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Thickness shear mode BAW resonator based on epitaxial $(10\bar{1}2)$ $LiNbO_3$ / $(11\bar{2}0)$ AZO / $(10\bar{1}2)$ Al_2O_3

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1. Introduction

$LiNbO_3$ crystal is suitable for SAW filter applications because of their high Q and electromechanical coupling coefficient k. However, $LiNbO_3$ films have not been successful in the BAW industry because thickness extensional mode k_t^2 in the easily grown c-axis oriented $LiNbO_3$ film is significantly low (k_t^2 = 4%), as shown in **Fig. 1**. To obtain high electromechanical coupling, quasi-shear mode k_{35}^2 in the 168° Y-cut $LiNbO_3$ is the best candidate as shown in **Fig. 1**. Therefore, the mechanical thinning of bulk $LiNbO_3$ single crystal plate has been used to obtain the thin single crystalline layer for BAW resonators.[1-4] However, the wafer size of these top-down process is limited to 6 inch which is the size of the bulk $LiNbO_3$ single crystal wafer. In contrast, bottom-up process such as sputtering growth is well-developed in the 8 inch wafer such as AlN films. For bottom-up proccess, Park's group achieved the epitaxial growth of $(10\bar{1}2)$ $LiNbO_3$ films on $(10\bar{1}2)$ Al_2O_3 single crystal substrate.[5] In order to estimate electromechanical coupling and to characterize resonator properties of $(10\bar{1}2)$ $LiNbO_3$ layer, epitaxial bottom electrode layer is required. In this study, we reported the epitaxial growth of $(10\bar{1}2)$ $LiNbO_3$ on epitaxial $(11\bar{2}0)$ Al doped conductive ZnO layer (AZO)/$(10\bar{1}2)$ Al_2O_3 substrate. Shear mode acoustic properties of the resonator were then investigated.

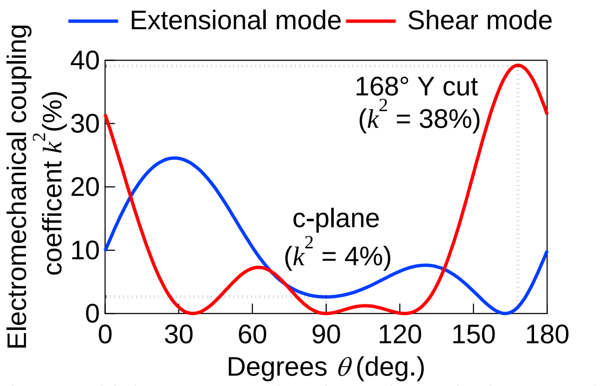

Fig. 1 Thickness extensional mode and shear mode electromechanical coupling k^2 as a function of angle in $LiNbO_3$.

2. Crystallographic orientation

The epitaxial film resonators for $(10\bar{1}2)$ $LiNbO_3$ film was fabricated by RF magnetron sputtering technique. The resonator has with Au film / epitaxial $(10\bar{1}2)$ $LiNbO_3$ film (900 nm) / $(11\bar{2}0)$ Al doped conductive ZnO layer (AZO) / $(10\bar{1}2)$ Al_2O_3 substrate (0.5 mm) structure. The crystalline properties were evaluated by the X-ray diffraction. **Fig. 2** show the XRD patterns of AZO layer and $LiNbO_3$ layer of $(10\bar{1}2)$ $LiNbO_3$ films, respectively. $(10\bar{1}2)$ $LiNbO_3$ peak and $(11\bar{2}0)$ AZO were clearly observed. Rocking curve FWHM of $(11\bar{2}0)$ AZO layer and $(10\bar{1}2)$ $LiNbO_3$ layer was found to be 1.5° and 5.7°, respectively.

