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Development of Polycrystalline Ferrite Based Smart Sensor module using Mixed Signal Programmable System on Chip

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Abstract

Development of smart sensor module based advanced technology with high performance, large adoptability, portability, to sense the physical parameters is highly needed for electronic instrumentation. Therefore, based on an innovative technology of VLSI design a smart temperature and humidity sensor module is designed and presented in this paper. The composition of nano sized (35nm) Magnesium -Zink ferrites are synthesised by co-precipitation and formation of single-phase compositions are confirmed by x-powder diffraction. The sensor is designed by screen printing technique and implemented for sensor module development. The electrical resistance (R) measured against temperature and variable humidity in RH percentage shows decrease resistance with increase in the temperature and humidity. This nature of the sensor is considered for designing of sensor module. A programmable System on-chip, Cypress PSoC BLE, emphasizing analog reconfigurability and hence ensures mixed signal design is employed as an embedded device. The sensor under investigation is interfaced to the cypress PSoC BLE. Rest of analog part comprising, signal condition, DAS, ADC etc are designed by availing on chip resources Microcontroller CY8CKIT is working at backend. PSoC designer and PSoC creators are the designing tools. Firmware is designed by using embedded C platform. A smart sensor module designed is calibrated. Actually, the sensor is negative coefficient semiconductor, exhibiting exponential behaviour. However, by incorporating a specific module in firmware the response is linearized. The present sensor module is showing temperature reading in ^{0}C and humidity in RH% with great accuracy. It also provides the output in DC voltage varying linearly up to 256 mV for temperature and humidity. This helps to enhance the portability of the present sensor module.

Keyword: Smart Sensor Module, Mixed signal SoC, polycrystalline ferrite, Cypress PSoC, CY8CKIT BLE, humidity.

Introduction

Development of smart sensor module for precise measurement and control of environmental parameters is need of hour for various applications [1, 2]. Applications such as, agricultural, food processing, paper industry, medical stores etc. During Early days, the designers use discrete analog components and controlling unit for development of embedded system. However, the programmable system on chip (PSoC) based mixed signal design consists of reconfigurable analog resources available on chip, which realize mixed signal VLSI technology based smart design. Recent PSoC system provides on chip Bluetooth and Wi-Fi facility. Therefore, use of such advanced technology system becomes smarter, compact and reliable for IoT application. The polycrystalline ferrites-based system already designed based on AVR and PIC microcontroller [3-5].

However, this controller required external signal conditioning circuit, Bluetooth or Wi-Fi devices for communication. Therefore, the size, cost and power consumption increase in this embedded system. To overcome this problem, it is proposed to develop a system based on Cypress Programmable System on Chip BLE model. For smart sensor module sensor plays significant role of for measurement humidity, temperature, concentration of gases, detection of toxic gases, smoke, fire, industrial emissions etc. [6, 7] On survey, it is found that ferrite materials are highly suitable for sensor-based applications, due to its semiconducting behaviour.

Therefore, these materials are now widely used in the development of smart sensors. Therefore, in the present research work the humidity and temperature sensing materials of promising features is synthesize using $Mg_xZn_{1-x}Fe_2O_4$ and deploy for smart sensor module design. Therefore, based on polycrystalline nano ferrite materials, synthesized in the laboratory, the humidity and temperature sensors are fabricated and interface to PSoC BLE kit for smart senor module application.

Methodology

The compositions of $Mg_xZn_{1-x}Fe_2O_4$ (x=0.2, 0.4, 0.6, 0.8) polycrystalline ferrites were prepared by co-precipitation method, at sintering temperature of 1000^{0}C and characterized by using X-ray powder diffraction is employed for confirmation of formation of spinel ferrites and composition (x = 0.4) is shown in the figure 2. The diffractograms have well defined reflections without any ambiguity, with (311) as a prominent reflection, which is a prime characteristic of the spinel structure [8]. This peak suggests the formation of cubic spinel structure, with Fd3m space group symmetry [9].

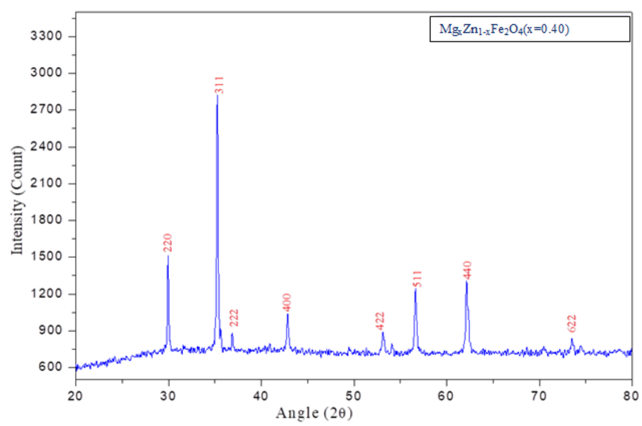

Figure 1: Typical X- ray Diffractogram for the composition (x=0.40)

