Research Fellow: Md Rahat Mahboob
Supervisor: Dr. Tarikul Islam
Department: Electrical Engineering
Topic: Development of Integrated Sensor for Wireless Humidity Detection

Keywords: Capacitive sensor,Al_2O_3, moisture measurement, passive wireless tag, ppm, polyimide, PEG.

Moisture measurement in ppm level is always challenging and costly. Among different technologies available for moisture measurement, the thin film capacitive sensor-based dew point meter offers a low-cost solution. Still, the cost of the dew point meter is high and it suffers from high response time. There is a need of wireless moisture measurement in ppm level that is not available with the commercial meter according to our knowledge.
The main focus of this thesis is on the development of a low cost wireless measurement system for the measurement of humidity inside a sealed chamber. For this,we first fabricate the capacitive type thin film humidity sensor coupled with inductor named as integrated sensor (LC Sensor). The sensor has been fabricated by using nanostructure porous aluminium oxide (Al2O3) thin film by sol-gel method by adopting Yoldas method. Porous Al2O3 is one of the most suitable ceramic sensing materials that have potential to measure humidity over wide range. Its small pore radius makes it very sensitive and attractive to low humidity. Two different types of LC sensors have been fabricated for above and below 100 ppm. The use of inductor adds the wireless feature to the sensors. The sensors are then characterized to determine their important electrical characteristics such as resonant frequency shift, response time, recovery time, repeatability and hysteresis. The electrical characteristics of the sensors have been measured using Agilent 4294A impedance analyzer. Based on the experimental response behavior, the frequency sensitivity of the first LC sensor in the moisture range of 100 to 5000 ppm is nearly 119 Hz/ppm with the 7 s response time and 24 s recovery time. Sensitivity of 712.9 ppm/Hz is achieved in the moisture range of 8 to 100 ppm with the help of second LC sensor. Then in order to reduce the cost, shorting problem and also to increase the sensitivity of the sensor further second set of sensor fabrication is carried out. A metal-oxide-based sensor on polyimide substrate for measuring moisture in ppm level has been developed. The sensor consists of a parallel plate capacitive structure having γ-Al2O3 nano-structured sensing film deposited on the polyimide by sol–gel method. The pore morphology of the thin film has been studied by Brunauer–Emmett–Teller (BET), Atomic Force Microscopy (AFM), and Field Emission Scanning Electron Microscopy (FESEM). The sensor has been designed to make it suitable for integrated type of application. The sensitivity of the sensor for 3.5-800 ppm humidity range is 0.13 pF/ppm. The response and recovery time are 158 and 216 s, respectively. The purpose is to develop a low power consumption sensor on a fully flexible and plastic substrate commercially used in printed circuit board.
The sensitivity of the capacitive sensor can be further increased by altering the pore morphology of the sensing layer. It has been observed that the addition of suitable amount of PEG (polyethylene glycol) in sol-gel solution improves the electrical characteristics of the sensor significantly in the range of 10–210 ppm moisture. Response characteristics of the sensors are highly linear (R2=0.995) and the sensitivity is almost twice in comparison to a sensor fabricated without PEG addition.
The humidity is normally affected by the ambience temperature. So, a detail investigation on the performance characteristic of the fabricated capacitive humidity sensor under different temperature was also carried out. A special experimental setup has been developed which facilitates the heating of the sensor only without heating the surrounding of the sensor. The study was carried out in high and very low moisture level.

At high level moisture the interdigitated type sensor was used. Then the sensor was exposed to different temperature and different humidity condition. The study was performed to understand the effectiveness of our fabricated sensor to work widely at different humidity and temperature range. The experimental results show some interesting phenomenon, which may become quite an important tool for enhancing the sensitivity of the sensor, particularly in trace level.

Two different interface electronic circuits have been developed for interfacing the developed parallel plate capacitive sensor. The first interface electronics is based on traditional Colpitt oscillator and gives a highly precise and stable reading on acquiring and processing raw signal data from the capacitive sensors. The stand alone readout system accurately measures the sensor capacitance in real-time and converts to frequency. The performance of the system was first calculated mathematically and was tested with discrete capacitors. The theoretical findings are compared with the experimental results obtained with the developed system. It was found the system can accurately measure all types of capacitive sensors within the range of 191.6 pF to 1368 pF with a maximum error of ±2.54%. The capacitance to frequency conversion sensitivity of the circuit for discrete capacitance was found as 65 Hz/pF at oscillator frequency of 100 kHz. The whole system is capable of measuring humidity with an accuracy of ±1 ppm moisture. Finally, desktop type digital hygrometer was developed.

The second interface electronic is a modified version of traditional Colpitt oscillator. It was used for the development of passive wireless humidity measurement system. A low cost passive wireless tag for capacitive type sensors has been successfully developed. The tag can be energized by any 13.56-MHz commercial tag reader from a distance of 1 cm (approx). The tag is capable of transmitting sensor data at 2.4-GHz ISM band up to a distance of 12 m. An efficient algorithm has been developed to reduce the power consumption of the tag. The prototype system has been tested with two fabricated capacitive sensors to measure humidity over a wide range. Finally, a low-cost (approximately U.S. $250) digital hygrometer to measure trace moisture has been developed. The performances of the digital hygrometer have been compared with the commercial dew point meter, and accuracy is found to be nearly ±1% in the range of 6.5–127-ppm moisture. The system can be employed for contactless measurement with any capacitive sensor in the range of 50–3200 pF.

Present thesis work is aimed, to design and develop a highly sensitive non-contact type measurement system. Design and analysis of interface electronics for very low trace moisture level (ppb level) may be the further extension of the presented work. The future extension of the work is to completely transfer the whole sensor tag on polyimide substrate. The sensor as well as the circuit can be integrated on same polyimide substrate. Moreover, there is possibility of making the sensor tag completely IC free that is chip-less humidity sensor tag on polyimide substrate. Still, we need to energize the sensor tag from a maximum distance of 5 cm, future work is based on the extension of this detection distance as well as on the orientation of the energizing tag. Therefore, the sensor tag can be energized from a large distance like the measurement of humidity inside a well or some deep hole. For energizing sensor tag, a high frequency input has been used initially, which introduces some frequency error in the obtained data. Detailed analysis of the frequency effect on the sensor responses and developing a signal conditioning unit can be future scope of research.

The developed sensor tag and it efficacy was not established on a real time application. The application of the developed wireless system on measuring other parameters with the capacitive sensor may be the future extension of the work. Wireless moisture measurement method proposed can be used for structural health monitoring.