



HAL
open science

8 inch Surface and Bulk Acoustic Wave devices based on POI substrate for 5G

Marie Bousquet, Alice Joulie, Clémence Hellion, Marc Sansa Perna, Julien Delprato, Pierre Perreau, Grégory Enyedi, Gabriel Lima, Jean Guerrero, Gaël Castellan, et al.

► To cite this version:

Marie Bousquet, Alice Joulie, Clémence Hellion, Marc Sansa Perna, Julien Delprato, et al.. 8 inch Surface and Bulk Acoustic Wave devices based on POI substrate for 5G. IEEE IFCS-EFTF 2023 - Joint Conference of the IEEE International Frequency Control Symposium and the European Frequency and Time Forum, held with ATF, the Asia-Pacific Workshop on Time and Frequency, May 2023, Toyama, Japan. cea-04528409

HAL Id: cea-04528409

<https://cea.hal.science/cea-04528409v1>

Submitted on 1 Apr 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

8 inch Surface and Bulk Acoustic Wave devices based on POI substrate for 5G

M. Bousquet¹, A. Joulie¹, C. Hellion¹, M. Sansa¹, J. Delprato¹, P. Perreau¹, G. Enyedi¹, G. Lima¹, J. Guerrero¹, G. Castellán¹, A. Tantet¹, S. Chevallet¹, T. Monniez¹, I. Huyet², A. Clairet³, T. Laroche³, S. Ballandras³, A. Reinhardt¹

¹Univ. Grenoble Alpes, CEA-LETI, MINATEC Campus, FRANCE

²Soitec, Bernin, France

³freq/n/sys, Besançon, France

marie.bousquet@cea.fr ; alexandre.reinhardt@cea.fr

Summary — The availability of Piezoelectric-On-Insulator (POI) substrates, made of a thin single crystal LiTaO₃ film atop a silicon substrate, has promoted the development of innovative Surface and Bulk Acoustic Wave devices (SAW and BAW). However, these substrates are so far only commercially available in 4 and 6 inch diameter. In this work, we successfully fabricate acoustic devices based on 8-inch POI substrates. SAW resonators display an electromechanical coupling coefficient of 8.83% at a resonance frequency of 1.6 GHz. Film Bulk Acoustic Resonator (FBAR) and Solidly Mounted Resonator (SMR), which integrate more complex layer stacks, such as a buried electrode and acoustic isolation structures, have been also fabricated. The FBAR exhibits a single resonance at 2.8 GHz, with an electromechanical coupling coefficient of 8.75% and a quality factor close to 190. The SMR based on a dielectric (AlN/SiO₂) Bragg mirror exhibits a coupling coefficient of 6.1% and a quality factor of 405 at 4 GHz. A Temperature Coefficient of Frequency (TCF) of -14 and -22 ppm/°C at resonance and antiresonance are obtained respectively. Such TCF values are among the lowest ever reported for LiNbO₃ and LiTaO₃ BAW resonators. These results offer promising perspectives towards the development of SAW and BAW filters on 8-inch POI substrates.

Keywords—8-inch, Piezo-On-Insulator (POI) substrate, Bulk Acoustic Wave (BAW), Surface Acoustic Wave (SAW)

I. INTRODUCTION

The radiofrequency (RF) filter market has been moving fast in the last ten years, with the deployment of the 5th Generation of mobile applications (5G), especially in the sub-6 GHz range [1]. In this crowded RF spectrum, RF filters need to continuously improve their performances while new frequency bands introduce challenges regarding higher operation frequency and larger fractional bandwidths. Two RF filter technologies coexist in the current market: (i) Surface Acoustic Wave (SAW) where acoustic waves are excited by interdigitated electrodes on top of a bulk (LiNbO₃ or LiTaO₃) piezoelectric or a Piezo-On-Insulator (POI) substrate. SAW filters are usually manufactured on 4- or 6-inch wafer production lines [2]. (ii) Bulk Acoustic Wave (BAW) where a thin piezoelectric layer is sandwiched between two electrodes and acoustically isolated from the substrate either by an air gap (FBAR – Film Bulk Acoustic Resonator) or a Bragg mirror (SMR – Solidly Mounted Resonator). Sputtered AlN and its derivatives (e.g., Al_{1-x}Sc_xN) is currently the prime material for BAW manufacturers, which operate in 6- or 8-inch production lines [1]. New devices

exploiting bulk acoustic waves in single crystal LiNbO₃ and LiTaO₃ piezoelectric films such as XBAR and BAW have been recently emerged as promising candidates for wide bandwidth filters in the sub-6 GHz range [3][5]. Up to now, their potentialities have been only demonstrated on 4-inch wafers, due in part to limited wafer size availability.

In this paper, we demonstrate the integration and associated performances of SAW and BAW devices based on 8-inch POI substrates highlighting the potential for wafer size upscaling.

