High-Q SH-SAW Resonator Using 36° YX-$LiTaO_3$ on SiC

Zonglin Wu, Shuxian Wu, Hangyu Qian, Feihong Bao*, Guomin Yang, Jie Zou*
School of information science and technology
Fudan University
Shanghai, China
*e-mail: baofh@fudan.edu.cn, Jiezou@fudan.edu.cn

Gongbin Tang
Institute of novel semiconductors
Shandong University
Shandong, China
e-mail: gongbin.tang@sdu.edu.cn

***Abstracts*—Acoustic wave resonators show promising application in filters, oscillators, and sensors. A high quality factor (*Q*) is the required feature for shear-horizontal (SH)-surface acoustic wave (SAW) resonators because the high *Q* will provide the low insertion loss for acoustic filters. Therefore, the SH-SAW resonator with 36° YX $LiTaO_3/SiO_2$/SiC structure is proposed to achieve a high *Q*. The fabricated resonators demonstrate a very high Bode-Q_{max} of 3917 and an effective coupling coefficient (k^2_{eff}) of 12.3%. Accordingly, a high figure of merit (*FoM* =482 at 1 GHz) is achieved. Compared with the conventional SH-SAW resonator using 36° YX-LiTaO3/SiO_2/Si structure, the *Bode-Q* maximum of the fabricated resonator with silicon carbide (SiC) shows a 1.6-fold enhancement.**

Keywords—SAW resonator; silicon carbide; quality factor; Lithium Tantalate.

I. INTRODUCTION

Acoustic wave resonators show fascinating prospects in many applications such as filters, oscillators, and sensors, due to their property of small size and low power compared to the traditional electrical resonators. It is known that a high quality (Q) is desired since the high Q will provide the low loss for electrical devices, the low phase noise for oscillators and the high sensitivity for sensors. Therefore, it is necessary to pursue a high Q for promoting the practical application of acoustic resonators in many fields [1][2].

Surface acoustic wave (SAW) resonators are widely used in a large number of applications as part of acoustic resonator. However, the traditional shear-horizontal (SH) SAW resonator is difficult to achieve a relatively high Q, for SH mode coupled to the bulk mode in substrate propagates on the substrate directly as a leaky wave. By bonding the sub-wavelength-thick $LiTaO_3$ (LT) or $LiNbO_3$ (LN) layer onto high-phase-velocity (v_p) substrates, the leaky component is effectively eliminated [3]. Recently, Multilayered substrate incredible high-performance (I.H.P.) SAW devices show a high *Bode*-Q_{max} around 4,000 [4]. For the multilayered substrate, material chosen is also an important factor of acoustic resonator. Given this, a high-performance lamb wave resonator using SiC substrate is reported [5].

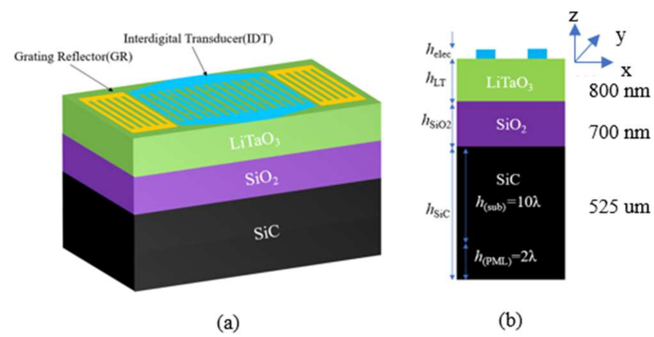

Fig.1. Schematic of the proposed SH-SAW resonator. (a) perspective view. (b) Cross-sectional view of model in COMSOL. The thickness of each stacks of the proposed SH-SAW resonator are h_{elec}=297 nm, h_{Lt}=800 nm, h_{SiO2}=700 nm, h_{SiC}=525 um.

TABLE I.

THE KEY PARRAMETERS OF MULTILAYER SAW RESONATOR

Parameter	Wavelength(λ)	Electrode finger width	IDT finger number
value	4 um	1um	150

Silicon is usually used as the substrate in multilayer SH-SAW resonator for its inexpensive. In this work, the SiC substrate replaces Si substrate since its low acoustic loss which provides higher Q. For comparison, two kinds of multilayer SH-SAW resonator which are completely identical except the substrate are fabricated to observe the influence of SiC substrate. The fabricated SH-SAW resonator on SiC substrate shows high *Bode*-Q_{max} of 3917.8, which is 1.6-fold enhancement than that of SH-SAW resonator on Si substrate, and admittance radio at 92 dB.

II. RESONATOR DESIGN AND SIMULATION

The schematic of a typical one-port multilayer SH-SAW resonator is shown in Fig. 1 with the thickness of each layer.

