Name of Research Scholar: Zubair Hassan Zargar

Name of supervisor: Prof. Tarikul Islam

Department: Electrical Engineering**,** Faculty of Engineering and Technology**,** Jamia Millia Islamia**,** New Delhi

DESIGN AND FABRICATION OF THIN FILM IMPEDANCE SENSORS USING THOMPSON-LAMPARD THEOREM

ABSTRACT

The accuracy and reliability of any impedance sensor depends on the stability of the electrode structure used to fabricate the sensor. Less the number of physical parameters of electrodes on which the output impedance of the sensor depends, the more will be its accuracy and stability. It is known that the output impedance (resistance, capacitance or both) of the widely used interdigitated and parallel plate type impedance sensors depends on many geometrical dimensions of the electrodes, and hence may reduce their accuracy with time.

The main focus of this thesis is on the fabrication of the impedance sensors (resistive and capacitive) for humidity measurement, and non-contact micro droplet detection using the cross-capacitor proposed by Thompson-Lampard (TL) theorem. The extension of the TL theorem can be used to develop cross-conductive humidity sensor. The capacitance of such type of electrode structure depends on the single length dimension of the electrode, thus may increase the accuracy of the measurement system by fair amount. A detailed investigation of the cross-capacitive structures proposed by TL theorem is done using finite element analysis software (Ansys Maxwell 3D).Various modified designs satisfying the TL criteria, like infinitesimal gaps and one line symmetry have been designed and modeled. For experimental validation, the cross-capacitors are fabricated with different geometrical parameters. The measured capacitance values are compared with the simulated and analytical values.

We first design and fabricate the cross-conductance type thin film humidity sensor for relative humidity (%RH) measurement. The electrode structure is the modified version of practical TL calculable capacitor. The sensor consists of four symmetrically placed gold electrodes having circular symmetry placed on the alumina substrate by screen printing technique. A nanostructure thin film of porous aluminium oxide (γ-Al_2O_3) is used as a humidity sensing layer. The solution of metal oxide is prepared using efficient sol-gel process by adopting the Yoldas method. The solution is coated in the space within the electrodes using dip coating technique. Porous Al_2O_3 is one of the most suitable ceramic sensing materials, which is suitable to measure humidity over wide range. It is due to its high surface to volume ratio and suitable nano porous structure. A simple interface electronic circuit is developed to determine the electrical characteristics such as humidity response (10 % RH to 90 % RH), transient response, hysteresis, and cross-sensitivity of the cross-conductive humidity sensor. The interface electronic circuit converts the cross-conductance change due to humidity into corresponding analog voltage signal. The sensitivity of the circuit output above 56 %RH is 95.03 mV/ % RH, and below 56 % RH is 4.65 mV/ % RH. The cross-conductance of the sensor increases from 2 µS to 27 µS due to adsorption of vapor molecules in the thin layer of porous γ-Al_2O_3. Time constant is also determined from the transient response curve and is found to be 55 s. It guarantees fast response of the sensor and may prove useful where fast variations in the values of humidity are taking place. The results also show that the hysteresis error of the humidity sensor is very low (± 0.35%). The performance comparison of the cross-

conductance sensor with the widely used interdigitated resistive and the capacitive humidity sensors is also discussed.

Further, a novel effort has been made to explore the usefulness of the cylindrical cross-capacitive structure with circular symmetry using TL theorem for precise and accurate measurement of relative humidity. For this purpose, the quartz tube of required dimensions is used as a substrate for sensor fabrication. The inner wall of the tube is coated with thin layer of γ-Al_2O_3, and the four identical silver electrodes are screen printed on the outer wall of the quartz tube. The cross-capacitive response of the fabricated sensor is then determined at different humidity levels in the range of 0 %RH-90 %RH using AD 7150 capacitance to digital conversion board interfaced with PC. For practical application of the proposed cross-capacitive humidity sensor, other important electrical characteristics like response and recovery time, repeatability of the output, hysteresis, and drift due to ageing are also determined. The sensitivity of the sensor for 50-90 %RH range is 4.58 fF/%RH, and below 50 %RH is 0.64 fF/ %RH. The response and recovery time of the fabricated sensor are 104 s and 160 s respectively. The sensor response is highly repeatable (± 0.01%), has very little hysteresis error (± 0.3%), and negligible drift due to ageing. The effect of porous sensing layer of γ-Al_2O_3 on the sensitivity of the sensor is also investigated. For this purpose, two identical cross-capacitive sensors one with sensing layer and other without sensing layer are designed and fabricated. The sensor without sensing film shows a small capacitance change with the variation of humidity. The sensitivity of the humidity sensor increases manifolds due to presence of hydrophilic layer of alumina on the inner surface of the quartz tube.

Another capacitive sensor for non-contact detection of micro droplets is fabricated and tested successfully using simple, highly accurate, and stable cross-capacitive structure. Such a novel application of this theorem has not been explored so far to the best of our knowledge. The sensor consists of four identical copper electrodes with very small adjacent gaps made out from double sided copper cladded polyimide substrate by chemical etching process. There is a hollow Teflon shell through which water droplets fall, and the electrodes are placed on the outer periphery of the shell. This arrangement avoided contamination of the copper electrodes by different liquid samples as the sensor electrodes are not exposed directly to the dispensing liquid droplets. Also, the free-flying droplets can be used for any purpose after the sensing event. In addition, the solid thick Teflon shell provided mechanical strength as well as proper symmetry to the structure. The cross-capacitive response of the sensor for different micro droplets is obtained by capacitance to digital converter AD 7150 board. The sensor is tested for water droplets of different volumes ranging from 3 µL to 9.3 µL and also droplets of liquids having different dielectric constant and conductivities. To investigate the sensor for real time application, the repeatability and drift due ageing of the sensor output are also determined. The maximum sensitivity of the cross-capacitive sensor is found to be 0.59 fF/µL. The sensor output is highly repeatable with the best repeatability of ± 0.13% and has negligible drift due to ageing. It is seen that the proposed sensor can be used for the non-contact precise and accurate measurement of volume of micro droplets as well as their dielectric constants. Low cost, ease of fabrication, no shorting problem, mass production, high repeatability, negligible drift, and superior response characteristics are some of the important features of the fabricated sensor.