II. 8 INCH SURFACE ACOUSTIC WAVE RESONATORS (SAW)

Single-port synchronous resonators based on 200 nm-thick AlSi interdigitated electrodes with a pitch of 1.2 μm (a/p=0.5) patterned by using standard UV-photolithography and dry etching were used to extract SAW characteristics on 8-inch POI wafers. They exhibit an electromechanical coupling coefficient of 8.83% at 1.6 GHz (Fig. 1), which is comparable to the performances previously reported for 6-inch POI substrates [2] and thus validates that the wafer scaling did not degrade the substrate quality.

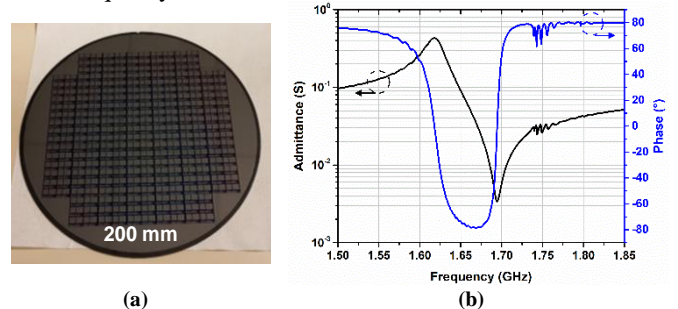


Fig. 1. (a) 8-inch full POI-based SAW device, (b) Modulus (in black) and phase (in blue) of the admittance of the tested single-port resonator at 1.6 GHz.

III. 8 INCH BULK ACOUSTIC WAVE (BAW) RESONATORS

Y+42°-cut LiTaO₃, which is the conventional cut used for SAW devices, promotes a pure longitudinal bulk wave with an electromechanical coupling coefficient of 9.0%, similar to AlScN [5]. The process fabrication of FBAR and SMR devices based on 8-inch POI substrate is described in [6].

A. Film Bulk Acoustic Wave Resonator (FBAR)

The FBAR stack is as follows (from top to bottom): AlSi 100 nm / Y+42°-cut LiTaO₃ 630 nm / Pt 100 nm / SiO₂ 350 nm. Fig.

2a presents a typical admittance curve and reveals resonance and antiresonance frequencies of respectively 2.82 and 2.97 GHz, leading to an electromechanical coupling coefficient of 8.75%. Quality factors at resonance and antiresonance are respectively 190 and 120. A comparison of the electric response with Mason's model indicates an excellent agreement confirming that the intrinsic coupling coefficient ($k_{int}^2 = 9.0\%$) of the film is in line with theoretical expectations for the bulk material (Fig. 2b). The discrepancy between the fitted mechanical quality factor ($Q_{int} = 300$), *i.e.* free of the contribution of electrical losses, and quality factor at resonance is primarily due to resistive losses due to Pt bottom electrodes [5].

B. Solidly Mounted Resonator (SMR)

Solidly Mounted Resonators, based on a nine layers Bragg mirror alternating high acoustic impedance (AlN) and low acoustic impedance (SiO₂) layers, was also fabricated. This mirror is centered around 4 GHz and is designed to reflect both longitudinal and shear waves [7]. The SMR stack is as follows (from top to bottom): AlSi 100 nm / Y+42°-cut LiTaO₃ 680 nm / AlSi 100 nm / (AlN/SiO₂) Bragg mirror (Fig. 3a). The dispersion curves for modes in this stack are calculated using periodic Finite-Element modal analyses (Fig. 3b). They indicate a type I dispersion, ensuring an energy trapping configuration [7]. From the spacing between resonance ($f_r = 4.03$ GHz) and antiresonance ($f_a = 4.14$ GHz) frequencies, an electromechanical coupling coefficient of 6.11% is calculated (Fig. 3c). This number is mostly limited by the design of the Bragg reflector. The quality factor at resonance and antiresonance are equal to 405 and 235, respectively. Fitting the electric response with a Mason's model allows estimating an intrinsic electromechanical coupling coefficient and quality factor of 7.1% and 300,

respectively. A Q_{Bode} of 400 and an impedance ratio of 175 (45 dB) are obtained. Finally, the resonators exhibit a linear frequency shift with frequency, with temperature coefficients of respectively -22 and -14 ppm/K for the resonance and antiresonance. These TCF values are the lowest reported up to now for LiNbO₃ and LiTaO₃ BAW resonators [4], [5].

II. CONCLUSIONS

8-inch surface and bulk acoustic devices based on a POI substrate have been successfully fabricated and characterized and exhibit performances in agreement with similar devices fabricated from 4-inch wafers. Such 8-inch integration paves the way towards the development of POI (LiTaO₃ and LiNbO₃) SAW and BAW filters compliant to 5G requirements.

