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A surface acoustic wave impedance loaded sensor for wireless humidity measurement

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The humidity monitor is required in various areas such as the smart living space, industry, agriculture, and medicine. To reduce cost and increase lifetime, a wireless humidity sensor without an additional power supply should be developed to fulfill their needs. Recently, there are more and more efforts on the surface acoustic wave (SAW) impedance loaded sensor. The hybrid sensor primarily consists of a SAW tag and an external sensor. Due to the capabilities of passive operation and wireless connection, the SAW impedance loaded sensor is suitable for remote humidity sensing. Therefore, in this study, a wireless humidity sensor is accomplished by integrating a 433MHz 128°YX $LiNbO_3$ SAW impedance loaded sensor with a resistive humidity sensor. Because nanostructured sensing materials possess high surface-to-volume ratio, large penetration depth, and fast charge diffusion rate, camphor sulfonic acid doped polyaniline nanofibers are synthesized by the interfacial polymerization method and further deposited on the resistive humidity sensor as hygroscopic film to enhance sensitivity. Finally, the sensor was constructed and measured. Results indicate that our proposed sensor exhibits short response time, satisfactory sensitivity as well as excellent linearity and repeatability.

1 Introduction

The humidity monitor is very crucial in various areas such as the smart living space, industry, agriculture, and medicine. In the past, wireless sensors have been employed widely to fulfill this need because of their convenience. However, most of wireless sensor systems consist of active RF modules and must be powered by battery. This not only limits lifetime but also increases cost and size. On the contrary, passive wireless sensors are definitely maintenance free and their lifetime is independent of battery. Therefore, the passive wireless sensor is more suitable to be employed for humidity monitor.

Surface acoustic wave (SAW) devices have played a critical role in consumer and communication systems because of their small sizes and high performance. In recent years, there are more and more efforts on the SAW device applications in passive wireless sensing system [1-5]. This system primarily consists of a reader and transponders with SAW tags and antennas. By connecting an external sensor to the tag, the sensing information can be accessed wirelessly without an additional power supply. This configuration is called the SAW impedance loaded sensor and is a promising candidate to achieve the requirement of passive wireless sensing. At present, the studies on the SAW impedance loaded sensor for humidity sensing are limited. In 2001, Reindle et al. [4] utilized the sensor for remote measurement of water content in sandy soil. In this study, the bus bars of one reflector in a SAW tag were connected with two measuring rods inserted into sandy soil. However, the research on the SAW impedance loaded sensor for sensing humidity in the air is still waiting.

The resistive humidity sensor has been widely developed over the last decade. Ordinarily, a hygroscopic film must be deposited on the resistive sensor for the purpose of humidity sensing. Recently, much interest in investigating the sensing characteristics of various hygroscopic films, such as polymers [6-12] and nanostructured materials [12-17], has been aroused. The nanostructured hygroscopic films have received much attention due to their high surface-to-volume ratio, large penetration depth, and fast charge diffusion rate. This make the resistive humidity sensor with the nanostructured hygroscopic film not only possess high sensitivity but also accelerate response and recovery time.

This paper proposes a novel passive sensor for remote measurement of humidity in the air. The passive sensor was accomplished by connecting a SAW tag with a resistive humidity sensor with nanostructured hygroscopic film. The SAW impedance loaded sensor was based on 128°YX $LiNbO_3$ substrate and fabricated by micro-electro-mechanical system (MEMS) process. Moreover, camphor sulfonic acid doped (CSA-doped) polyaniline (PANI) nanofibers were chosen as the hygroscopic film of our resistive humidity sensors. The nanofibers were synthesized by the interfacial polymerization method and further deposited on the resistive humidity sensor. Finally, the SAW impedance loaded humidity sensor was constructed and measured.

2 Experimental setup

2.1 Fabrication of the SAW tag

As shown in Fig.1, our SAW tag includes three pairs of interdigital transducers (IDTs); one is for signal input and output, the others are for reflections. One of the two reflectors is terminated with a resistive humidity sensor and the other is used as reference.

The design parameters of our tags are listed in Table 1. The interdigital transducers were patterned after the 128°YX $LiNbO_3$ substrate deposited by aluminum film. Following the MEMS fabrication processes including traditional exposure and development, the SAW tags were carried out.

