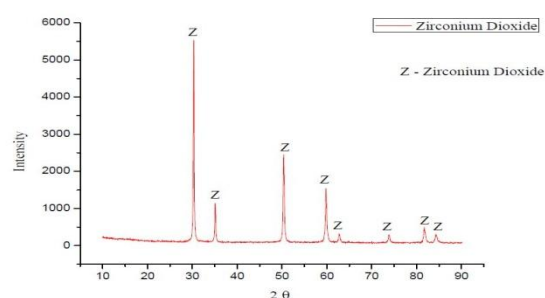
Fig.9 Fabricated sensor

VII. RESULTS

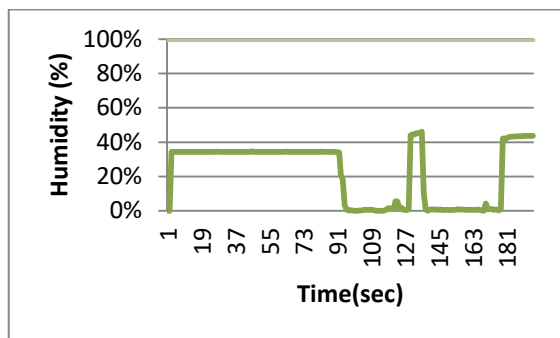
The fabricated sensor was interfaced with LabVIEW Data Acquisition system. As per the work sensor shows the wide range of resistance changes with respective humidity exposure at 100 KHz frequency. Comparatively, fabricated sensor has faster response than commercially available humidity sensor



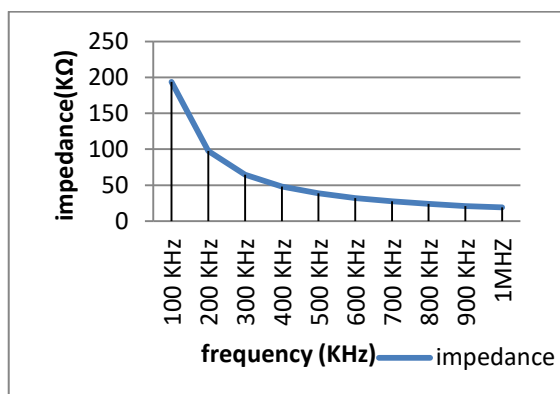
Graph 1 XRD Spectra of Alumina



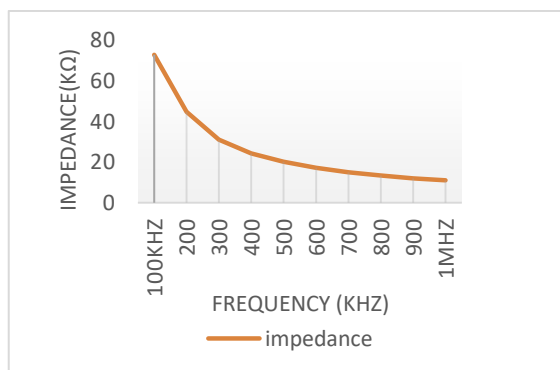
Graph 2 XRD Spectra of Zirconium Dioxide



Graph 3 Change in Humidity



Graph 4 Change in Resistance (Without Humidity)



Graph 5 Change in Resistance (With Humidity)

Graph 4 shows the graph of change in impedance over frequency 100 kHz to 1MHz without humidity and graph 5 shows the graph of change in impedance over frequency 100 kHz to 1MHz with humidity. Comparatively the impedance value at 100 kHz is 193.79 kΩ without considering the humidity and 72.90 kΩ with considering the humidity i.e. the change in impedance value with respect to humidity exposure shows that the fabricated humidity sensor detects the humidity.

VIII. CONCLUSION

This paper has discussed about the fabrication of humidity sensor based on Alumina and Zirconium Dioxide materials. The Operation of the humidity sensor was based on the change of impedance of the sensitive material as a function of change in humidity the surrounding environment. ZrO_2 was used as the sensing material in the work due to its linear behavior and stability throughout the operating temperature range. It has high sensitivity relative to changes in humidity.

The humidity sensor was realized by depositing the ZrO_2 at the top of the Interdigitated metallic electrode on the Al_2O_3 substrate. The Interdigitated pattern has advantages such as a simple structure and more contact area. The experimental results show that the developed humidity sensor has faster humidity detecting response than the commercially available sensors. Experimental results also showed stable data in a short time with low hysteresis when increases and decreases humidity.

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