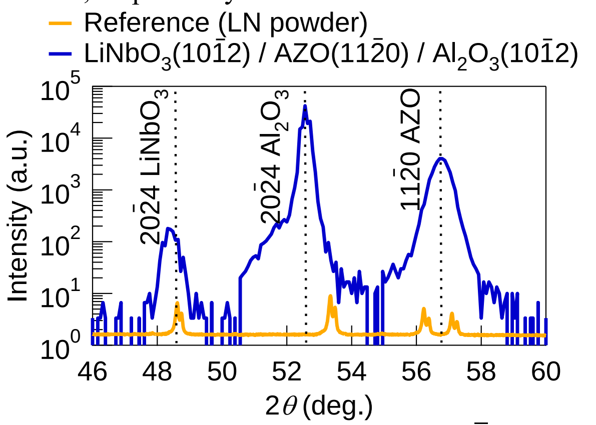

Fig. 2 2θ-ω scan XRD patterns of epitaxial $(10\bar{1}2)$ $LiNbO_3$ film / $(11\bar{2}0)$ AZO / $(10\bar{1}2)$ Al_2O_3 substrate.

The epitaxial growth of the $(10\bar{1}2)$ $LiNbO_3$ resonator was investigated by the of $(10\bar{1}4)$ XRD pole figure. $LiNbO_3$ XRD peak was expected to appear near the Al_2O_3 peak because their crystal structures were based on trigonal system. Therefore, the XRD patterns of $(10\bar{1}2)$ $LiNbO_3$ resonator at χ = 42° were measured as shown in **Fig. 3**. $LiNbO_3$ XRD peak and Al_2O_3 peak are successfully separated.

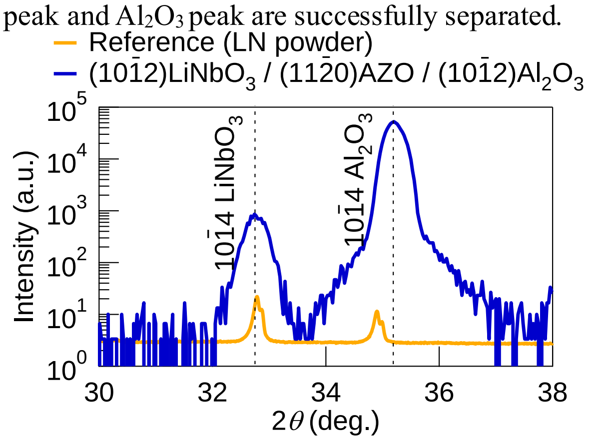

Fig. 3 2θ-ω scan XRD patterns (χ = 42°) of epitaxial $(10\bar{1}2)$ $LiNbO_3$ film.

As shown in **Fig. 4**, pole concentration in the $(10\bar{1}4)$ pole figure indicates epitaxial growth of $(10\bar{1}2)$ $LiNbO_3$ film because two of the three-fold symmetry of the pole figure are observed.

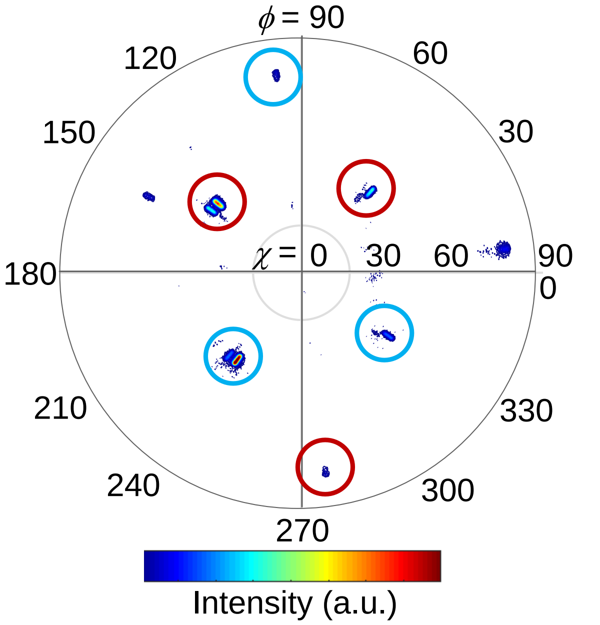

Fig. 4 $(10\bar{1}4)$ pole figure of epitaxial $(10\bar{1}2)$ $LiNbO_3$ film/ $(11\bar{2}0)$ AZO / $(10\bar{1}2)$ Al_2O_3 substrate.