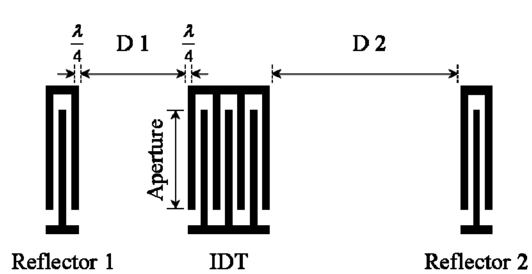

Fig.1 Schematic diagram of the SAW tag.

2.2 Fabrication of the resistive humidity sensor

The schematic diagram of our resistive humidity sensor is shown in Fig. 2. The sensor consists of a glass substrate and one pair of interdigital transducer. The 7740 glass wafer possesses excellent insulation and was chosen as the substrate of the sensor. The electrode material is gold. The widths and gaps of electrode stripes were designed to be 50 μm and 10 μm. The resistive humidity sensors were patterned by MEMS technology. The fabrication flow is similar to that of SAW tags mentioned above. The size of the resistive humidity sensor is about 10mm×10mm×2mm.

Substrate	128 YX $LiNbO_3$
Central frequency	440 MHz
Wavelength λ	8.8 μm
Aperture	50 λ
D1	670 λ
D2	840 λ
Pairs of IDT	20
Pairs of reflectors	20

Table 1 Design parameters of SAW tags

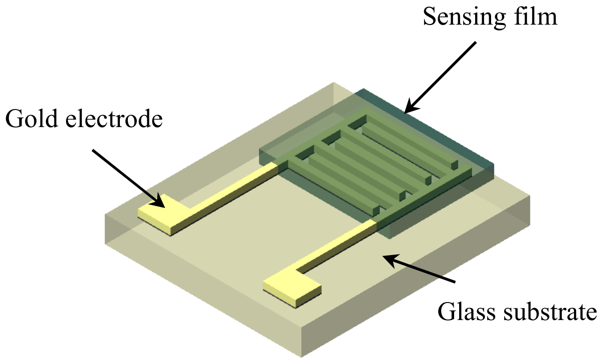

Fig. 2. Schematic diagram of the resistive humidity sensor.

2.3 Synthesis of the hygroscopic film

CSA-doped PANI nanofibers were synthesized by the interfacial polymerization method and further deposited on the resistive humidity sensor as hygroscopic film to enhance sensitivity. The synthesis steps are stated as follows: First, 1M of proton acid in 10 ml dissolved 1 mmole of ammonium peroxydisulfate. 4 mmole aniline monomer was added to 10 mL hexane organic phase. Next, the two aqueous solutions were mixed uniformly in a 20 ml glass vial and an interfacial polymerization was occurred. The reaction was completed after placing the mixed solution overnight. The extra acid and byproducts in the mixed solution were removed by purifying the solution with deionized water, an air-extracting equipment and 0.2 μm filter papers. After drying it in atmosphere, the dark green granular PANI nanofibers were acquired and then dissolved by little deionized water. Finally, a micropipette with 5-50 μl capacity was adopted to spread 40 μl solution onto the sensing area of the resistive humidity sensor. The sensor was placed in a vacuum chamber overnight to dry.

2.4 Gas flow system

The gas flow system consists of an acrylic chamber, two flowmeters and a commercial humidity sensor, KIMO TH100, which has an accuracy of ±3% with respect to relative humidity (RH) range of 0~100%. The completed SAW impedance loaded sensor, as shown in Fig. 3, was mounted in the chamber with a volume of $120cm^3$, which was drilled for the sake of wire link, gas entrances and power supply. To prevent gas leakage, all gaps were filled with silicone. Nitrogen was used as carrier and reference gases to adjust the RH inside the chamber. The flow paths were split by a 3-way joint. One path was leaded to the bubbler and brought water vapor into the chamber through a 10-100mL/min flow rate flowmeter. The other was connected to a 50-500mL/min flow rate flowmeter for purging the chamber. The humidity inside the chamber was also measured via the commercial humidity sensor for reference.

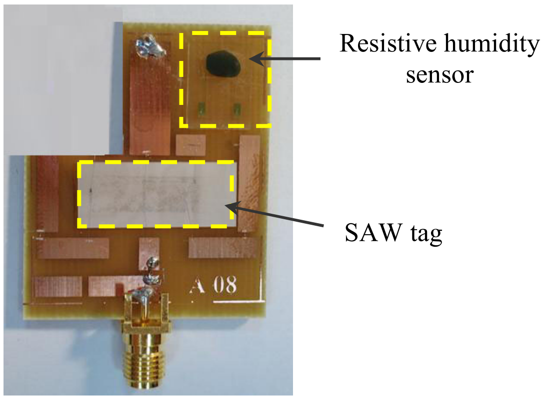

Fig. 3. Configuration of the SAW impedance loaded humidity sensor.