To keep pace with objectives of smart sensor module, electrical properties and designing of smart sensor module based on PSoC, the compositions of the ferrite material under investigation are shaped as per the requirement of sensor node using screen painting technology. On literature survey, it is found that, polycrystalline spinel ferrite material mostly suitable for sensor-based applications due to its semiconducting behavior and micro structure properties. Due to humidity electrical conduction mechanism of ferrite material, it is mostly suitable for humidity sensor application. The relative humidity dependent electrical conduction mechanism of magnesium substituted zinc ferrite is described by Patil *et al.* [10]. It is also found that, temperature sensitive electric properties proved that, ferrite material exhibiting semiconducting nature, are suitable for development of temperature sensor. Therefore, as per the requirement of sensor module, sensor under investigation has prepared on rectangular ceramic substrate for humidity and temperature depicted in figure 2.

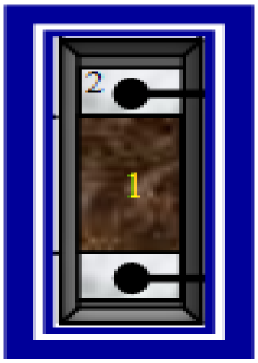

Figure 2: The schematic of the sensor fabricated by using ferrite material under investigation

The prepared sensor employed for investigation of temperature and humidity dependent electrical properties. Experimental arrangement for measurement of humidity and temperature dependent characteristics of the prepared sensor is shown in figure 3. The electrical resistances of the prepared sensor were measured with variable relative humidity in the range from 30 RH% to 95RH% and temperature range from room temperature to 150 ^{0}C. The highly precise Tektronix Make model DMM4050 digital meter is employed for resistance measurement of prepared sensor, whereas highly calibrated humidity chamber is used to provide controlled humidity environment. The experimental arrangement is shown in figure 3.

Figure 3: Experimental arrangement for humidity dependent resistance measurement.

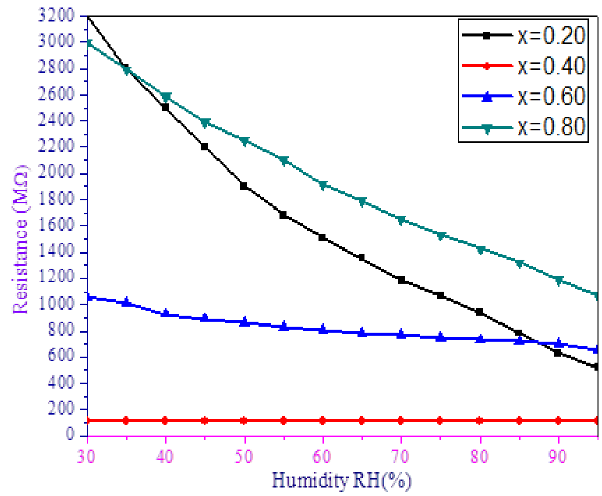

Figure 4: Graph of Resistance (R_H) against applied relative humidity (RH%)

The humidity dependent resistance measure and depicts in figure 4. On inspection of the graph, it is found that, increasing humidity resistance of the sensor decrease. The resistance of the composition x=0.40 is linear with 120MΩ maximum resistance. Moreover, remaining three composition shows higher resistance in GΩ rang. Therefore, for designing smart sensor module the resistance of the sensor module is considering. Temperature dependent resistance also measure from room temperature to 150 ^{0}C and shown in figure 5.

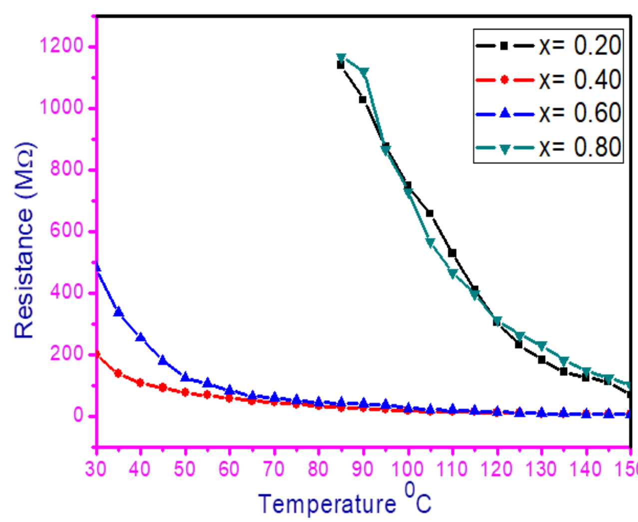

Figure 5: Graph of Resistance (R_H) against applied temperature (^{0}C)

Result and Discussion

The main objective is to design a smart sensor module, wherein entire hardware is designed on a single chip. Therefore, it is proposed to design system using Cypress Programmable System on Chip BLE model. Analog part, signal conditioning stage is configured on chip PGA. The on-chip sigma-delta ADC is configured for digitization. The development tools PSoC designer and PSoC creator are used to co-develop the system on chip. The schematic of hardware designed by using Cypress PSoC BLE is shown in figure 6.