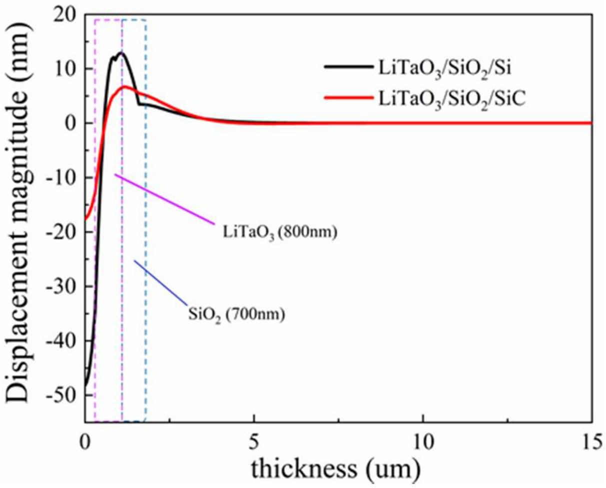

Fig.2. The curve of thickness and displacement shows that comparing the SH-SAW resonator on SiC substrate and the SH-SAW resonator on Si substrate. The magnitude of the displacement is mapped to the acoustic energy in the thickness-direction. The SH-SAW resonator on SiC substrate can better retain the energy in the piezoelectric layer, that is reduces energy loss.

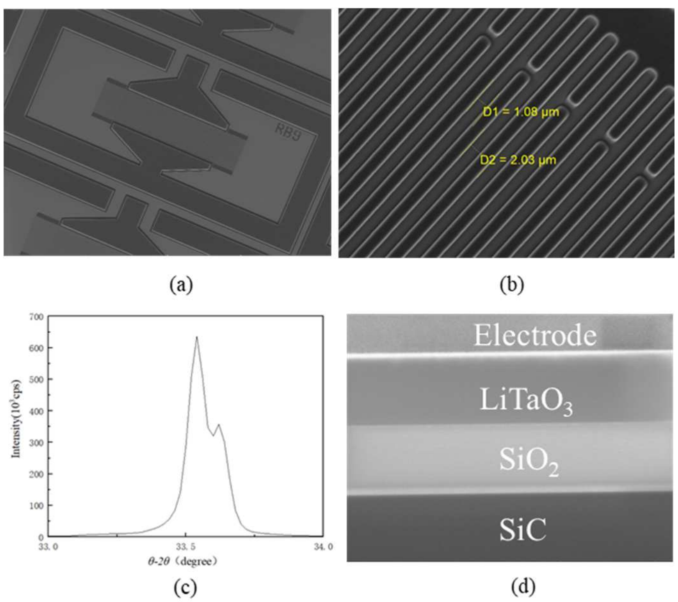

Fig.3. (a) The SEM image of fabricated resonator top view. (b) The enlarge SEM image of the IDTs. (c)XRD rocking curve for SiC substrate. (d) The cross section of the proposed resonator by SEM image.

The key parameters are listed in Table I. The perspective view of the resonator is shown in Fig. 1 (a), where two grating reflectors are placed at both ends of interdigital transducers (IDTs). The IDTs are composed of 75 pairs of metal strips aligned and connect to the busbars periodically, while grating reflectors are composed of 20 pairs of shorted metal strips. The period distance of the grating reflectors is set to half of λ so that the resonant frequencies of IDT and reflectors are identical and desired mechanical reflection can be achieved. The cross view of the resonator is shown in Fig.1(b) and the thickness of each