3 Measurement results

The completed SAW impedance loaded humidity sensor was tested at room temperature to evaluate its repeatability and sensitivity. Its frequency response was measured using network analyzer (Agilent 8714ES RF Network Analyzer). The time-domain response was obtained by utilizing IFFT. The time-domain response contains two reflection peaks; the first one carried the humidity sensing information, the second one was reference for eliminating noise. The humidity sensing information was expressed with the

3.1 Repeatability

Prior to the experiment, pure nitrogen was used to purge the chamber and attain a steady state. Subsequently, nitrogen or mixed water vapor flowed into the chamber to alter the RH inside the chamber. Testing cycles were performed with constant exposure time and purge time to reach a new steady state of the sensors signals or re-establish the baseline signal. As shown in Fig. 4, the repeatability response of the SAW sensor towards on-off cycles of 51% to 83 % RH. The variation of return loss is about 1.5 dB. The results show that the sensor possesses an excellent repeatability and short response time.

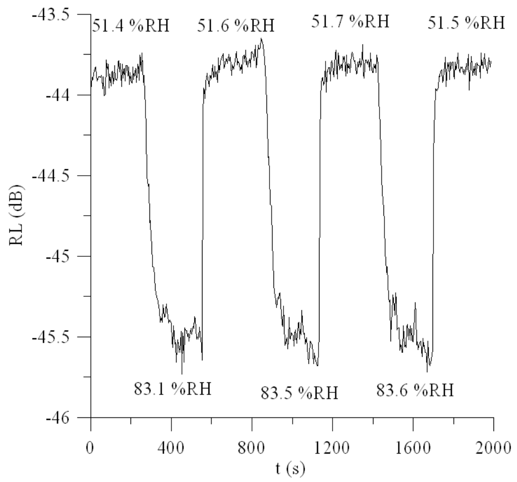

Fig. 4. Repeatability of the SAW impedance loaded humidity sensor.

3.2 Sensitivity

In order to evaluate the sensitivity of the sensor response to RH, several experiments of on-off cycles for different RH values were done. The sensor was first connected to network analyzer. The sensing information was real-time recorded. For the purpose of eliminating noise, return loss at specific RH is determined by averaging all return loss data in the period under test. Fig. 5 is the sensitivity of the SAW impedance loaded humidity sensor. Two linear regions were observed from 10% to 50% RH and from 50% to 80% RH. The sensitivity of the first linear region is about 107.1ppm / % RH, and the second linear region is about 582.4 ppm / % RH. The results show that the sensor possesses satisfactory sensitivity and an excellent linearity.

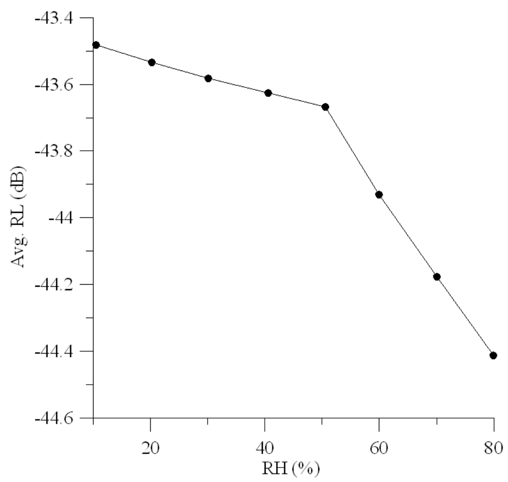

Fig. 5. Sensitivity of the SAW impedance loaded humidity sensor.

4 Conclusion

In this paper, the SAW impedance loaded sensor is developed for sensing humidity in the air for the first time. The sensor is successfully realized by integrating a SAW tag with a resistive humidity sensor with nanostructured sensing film. CSA-doped PANI nanofibers are chosen as the hygroscopic film due to their excellent characteristics such as fast electron mobility and high surface-to-volume ratio. Results show that the proposed humidity sensor provides short response time, satisfactory sensitivity as well as excellent linearity and repeatability.

Acknowledgments

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