Sensors and Actuators A 169 (2011) 74–82

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Studies of a high-sensitive surface acoustic wave sensor for passive wireless blood pressure measurement

Xuesong Ye[a,*], Lu Fang[a], Bo Liang[a], Qiong Wang[a], Xuejun Wang[a], Lisong He[b], Weibin Bei[b], Wen H. Ko[c]

[a] College of Biomedical Engineering & Instrument Science, Biosensor National Special Laboratory, Key Laboratory of Biomedical Engineering, Ministry of Education, Zhejiang University, Hangzhou, Zhejiang 310027, China
[b] CETC HuaYing Electronics, Deqing, Zhejiang 313200, China
[c] Department of Electrical Engineering & Computer Science, Case Western Reserve University, Cleveland, OH 44106, USA

ARTICLE INFO

Article history:
Received 19 September 2010
Received in revised form 17 May 2011
Accepted 19 May 2011
Available online 27 May 2011

Keywords:
SAW sensors
Blood pressure sensors
Remote measurements
COMSOL Multiphysics

ABSTRACT

This paper develops a novel, high-sensitive surface acoustic wave (SAW) blood pressure sensor based on a 434.5 MHz resonator fabricated on an ST-cut quartz beam. First, 50 types of resonators with different layouts were designed, and then the sensitivity of the pressure sensors with different structures and sizes was simulated and calculated by using COMSOL Multiphysics software. Finally, a resonator with good performance was selected to fabricate a set of blood pressure sensors in different sizes, and these sensors were tested and evaluated through the use of both static and dynamic pressure measurements as well as animal experiments. For the sensor with a beam size of 10 mm × 1.3 mm × 0.3 mm, the results showed that in the range of 0–300 mmHg the pressure sensitivity was about 1.9 kHz/mmHg with good linearity, which matched well with the simulation results, additionally, the maximum non-linear curve fitting error was found to be less than ±1 mmHg. Moreover, it could detect a pressure change as small as 0.1 mmHg. This sensor can be used to monitor blood pressure passively and wirelessly, and it will hopefully be applied in implantable devices for body pressure measurements in further research.

1. Introduction

Surface acoustic wave (SAW) sensors based on resonators have been widely used in the industry for a long time due to their advantages, including having a compact size, good stability, a low cost, the ability to work passively and wirelessly as well as the ability to take measurements even in harsh environments. In order to detect some basic physical quantities such as temperature, pressure and humidity a multifunctional integrated SAW sensor was designed to measure temperature and pressure in power stations and combustion engines [1], and a high-sensitive SAW sensor made of 128° YX-$LiNbO_3$ with the resonant frequency of 145 MHz was used to measure relative humidity [2]. In addition, a novel SAW gas sensor was fabricated and used for the detection of C_2H_4 in N_2 in high temperature applications [3]. However, there is little literature reporting their applications in the area of biomedical engineering. For example, Gopalsami et al. developed an implantable SAW temperature microsensor for early detecting and monitoring of seizures [4]. Martin et al. reported a wireless SAW temperature sensor system for measuring the inner body temperature of a dog [5].

Nowadays, the body sensor network is becoming more and more popular in patient diagnosis and monitoring [6–8]. Most proposed sensors were made using the semiconductor process and powered by small batteries, which usually limited the lifetime of the sensor [9–11]. To overcome this shortcoming, a lot of RF powering systems have been studied in the past several years but these systems increased the complexity of the circuit [12–14]. So it is desirable to develop a passive and wireless SAW remote measurement technique for biomedical applications, particularly for implantable devices. In addition to these above mentioned advantages of SAW sensors, another advantage is the ease with which they are able to form RFID sensor networks [15–17].

As one of the principal vital signs, blood pressure is of great significance in the clinic. However, to the best of our knowledge, SAW pressure sensors used for blood pressure measurement have rarely been reported yet. Most proposed SAW pressure sensors have a large measuring range and a relatively low sensitivity (0–10 bar, 40 kHz/bar ≈ 54 Hz/mmHg) thus are suitable for high pressure environments as found in tires and machine tools [1,18,19]. In this study, we developed a novel, high-sensitive, passive and wireless pressure sensor based on the 434.3 MHz SAW resonator. Under the same maximal size of the substrate, the sensitivity of this sensor was about ten times higher than a similar sensor fabricated in the circular substrate. In the range of 0–300 mmHg, the pressure sensitivity was about 1.9 kHz/mmHg with good linearity, and the

* Corresponding author. Tel.: +86 0571 87951090; fax: +86 0571 87951676.
E-mail address: yexs@mail.bme.zju.edu.cn (X. Ye).

0924-4247/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2011.05.022

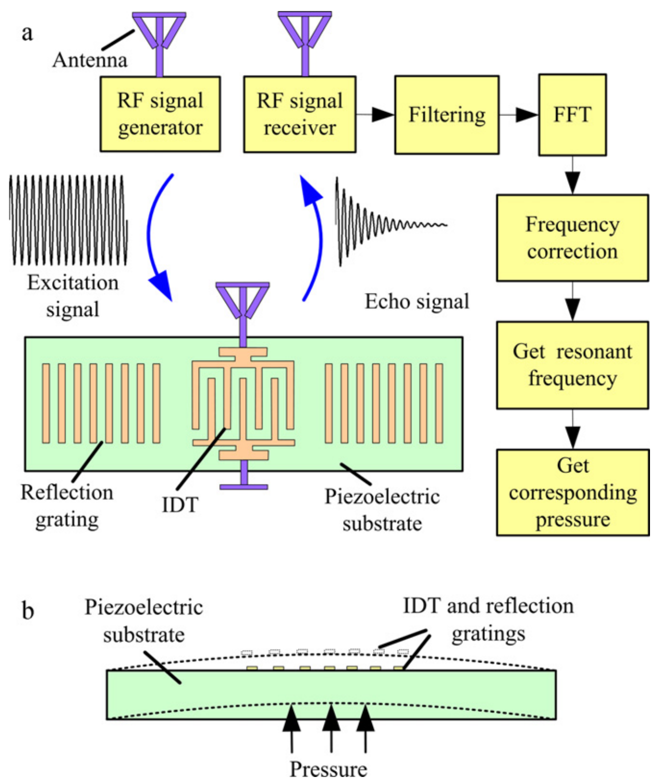

Fig. 1. (a) Principle of passive remote measurements of the SAW resonator. (b) Piezoelectric substrate bending brought about by external pressure.

