Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 120 (2015) 364 – 367
Procedia Engineering
www.elsevier.com/locate/procedia

EUROSENSORS 2015

Flexible surface acoustic wave humidity sensor with on chip temperature compensation

WeiPeng Xuan[a], JinKai Chen[a], XingLi He[a], WenBo Wang[a], Shurong Dong[a] and Jikui Luo[a,b]*

a. Department of Information Science & Electronic Engineering, Zhejiang University and Cyrus Tang Center for Sensor Materials and Applications, 38 Zheda Road, Hangzhou 310027, China.
b. Institute of Renewable Energy and Environment Technology, Bolton University, Deane Road, Bolton BL3 5AB, United Kingdom
[b]Second affiliation, Address, City and Postcode, Country

Abstract

This paper reports the development of flexible surface acoustic wave (SAW) based humidity sensors on polyimide substrate. The SAW devices have two resonant peaks, named the A0 and S0 Lamb modes, which have different temperature coefficients of frequency. Graphene oxide (GO) is used as the sensing layer owing to its large surface area and hydrophilcity to water. The sensors show high sensitivity up to 145.83 ppm/%RH, comparable to those on rigid substrates, and fast response time of 4.4s. The sensitivity increases with the increase of GO thickness and resonant frequency. By utilizing the S0 mode as the temperature reference, a SAW Humidity-sensor with an on chip temperature compensation capability is demonstrated. The humidity sensors also show the ability to work under severe bending condition, demonstrated its great potential for flexible/wearable applications.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: hudimity sensor, temperature compensation, flexible electronics

1. Introduction

Humidity measurement, monitoring and control are extremely important for meteorology, historical relic's protection, laboratory environment maintain and industry production *etc*. With the rapid progress of flexible

* Corresponding author.+(86)571-87952867
E-mail address: jackluo@zju.edu.cn

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.639

electronics and internet of thing, the demands for various sensors including the humidity and temperature sensors increase steadily. Surface acoustic wave devices (SAW) are a type of basic devices for modern electronics and communication as frequency filters, duplexers, resonators, sensors, and in microfluidics and lab-on-chips due to their high performance, small size and low cost *etc* [1]. Furthermore, thin film based SAW sensors can be integrated with other devices on the same substrate. recently, we have developed flexible SAW technology, and showed they are able to work under severe bending conditions[2]. This paper reports the development of flexible SAW based high sensitivity humidity sensors with temperature compensation capability. Graphene oxide (GO) is a two dimension material which is highly sensitive to humidity variation [3]. GO is used as the sensing layer for the SAW humidity sensors (H-sensor) to enhance the performance of the devices in this work.

2. Experimental

The sensors were fabricated on polyimide (PI) substrates, with a sputtering deposited ZnO thin film (~4 um) as the piezoelectric layer. Figure 1(a) are the optical images of the fabricated SAW devices on a PI substrate and the interdigitated transducer. The devices possess excellent flexibility and have two resonant peaks with large amplitudes. Detailed theoretical analysis revealed that the two resonant peaks are the A0 and S0 Lamb wave modes. For humidity sensing, graphene oxide (GO) layer was used as the sensing layer owing to its large surface area and high sensitivity to humidity [2]. A GO sensing layer was deposited on the surface of the devices with the thickness of 400 nm by dispensing GO-water drops on the surface and dried in air at room temperature. The transmission parameter (S21) of the SAW devices was used to assess the response of the sensors to humidity change. The measurements were controlled by a LabView software in real time.

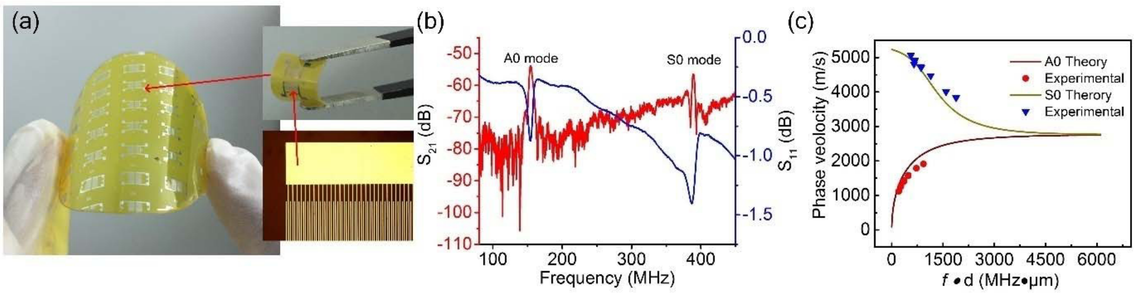

Figure 1. (a) Optical images of the flexible SAW devices fabricated on PI, (b) the transmission spectra of the device with a wavelength of 12 μm, (c) dependence of the phase velocities of the two modes as a function of normalized thickness of the ZnO piezoelectric film.