3. Impulse response

Piezoelectric properties of resonators were evaluated by time domain impulse responses and insertion loss. First, S_{11} were measured by network analyzer. The time domain impulse response was obtained by inverse Fourier transform of S_{11}. The time domain impulse response of the $(10\bar{1}2)$ $LiNbO_3$ resonator was shown in **Fig. 5.** Time interval of longitudinal wave echo can be predicted from acoustic velocity and thickness of the substrate. From the result, $(10\bar{1}2)$ $LiNbO_3$ resonator clearly excited the shear waves, as expected. Fourier transform of the response showed the quasi-shear mode operation of the $LiNbO_3$ layer in the 1.1 GHz.

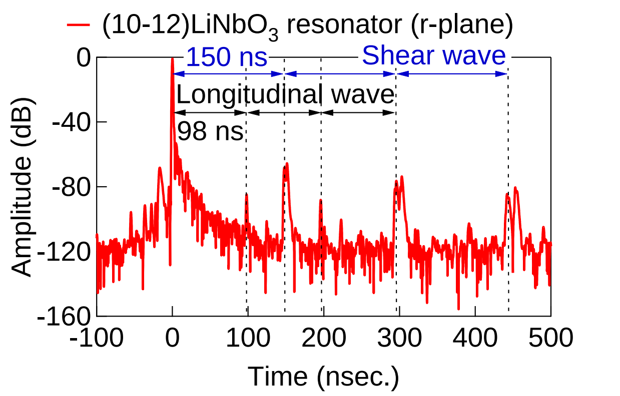

Fig. 5 The time domain impulse response obtained from an inverse Fourier transform of S_{11}.

4. Conclusions

We demonstrate the epitaxial growth of $(10\bar{1}2)$ $LiNbO_3$ film by RF magnetron sputtering technique. The shear wave excitation was observed in the epitaxial $(10\bar{1}2)$ $LiNbO_3$ film.

In the future, we would like to estimate an electromechanical coupling coefficient quasi-shear mode k_{35}^2 in the epitaxial $(10\bar{1}2)$ $LiNbO_3$ film

Acknowledgment

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References

1. M. Bousquet, P. Perreau, C. Maeder-Pachurka, A. Joulie, F. Delaguillaumie, J. Delprato, G. Enyedi, G. Castellan, C. Eleouet, T. Farjot, C. Billard, and A. Reinhardt, in *Proceedings of IEEE International Ultrasonics Symposium* (IEEE,2020), pp. 1-4.
2. M. Bousquet, M. Bertucchi, P. Perreau, G. Castellan, C. Maeder-Pachurka, D. Mercier, J. Delprato, A. Borzi, S. Sejil, G. Enyedi, J. Dechamp, M. Zussy, P. Sylvia Pokam Kuisseu, F. Mazen, C. Billard, and A. Reinhardt, in *Proceedings of IEEE International Ultrasonics Symposium* (IEEE,2019), pp. 84-87.
3. L. Lv, Y. Shuai, X. Bai, S. Huang, D. Zhu, Y. Wang, J. Zhao, W. Luo, C. Wu, and W. Zhang, in IEEE Trans. Ultrason., Ferroelect., Freq. Contr., **69**, 1535-1541 (2022).
4. Z.-H. Qin, S.-M. Wu, Y. Wang, K.-F. Liu, T. Wu, S.-Y. Yu, and Y.-F. Chen, Micromachines, **12**, 1039 (2021).
5. Sung-Kun PARK, Min-Soo BAEK, Seoung-Choon BAE, Ki-Wan KIM, Sung-Yul KWUN1, Young-Jin KIM2, and Jee-Hyun KIM3, Jpn. J. Appl. Phys., **38**, 4167-4171 (1999).

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