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Li, Ying-ge; Ma, Lian-xiang; Sarro, P.M.; Du, Dong-xing; Liu, Xue-feng

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MASS SENSITIVITY OF ALUMINUM NITRIDE THIN FILM BASED SURFACE ACOUSTIC WAVE SENSORS PREPARED FOR BIOSENSING APPLICATION

Ying-ge LI[1, 2, *], Lian-xiang MA[2], P. M. SARRO[3], Dong-xing DU[2], Xue-feng LIU[1]
[1]College of Automation and Electrical Engineering, Qingdao University of Science and Technology, Qingdao, 266042, China
[2]College of Electromechanical Engineering, Qingdao University of Science and Technology, Qingdao, 266061, China
[3]Department of Microelectronics, Delft University of Technology, 2628CD, Delft, the Netherlands
[*]Corresponding author, E-mail: 15066857079@126.com; Tel.: 0086-15066857079.

Aluminum Nitride (AlN) based Surface Acoustic Wave (SAW) sensors have shown great application potentials on serving as biosensors. In this paper, we investigate the mass sensitivity of SAW sensors, which were fabricated based on Si/AlN structure by depositing aluminum oxide (Al_2O_3) thin films on the active area between the input port and output port of the SAW devices. The material of the IDTs is aluminum. To validate the sample accommodation and protection function of the SiN thin film in bio-liquid detection processes, the contact angle of the SiN surface is also detected. We found that the mass sensitivity of the SAW devices is as high as 1958 MHz/g and the SiN surface is hydrophilic with contact angle of 45 degree. The research results indicate the AlN based SAW devices can be well employed in certain biosensing applications.

Keywords: SAW sensor; AlN thin film; Mass sensitivity; Contact angle; Biosensing

1. INTRODUCTION

Surface acoustic wave (SAW) resonators have been a major building block of electronic devices with wide applications for filters, frequency duplexers, RF-tags (RFIDs) and sensors [1-3]. Recently, SAW sensors have attracted promising interests as biosensors in the following areas [4-7]: 1) Medical science such as clinical medicine, gene diagnosis, human viruses and bacterial. 2) Material science such as polymer thin films, cell adhesion, soft matter research and tissue engineering. 3) Membrane particles such as Liposomes, virosomes/VLP's, viruses, bacteria, membrane proteins and Membrane Preparations. 4) Life Science such as reactions in cells or recognize abnormal cell. 5) Food engineering including pesticide residue, elementary composition, fermentation industry, bio toxin, objectionable microorganism. 6) Some military applications such as chemical and biological warfare agent.

Many studies on microfluidic applications using ZnO based SAW devices have been reported [8,9]. However, ZnO films present potential issues for biomedical and microfluidic applications, making them less ideal materials for microfluidic applications than other thin film piezoelectric materials such as AlN. ZnO is also prone to form oxygen vacancies, which act as donor-like impurities, thus making the material conductive and destroy in gits piezoelectric activity [10]. Conversely, AlN films have better chemical and thermal stability than ZnO films. AlN films have a reasonable good piezoelectric activity to obtain SAW sensors with a good enough coupling coefficient values although generally the coupling coefficient values of the ZnO/Si SAW devices are slightly higher than those of the AlN/Si SAW devices. In addition, due to the ZnO can not easily be fabricated by standard CMOS compatibility process, AlN becomes an attractive candidate for cost effective materials for wireless SAW sensors. Therefore, in this paper, we have designed and fabricated the surface acoustic wave sensors with AlN thin film on silicon substrate aiming for its biosensing applications.

2. EXPERIMENTS

2.1. Device fabrication:

The schematic structure of the employed SAW device is depicted in Fig.1. The aperture of the IDT is 4000μm and the gap between two IDTs, which is indicated with L. is specially kept for 5 mm long for sensing applications in liquid or bio sensing manipulation. The SAW device is 15mm long and 5mm wide, the wavelength of the SAW device is 20μm with equal interval of the IDT fingers. The substrate of the SAW sensor is crystal silicon, on which the AlN thin film deposited as piezoelectric materials and Si3N4 materials deposited as protection and sample accommodation layer. The different layers are represented by different colors and the thickness of each layer is marked in the figure as well. The fabrication details of the SAW devices can be referred to the reference [7].

2.2. Apparatus

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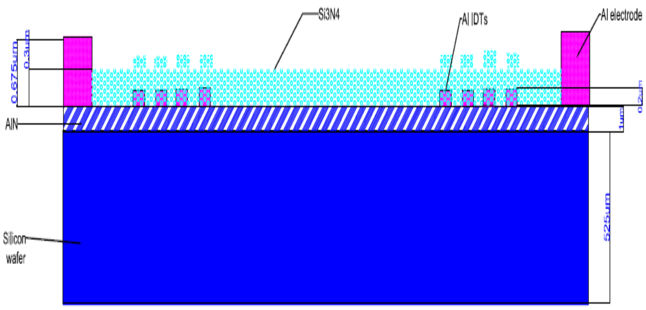
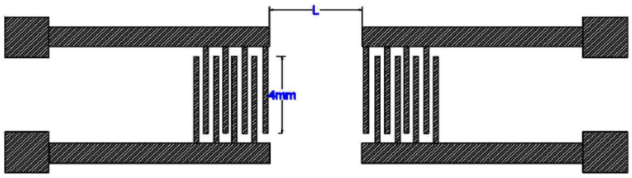
Firstly, we utilize standard CMOS technology to fabricate the SAW sensor. In order to test the mass sensitivity, we use atomic layer deposited (ALD) method to deposit Al_2O_3 thin films on the space between input and output IDTs (mass sensitive area).