maximum non-linear curve fitting error was less than ±1 mmHg. With its advantages of high sensitivity, small size, and the ability to work passively and wirelessly, this sensor will hopefully be used in implantable devices for blood pressure or intracranial pressure measurements in the body.

2. Principle of passive wireless SAW pressure sensor

The SAW resonator is composed of an interdigital transducer (IDT) and two symmetrical reflection gratings photo-etched on the piezoelectric substrate, as shown in Fig. 1(a). When the outside RF signal generator transmits the RF excitation signals through an antenna, if in an effective range, the resonator receives and converts the RF excitation signals into mechanical acoustic waves. The acoustic waves propagate on the surface of the piezoelectric substrate and oscillate in the resonator. When the RF excitation signals are terminated, the RF echo signals converted from the mechanical waves in the resonator can be detected by the RF signal receiver. After signal filtering, FFT and frequency correction, the resonant frequency *f* of the resonator can be calculated. On the other hand, the resonant frequency *f* is determined by the velocity of the acoustic waves propagating on the surface of the piezoelectric substrate V_{SAW} and the period of IDT and reflection gratings λ as follows:

$$f = \frac{V_{SAW}}{\lambda} \qquad (1)$$

As shown in Fig. 1(b), when the external pressure brings about the bending of the piezoelectric substrate, it induces a change of V_{SAW} and λ, which finally results in a change of the resonant frequency Δf, from which the corresponding pressure P can be obtained by:

$$P = k \times \Delta f \qquad (2)$$

where k is the reciprocal of the pressure sensitivity of the sensor.

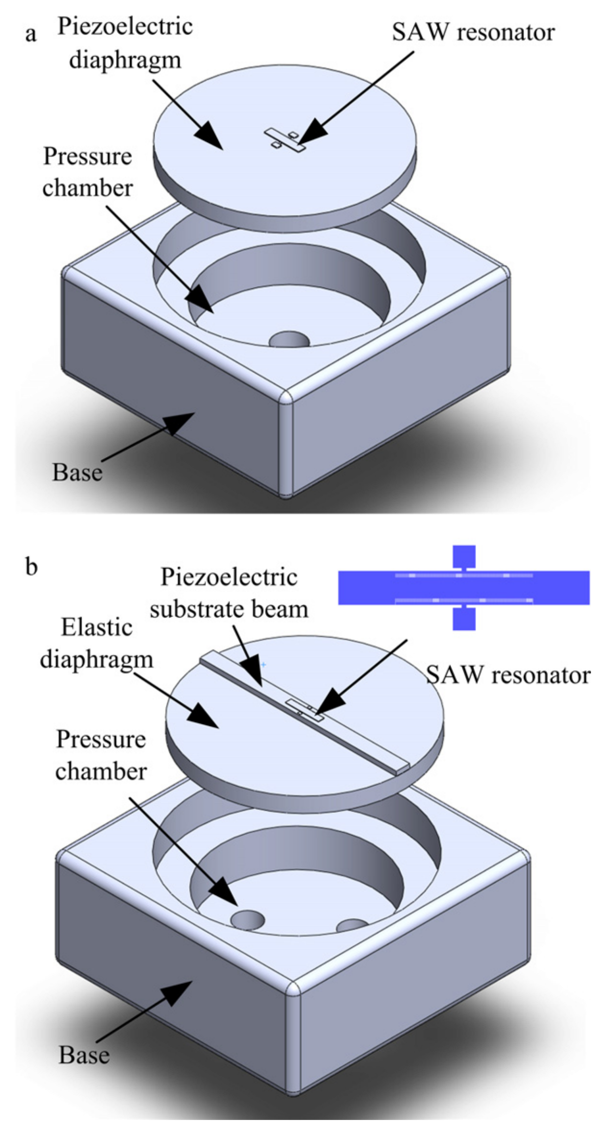

Fig. 2. (a) Schematic view of the typical and basic structure of SAW pressure sensor. (b) Schematic view of the improved SAW pressure sensor based on a piezoelectric substrate beam and elastic diaphragm structure.

3. Materials and methods

3.1. SAW blood pressure sensor structure design

There are two placement methods for current sensors used for blood pressure measurement: *in vivo* and *in vitro*. With the consideration that the sensor can also be used *in vivo* in future research, in addition to sensitivity performance, the device size was also taken into account in this study.

Fig. 2(a) shows a typical structure of SAW industrial pressure sensors applied in combustion engines and power stations [1]. The sensor consisted of a piezoelectric diaphragm and pressure chamber. Usually, the diaphragm was circular and a resonator was photoetched on the center of it to get the highest sensitivity. An improved structure based on an integrated diaphragm and pressure chamber in the same piezoelectric substrate was reported [18] but its fabrication required a more complicated process. To increase the sensitivity of this sensor, one can decrease the diaphragm thickness or enlarge its dimension, both of which, however, will make the fabrication process more difficult.

In order to increase the pressure sensitivity under the same maximal size of the substrate and reduce the fabrication difficulty,