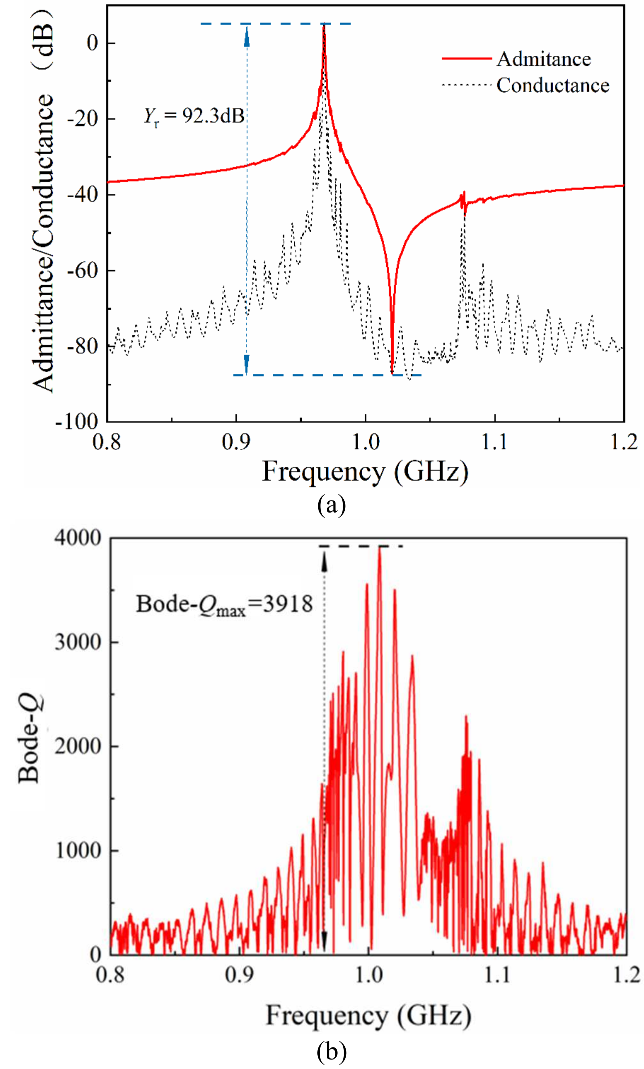

Fig.4. Measurement results of the proposed SH-SAW resonator on SiC substrate. (a) Admittance and conductance (b) Bode-Q of the fabricated resonator. Admittance radio is 92dB. What' s more, the *Bode*-Q_{max}=3917.8.

layer of multilayer SH-SAW resonator is shown. The thickness of $LiTaO_3$ film, SiO_2 and SiC is 800 nm (0.2λ), 700 nm (0.175λ) and 525 um, respectively, where the thickness of each layer is optimized by using the method of finite element method (FEM). What's more, Fig.1. (b) depicts the FEM simulated mode. Perfect matched layer (PML) physics is assigned to bottom layers of the 3D unit cell models to simulate the substrate which is too thick comparing to wavelengths to generate wave reflections from its bottom. The periodic conditions are applied to both x (perpendicular to IDT fingers) and y (in parallel with IDT fingers) directions so that the basic semi-infinite plane condition is assumed for the wave propagation.

As shown in Fig. 2, the displacement magnitude in the thickness direction of SH-SAW resonator on SiC substrate is smaller than that of the Si substrate, indicating that less acoustic energy leaks into SiC substrate, and then more acoustic energy is confined in the piezoelectric layer.

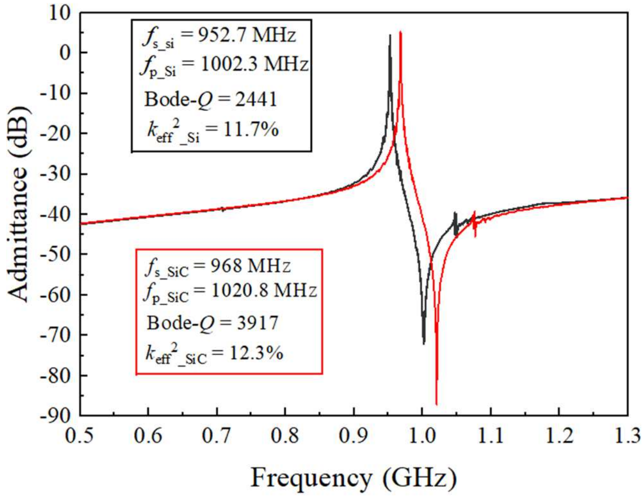

Fig.5. The measured admittance comparison between the proposed SH-SAW resonator with SiC substrate and the SH-SAW resonator with Si substrate. The SAW resonator with SiC has f_s=968MHz, f_p=1020.8MHz, *Bode-Q*$_{max}$=3918, and k_{eff}^2=12.3%. The SH-SAW resonator f_s=952.7MHz, f_p=1002.3MHz, *Bode-Q*$_{max}$=2441, and k_{eff}^2=11.7% based on Si. The SH-SAW resonator with SiC substrate shows higher *Bode-Q* and k_{eff}^2.

III. MESURSUREMENT RESULTS

Fig. 3(a) presents a top view of scanning electron microscope (SEM) image of the $LiTaO_3/SiO_2/SiC$ multilayer SH-SAW resonator. An enlarged view of the IDTs in Fig. 3 (a) is shown in Fig.3(b), and the IDTs can be seen clearly. The period of finger determines the operation wavelength of the SH-SAW resonator. The period of finger can be observed which is 2um, that is the operation wavelength at 4um. Fig. 3(d) presents a cross view of SEM image of the proposed resonator.

Fig. 4(a) shows the measured admittance and conductance response of the fabricated multilayer SH-SAW resonator with λ at 4um on SiC substrate. The series resonance frequency (f_s) and the parallel resonance frequency (f_p) are 968 MHz and 1020.8 MH, respectively. the admittance ratio (Y ratio) is used as a performance index of SH-SAW resonators for it is proportional to the square of a product of k^2_{eff} and Q as

$$\frac{Y_s}{Y_p} \propto (k^2{}_{eff}Q)^2, \tag{1}$$

where Y_s and Y_p are admittance at series resonance and parallel resonance, respectively. The Y ratio of the fabricated resonator on SiC resonator achieves 92dB.