REFERENCES

- [1] R. Aigner *et al.*, "BAW Filters for 5G Bands", 2018 IEEE International Electron Devices Meeting, pp. 14.5.1-14.5.4.
- [2] E. Butaud *et al.*, "Innovative Smart Cut™ Piezo On Insulator (POI) Substrates for 5G acoustic filters", 2020 IEEE International Electron Devices Meeting, pp. 34.6.1-34.6.4.
- [3] V. Plessky *et al.*, "5GHz laterally-excited bulk-wave resonators (XBARS) based on thin platelets of lithium niobate", Electron. Lett., vol. 55, pp. 98-100, 2019.
- [4] M. Bousquet *et al.*, "4.2 GHz LiNbO₃ Film Bulk Acoustic Resonator", 2021 IEEE International Ultrasonics Symposium, pp. 1-4.
- [5] M. Bousquet *et al.*, "Potentialities of LiTaO₃ for Bulk Acoustic Wave Filters", 2020 IEEE International Ultrasonics Symposium, pp. 1-4.
- [6] M. Bousquet, P. Perreau, and A. Reinhardt, "Process for fabricating a component comprising a layer made of single-crystal material compatible with high thermal budgets", US Patent 2022/0166398 A1.
- [7] S. Marksteiner *et al.*, "Optimization of acoustic mirrors for solidly mounted BAW resonators," 2005 IEEE Ultrasonics Symposium, pp. 329-332.

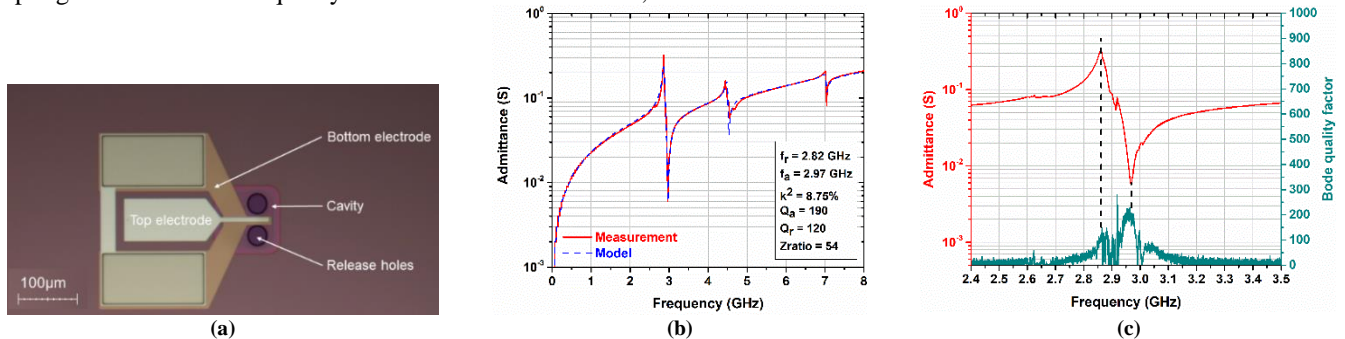


Fig. 2. 8-inch Y+42°-cut LiTaO₃ FBAR: (a) optical micrograph of a single resonator, (b) typical response (continuous red curve) and fit of the electric response (Mason's model, dashed blue curve), and (c) comparison between the measured admittance (red) and the calculated Bode quality factor (green).

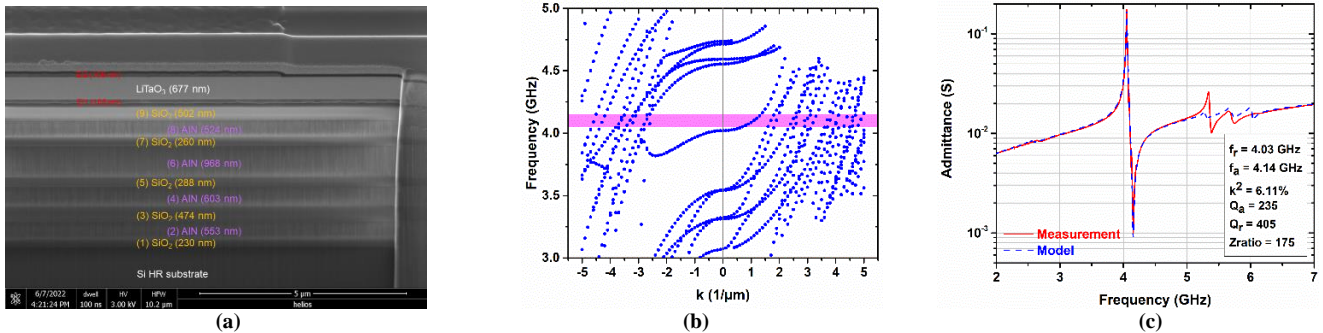


Fig. 3. 8-inch Y+42°-cut LiTaO₃ SMR: (a) cross-sectional view, (b) dispersion curves and (c) typical response (continuous red curve) and fit of the electric response (Mason's model, dashed blue curve).