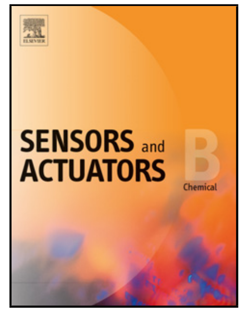

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A high performance humidity sensor based on surface acoustic wave and graphene oxide on AlN/Si layered structure

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Abstract

A surface acoustic wave (SAW) humidity sensor based on AlN/Si (doped) layered structure and graphene oxide (GO) sensing layer is proposed for high sensitivity and low temperature coefficient of frequency. With the GO thin film, the sensitivity of the humidity sensor is increased to 42.08 kHz/RH% when the relative humidity is greater than 80%RH. The humidity sensor performs well even at both very low (≤10%RH) and very high (≥90%RH) detection range of humidity. The present sensor has low hysteresis, excellent short term repeatability and long term stability (variation less than ± 2%). The sensor also shows a fast response and short recovery time. Moreover, using the AlN/Si (doped) layered structure, the thermal stability of the sensor is significantly improved. After being covered with GO thin film, the temperature coefficient of frequency (TCF) of the sensor is further reduced to -22.1 ppm/˚C, much smaller than the previously reported SAW humidity sensors.

Keywords: Humidity sensor, surface acoustic wave, graphene oxide, AlN thin film, highly doped Si.

1. Introduction

Humidity sensors play very important roles in various fields, such as industrial production process monitoring, living environment control and agricultural planting management [1-3]. The performance of the humidity sensors based on different working principles [4-7] has been studied for several decades. Surface acoustic wave (SAW) humidity sensors have gained extensive attention duo to the advantages of small size, fast response and high stability [8]. Typically, the SAW humidity sensors are covered by a layer of sensing material to improve sensitivity. With the development of material technology, many sensing materials have been applied to the SAW humidity sensors, mainly polymers [9-11] and nanomaterials [8, 12, 13]. Graphene oxide (GO) as a carbon nanomaterial has large surface to volume ratio and oxygen-containing hydrophilic functional groups like carboxyl groups [14], which makes it very suitable for humidity sensing. Moreover, GO can be directly deposited on the interdigitated electrodes (IDTs) owing to its characteristic of electrical insulation [15]. Previous studies have reported that GO humidity sensors [16, 17] have high sensitivity, fast response and little hysteresis.

Although the SAW based humidity sensors offer many advantages, they are susceptible to change of temperature [18]. It is particularly important to improve thermal stability of the SAW humidity sensors for accurate testing when ambient temperature changes. For most of the SAW humidity sensors, interdigitated electrodes are designed directly on bulk piezoelectric substrates such as $LiNbO_3$ [8], but this kinds of structure usually has a relative high temperature coefficient of frequency (TCF) [19]. Compared with the bulk SAW devices, the SAW devices with layered structures (the materials of piezoelectric layer and structural layer have opposite temperature coefficients) have lower TCF [20]. Aluminum nitride (AlN) film has recently received extensive attention due to its high acoustic wave velocity, CMOS process compatibility, good chemical and temperature stability [21]. SAW sensors based on AlN/Si layered structure have been proven to have good thermal stability [22], but still need to be improved for highly accurate humidity sensors.

Recent studies have shown that doped Si substrate layer is beneficial in further reducing the temperature sensitivity of frequency of piezoelectric devices [23]. In this work, we propose a SAW humidity sensor based on AlN/Si layered structure, where surface of the Si layer is highly doped before deposition of AlN. The SAW humidity sensor based on this kind of structure is easy to integrate into CMOS circuits, which can reduce processing costs and meet the needs of the internet of things. The GO layer is directly deposited on IDTs instead of SAW propagation path between the IDTs in order to reduce the size of the sensor while achieving high humidity sensitivity. Sensitivity of the GO based SAW humidity sensor is investigated before and after being coated with GO thin film, and the sensing mechanism of the humidity sensor is analyzed according to the experimental data. Detection range, hysteresis characteristic, stability, repeatability, response-recovery time and the effect of temperature changes on response of the humidity sensor are also studied.

2. Device design and fabrication

The SAW humidity sensor is fabricated on layered structure of AlN thin film and Si substrate layer with highly-doped surface to achieve temperature compensation. The schematic structure of the SAW device (before and after being covered with a GO film) with two-port configuration is illustrated in Fig. 1. Each interdigitated transducer (IDT) is composed of 60 pairs of interdigital electrodes. The W/W0 electrode structure (W is the acoustic aperture and the W_0 is the total aperture of the IDT) is designed to eliminate unwanted spurious frequency response [24]. The length ratio of W to W0 is 0.95. The