3. Results and Discussion

The humidity responses of both modes were investigated under various humidity levels. With the increase in humidity, the absorbed water molecules by the GO layer accumulate, induced a mass loading effect, hence the resonant frequency shifts. The S0 mode shows a lager frequency shift while the sensitivity is slightly lower than that of the A0 mode. We also investigated the response of the sensors with different frequencies as shown in figure 2(a), the frequency shift is induced by mass loading effect, as defined by equation (1). It shows that the higher the frequency, the higher the sensitivity (defined by equation (2)) of the sensor, and sensitivity up to 145.83 ppm/%RH has been obtained, comparable to or better than those SAW sensors on rigid substrates[4]. Both of the resonant peaks show good repeatability and fast response, in the range of 80%RH for rising and 10%RH for falling as shown in figure 2(b) the response time of the sensor is about 4.4 s (80%RH to 10%RH) 25 s (10%RH to 80%RH).

The definition of frequency shift by mass loading effect[5] and the sensitivity of the sensor are defined as follow:

$$\Delta f = -Cf_0^2 \Delta m / A \tag{1}$$

$$S_m = \frac{\Delta f}{f_0 \times \Delta RH} \tag{2}$$

where C is a constant related to the substrate, Δm is the mass change on the surface induced by the humidity absorption, A is the effective sensing area.

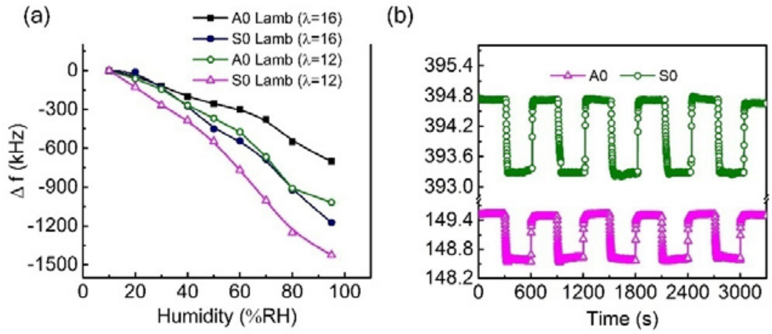

Figure 2. (a) is a summary of humidity responses of the sensors with both modes and different wavelengths, and (b) the repeatability and response of the sensor for a humidity change between 80%RH to 10%RH.

The resonant frequencies of the two modes were found to be influenced strongly by temperature with different coefficients as shown in figure 3(a). By utilizing the S0 Lamb as the temperature reference, we are able to develop a humidity sensor with temperature compensation capability. Figure 2(b) shows the frequency variation over a time period in which the temperature was varied. The large dip of the blue line is caused by the temperature variation. The red line is the curve after compensation of temperature, showing a constant frequency over the time. For simplicity, here we first only consider the frequency shift caused by temperature,

For A0 mode:

$$f_a = a \times T + b \tag{3}$$

For S0 mode:

$$f_s = c \times T + d \tag{4}$$

After temperature compensation, the frequency shift for the A0 mode is,

$$f_a = f_{a0} + \Delta f = f_{a0} + a \times \frac{\Delta f_s}{c} = f_{a0} + a \times \frac{f_{s0} - f_s}{c} \tag{5}$$

Therefore, after an on-chip temperature compensation, the temperature effect can be excluded, and the frequency shift induced by humidity wipe out the temperature shift effect is:

$$f_{a(RH)} = f_{a0} + a \times \frac{f_{s0} - f_s}{c} - Cf_0^2 \Delta m / A \tag{6}$$

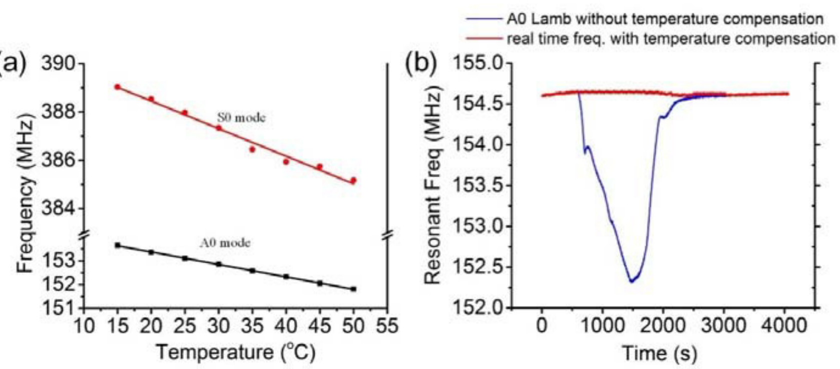

Figure 3. (a) is the frequency dependence on temperature variation, and (b) the frequency change with (red line) and without (blue line) temperature compensation under different temperatures.