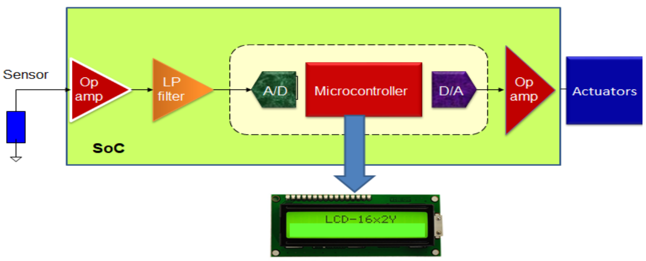

Figure 6: Schematic of the hardware design

Sensor, actuators and display unit connected externally and remaining circuitry design on chip. The Programmable Gain Amplifier using opamp, 10-bit delta sigma ADC is used for converting analog signal to digital. Both the sensor is resistive type. Therefore, it is wired in resistive divider configuration and resulting emf is read through configuring PGA and 10 bit sigma delta ADC. The firmware is developed using PSoC Creator 4.0 to reconfigure software and firm IPs.

The sensor is excited with +5V derived from on-chip resources and resulting emf is measured within humidity from 30RH% to 90RH%. The graph of observed emf (V_{obs}) in mV against relative humidity (H) in RH% is plotted and presented in figure 7, typically for x=0.4. On inspection of figure 7, it is found that the emf (V_{obs}) increases linearly with increase in humidity (H) in RH% within two regions. On employing process of regression the expression (Eq.1 and 2) is obtained.

Observed emf (V_{obs}) = 29.75 x H + 442.5 -------- (1)

Observed emf (V_{obs}) = 5.873 x H + 1894.65 --------- (2)

This expression is employed in the embedded firmware for further processing for representing voltage into relative humidity. This nature of the graph can be attributed to the conduction mechanism. In addition to the hopping mechanism, the ferrite exhibits photonic conduction mechanism [10].

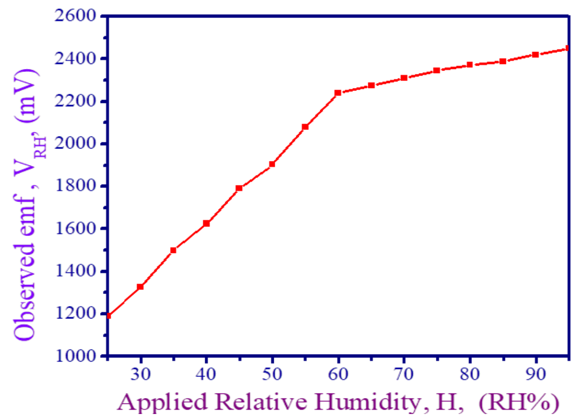

Figure 7: Graph observed emf against Humidity in RH% for the composition x=0.40

Similarly, temperature dependent emf(V_T) measured from 30 ^{0}C to 120 ^{0}C and shown in figure 8. The graph is increase linearly in two regions. Therefore, equation 3 and 4 obtain from 30 to 65 ^{0}C and 65 to 120 ^{0}C. The firmware updated further putting equation to represent humidity in RH% and temperature in ^{0}C.

Temperature (t) ^{0}C = ((V_T-136.0)/9.335) --- (3)

Temperature (t) ^{0}C = ((V_T+532.7)/20.83) --- (4)

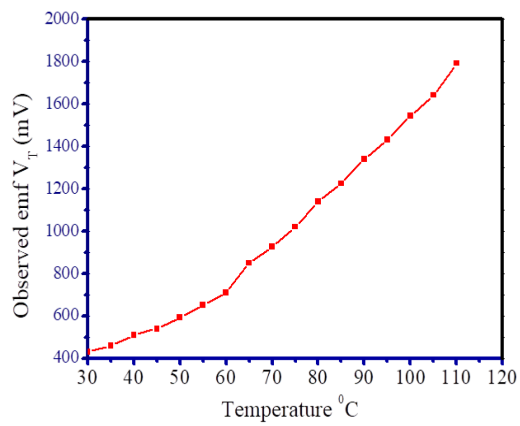

Figure 8: The Graph of Observed emf (V_T) in mV against applied Temperature in ^{0}C

Conclusions

From the result, it can be concluded that, the polycrystalline Magnesium -Zink ferrites are highly suitable material for development of the sensor. The humidity and temperature sensor module exhibits linear response over wide range from 30 RH % to 95RH % and 25 ^{0}C to 120^{0}C. The use of cypress PSoC BLE to design sensor module realizes the accuracy, reliability and portability of the design. Further system extended to Bluetooth configuration and IoT application.

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