(a) Side view of the SAW device



(b) Top view of the SAW device

Fig.1 Schematic structure of the employed SAW device.

We utilized the HP HEWLETT PACKARD 85047A S parameter test set and HP 8753E network analyzer to detect the frequency behaviors of the SAW sensor.

The wettability of the Si3N4 cover plate was examined with a sessile drop method using a DCA Contact Angle System.

2.3. Experimental procedures

In order to check whether the SAW devices are qualified for biosensing applications, we have characterized the mass sensitivity, measured the surface contact angle and investigated environmental dust effect on the frequency characteristics of the SAW devices. To carry out mass sensitivity studies, firstly, we deposited 1nm, 15nm thick Al_2O_3 thin films on the active area of the SAW devices to measure the response of the output signal of the sensors; then we measure the contact angle of SiN surface by water drops to prove its hydrophobic behaviors.

3. RESULTS AND DISCUSSIONS

3.1. Mass sensitivity characterization

Two separately fabricated samples, Sample No.1 and Sample No.2, are employed for the mass sensitivity characterizations. The measured data of S21 parameter of the SAW devices of Sample No.1 and Sample No.2 under two different layer thicknesses are displayed in Figure 2 and Figure 3. Based on the frequency change data extraction process, the mass sensitivity for both samples are listed in Table 1 and Table 2 respectively.

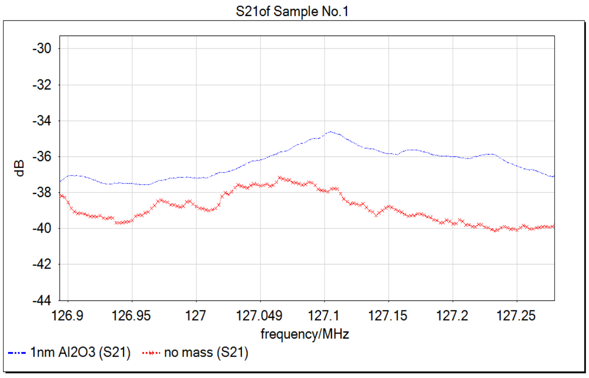


Figure 2. Characteristics of the measurement data of S21 for sample No.1

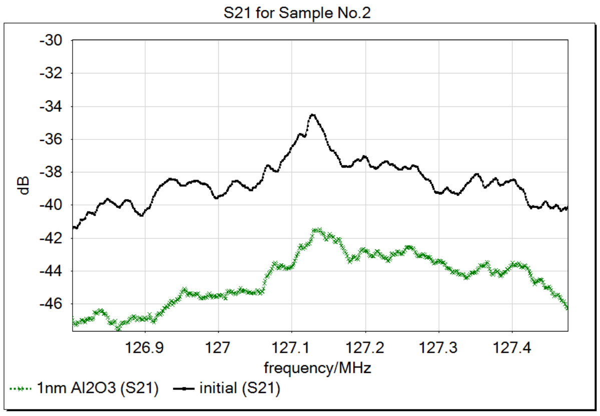


Figure 3. Characteristics of the measurement data of S21 for sample No.2

Table 1. Data extraction for sample No.1

No. of layers	*ΔMass (μg)*	*Frequency(MHz)*
0	0	127.069
1	33.96	127.128

Table 2. Data extraction for sample No.2

No. of layers	*ΔMass (μg)*	*frequency(MHz)*
0	0	127.16
1	33.96	127.234

Since the Al_2O_3 layers were deposited by atomic layer deposited (ALD) method, we take the density of it as $6.68*10^{22}$ cm^{-3} in the data extraction processes [11].

According to the sensing principle of SAW devices with thin film depositions, the output signal of the SAW can be expressed in equation 1:

$$\Delta f = f_0 h\rho(k_1 + k_2 + k_3) - \frac{\mu_0}{V_R^2} f_0 h\left(4k_1 \frac{\lambda_0 + \mu_0}{\lambda_0 + 2\mu_0} + k_2\right) \quad (1)$$

where k_1, k_2, k_3 are the constants of the substrate of the SAW device, f_0 is the initial resonant frequency of the SAW device without disturbance, Δf is the frequency shift when there is mass load on the SAW device, ρ is the density of the thin film material, h is the thickness of the thin film, λ_0 is the Larmor constant of the thin film, v_R is the SAW initial phase velocity, μ_0 is the shear modulus of the thin film material.

Based on equation 1 and the measured data listed in table 1 and table 2, the mass sensitivity of the average SAW devices, S_{aver}, can be calculated to be:

$$S_{aver}=1958 \text{ MHz/g} \quad (2)$$

3.2. Contact angle measurement

The wettability was examined with a sessile drop method using a Contact Angle System DCA. Approximately 10-μl double-distilled water was gently plated on the surface of Al_3N_4 films using a syringe. At least three readings on the area between two IDTs of the SAW sensors were averaged. And we have got the contact angle of SiN surface with water is 45 degree. The measured data indicates the Si3N4 layer is hydrophilic and could be potentially employed for liquid sample accommodation with corrosion protection capability.

4. CONCLUSION

The mass sensitivity of AlN based SAW resonators was characterized in this paper and they can be concluded that:

1. The mass sensitivity of the fabricated SAW resonators in this paper is 1958 MHz/g, which indicates the SAW devices could be employed in biosensing applications in certain area.

2. The contact angle of SiN layer is measured to be 45 degree, indicating the PECVD deposited plate is hydrophilic and therefore could be potentially employed for liquid sample accommodation with corrosion protection capability.

Based on the research results in this paper, we prove the feasibility of the fabricated AIN SAW devices for biosensing applications.

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