Fig 4. (b) shows the *Bode-Q* of the fabricated resonator, and the *Bode-Q* is defined as

$$BodeQ(f) = 2\pi f \frac{|S_{11}|}{1-|S_{11}|^2}\tau(S_{11}), \tag{2}$$

where $\tau(S_{11})$ is group delay of S_{11}. Finally, the *Bode-Q*$_{max}$ is extracted as 3917.8. The maximum *Bode-Q* is related to energy loss. A larger *Bode-Q* lead to less energy loss.

What's more, the admittance responses of two completely identical multilayer SH-SAW resonators other than the substrate are compared are shown in Fig. 5. As shown in Fig. 5., when SiC substrate is used, not only the performance of

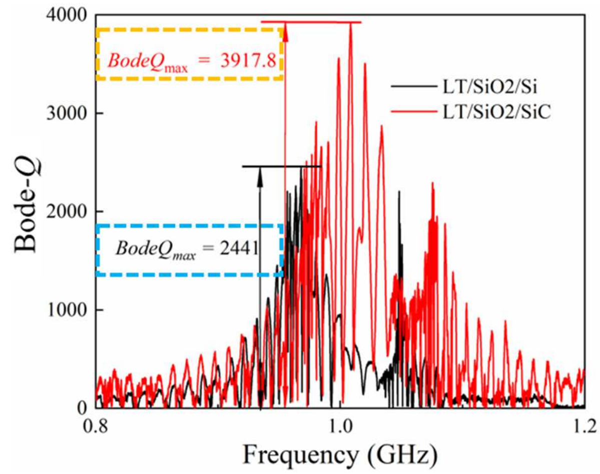

Fig.6. The measured *Bode-Q* comparison between the proposed SH-SAW resonator with SiC substrate and the SH-SAW resonator with Si substrate. The *Bode-Q*$_{max}$ of two resonators are 3917.8 and 2441, respectively.

TABLE II. COMPARISON OF ACOUSTIC RESONATORS

Ref	substrate	f(GHz)	Q_{max}	k^2_{eff}	$FoM(k^2_{eff}\cdot Q_{max})$
6	YX-42° $LiTaO_3$	1.9	1050	8	84
7	YX-20° $LiTaO_3$/40°Y 90°X quartz	0.45	3000	11.2	336
8	YX-15° $LiNbO_3/SiO_2/Si$	1.4	388	22.5	87
6	YX-50° $LiTaO_3/SiO_2/AlN/Si$	1.9	4200	9.8	411
9	YX-15° $LiNbO_3/SiO_2/SiC$	1.3	330	22	131
10	X-cut $LiNbO_3/SiO_2/SiC$	2.2	1228	26.9	330
This work	**YX-36° $LiTaO_3/SiO_2/Si$**	**1.0**	**2441**	**11.7**	**286**
This work	**YX-36° $LiTaO_3/SiO_2/SiC$**	**1.0**	**3918**	**12.3**	**482**

Bode-Q and k^2_{eff} improve, but also the series-resonance frequency (f_s) increases. Note that *Bode-Q$_{max}$* of SH-SAW resonator on SiC substrate is 1.6 higher than that on Si substrate. The use of SiC substrate provides better performance for multilayer devices and demonstrates the potential of SiC material.

Fig. 6. shows the *Bode-Q* comparison of the two fabricated multilayer SH-SAW resonators, and the difference between the two Bode-Q can be clearly seen. It is obvious that SH-SAW resonator on SiC substrate has higher *Bode-Q* than that on Si substrate.

A comparison between the above resonator and other acoustic resonators [6], [7], [8], [9] and [10] is shown in Table

II. By comparing, Although the *Bode-Q* of this work is not as high as 4200 in reference 6, it is higher than that of other's *Bode-Q*. However, the figure of merit (*FoM*) in this work is higher than reference 6. The fabricated SH-SAW resonator on SiC substrate shows the high performance.

IV. CONCLUSION

In this work, two kinds of SH-SAW resonators including SiC substrate and Si substrate are fabricated. The SH-SAW resonator using SiC substrate shows excellent performance, which demonstrates a high $Bode\text{-}Q_{\max}$ of 3917, a k^2_{eff} of 12.3%, thereby the high *FoM* of 482 is obtained. At the same time, the fabricated SH-SAW resonator on SiC substrate is 1.6 times higher than the *Bode-Q* of SAW resonator on Si substrate, which also shows the great potential of SiC for designing the high-Q resonator. Compared with other acoustic resonators, the fabricated SAW resonator on SiC substrate also has the highest *FoM*.

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