Moreover, the device show great flexibility. At a bending with a strain of 1500με, the devices still possess good performance. The maximum frequency shift induced by this strain is about 200 kHz, much less than that caused by the humidity change. The resonant frequency was found to be linearly correlated to the strain from our previous work[6], therefore it is also possible to consider strain compensation for this type of the humidity sensing. On the other hand, the sensors also show a good stability.

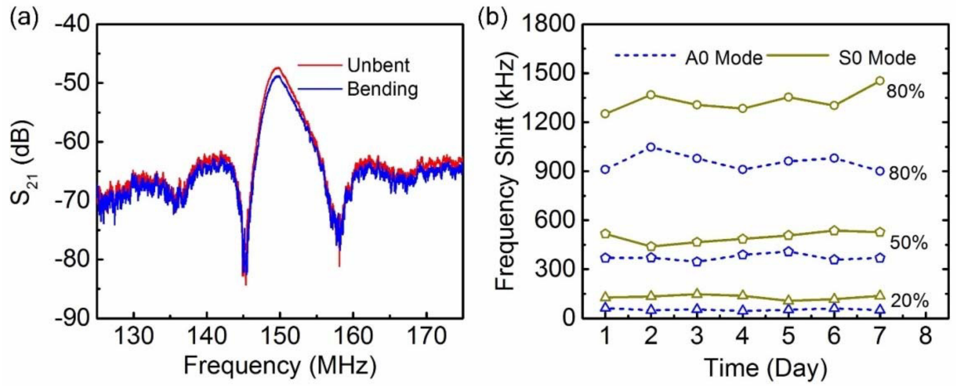

Figure 4 (a) the S-Parameter performance of the flexible sensor at bending and unbent status and (b) the stability of the humidity sensor for seven days.

4. Conclusions

We demonstrated the humidity performance of the flexible sensor using graphene oxide as the sensing film. The sensor possesses two resonant peaks, which have different temperature coefficient of frequency. Then, one of the resonate peaks is used as the temperature compensation to exclude the influence of the temperature change. The sensor also reveals great flexibility and stability, demonstrated great potential for flexible electronic and sensing applications.

5. **Acknowledgement:** This work was supported by the NSFC (Nos. 61376118, 61171038 & 61204124). The authors thank the Innovation Platform for Micro/Nano Device and System Integration and Cyrus Tang Centre for Sensor Materials and Applications at Zhejiang University.

References

[1] A. Afzal, N. Iqbal, A. Mujahid, R. Schirhagl, Advanced vapor recognition materials for selective and fast responsive surface acoustic wave sensors: a review, Anal Chim Acta, 787(2013) 36-49.
[2] W. Xuan, X. He, J. Chen, W. Wang, X. Wang, Y. Xu, et al., High sensitivity flexible Lamb-wave humidity sensors with a graphene oxide sensing layer, Nanoscale, 7(2015) 7430-6.
[3] S. Borini, R. White, D. Wei, M. Astley, S. Haque, E. Spigone, et al., Ultrafast graphene oxide humidity sensors, ACS Nano, 7(2013) 11166-73.
[4] W. Xuan, M. He, N. Meng, X. He, W. Wang, J. Chen, et al., Fast Response and High Sensitivity ZnO/glass Surface Acoustic Wave Humidity Sensors Using Graphene Oxide Sensing Layer, Scientific Reports, 4(2014) 7206.
[5] K. Bodenhöfer, A. Hierlemann, G. Noetzel, U. Weimar, W. Göpel, Performances of Mass-Sensitive Devices for Gas Sensing: Thickness Shear Mode and Surface Acoustic Wave Transducers, Anal Chem, 68(1996) 2210-8.
[6] J. Chen, X. He, W. Wang, W. Xuan, J. Zhou, X. Wang, et al., Bendable transparent ZnO thin film surface acoustic wave strain sensors on ultra-thin flexible glass substrates, J Mater Chem C, 2(2014) 9109-14.