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# Ultra Wide Band and High Frequency Resonators using SH Type Plate Wave in $LiNbO_3$ Thin Plate

## $LiNbO_3$ 薄板内の SH 型板波を用いた広帯域・高周波共振子

Michio Kadota[1], Yasuhiro Kuratani[2], Tetsuya Kimura[2], Masayoshi Esashi[1] and Shuji Tanaka[1]
([1]Tohoku University, [2]Murata Mfg. Co. Ltd.)
門田 道雄 [1], 倉谷 康博 [2], 木村 哲也 [2], 江刺 正喜 [1], 田中 秀治 [1] ([1] 東北大学, [2] 村田製作所)

## 1. Introduction

Tunable filters with wide tuning range are required by advanced mobile phones to simplify the wireless front-end circuit of a multiband or cognitive radio system [1]. Although various tunable filters were proposed, their tunable ranges were not sufficient for such applications [2]-[6]. To achieve wider frequency tunability, an ultra-wideband resonator is a key device. The most straightforward method is to use bulk or surface acoustic waves with large electromechanical coupling factor $k^2$.

The authors reported that 0th shear horizontal ($SH_0$) mode of a plate wave in a 30º YX-$LiNbO_3$ plate thinner than $0.1\lambda$ ($\lambda$: wavelength) had an ultra-large coupling factor of 55% [6]. Also, the authors reported that 2 MHz range $SH_0$ mode plate wave resonators with an Al interdigital transducer (IDT) on a single or double side of a $LiNbO_3$ substrate had ultra-wide bandwidths of 26~29% and large impedance ratios of 92~98 dB between resonance and anti-resonance frequencies ($f_r$ and $f_a$) [7]. The resonators were applied to a ladder type tunable filter in conjunction with variable capacitors, and achieved a tunable range of 13% [8]. Although this low frequency demonstration was promising, edge reflectors, which were used in the 2 MHz range resonators, cannot be used in high frequency devices, because the position accuracy of the edge reflectors (typically < $0.1\lambda$) is difficult to guarantee. In addition, ripples between $f_r$ and $f_a$ due to transverse modes must be suppressed.

In this study, we fabricated and tested high frequency $SH_0$ plate resonators using an extremely thin $LiNbO_3$ plate to meet the frequency range of digital terrestrial TV band (470~770 MHz), in which cognitive radio is being standardized as IEEE 802.11af. Also, the problems regarding the ripples and the position accuracy of the reflectors were addressed using an apodized IDT and grating reflectors, respectively.

## 2. Design

$SH_0$ plate wave shows large coupling factor in a 30º YX-$LiNbO_3$ plate thinner than $0.1\lambda$, whereas the phase velocity of $SH_0$ plate wave is as low as 5000 m/s as shown in Fig. 1. Therefore, a fine-pitched IDT on a very thin plate is required for a high frequency resonator with large coupling factor. The main design parameters of the $SH_0$ plate wave resonators are shown in Table I with those of a low frequency resonator reported in Ref. [7]. The $SH_0$ mode plate wave resonators use a self-suspended 0.5 μm thick 30º YX-$LiNbO_3$ plate, on which an Al IDT and grating reflectors are fabricated, as shown in Fig. 2. The IDT is apodized in a diamond shape.

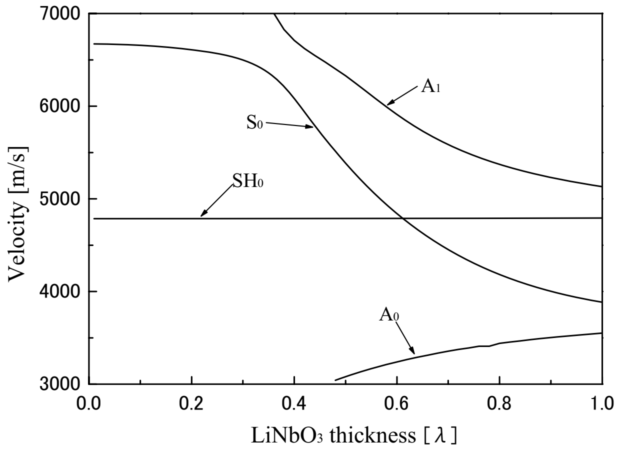


Fig. 1 Calculated phase velocity of plate waves on 30° YX-$LiNbO_3$ as a function of plate thickness.

Table I Design parameters of $SH_0$ mode plate wave resonators.

| | Low freq. type [7] | High freq. type (This study) | | | |
|---|---|---|---|---|---|
| $f_r$ (MHz) | 1.8 | 430 | 460 | 530 | 560 |
| Plate thickness (μm) | 200 ($0.1\lambda$) | 0.5 ($0.06\lambda$~$0.08\lambda$) | | | |
| $\lambda$ (μm) | 2000 | 6.2 | 6.4 | 7.43 | 7.75 |
| IDT pairs | 20 | 20 | 40 | 20 | 40 |
| AR | 0% | 0%, 60% or 100% | | | |
| Metalization ratio | 0.3 | 0.34 | | | |
| Reflector | Edge type | Grating type | | | |
| Structure | IDT/LN/IDT<br>IDT/LN | IDT/LN | | | |

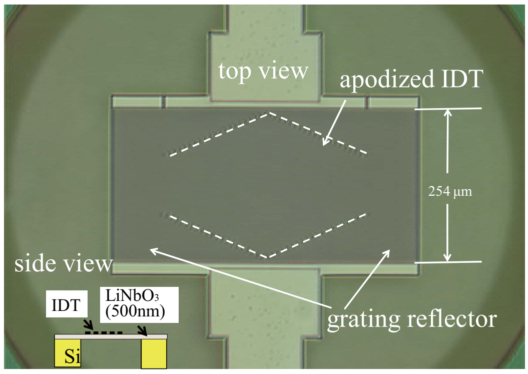


Fig. 2 High frequency $SH_0$ plate wave resonator fabricated on a 0.5μm thick 30º YX-$LiNbO_3$ plate (AR = 60%).

## 3. Result

Figure 3 shows the frequency characteristics of the fabricated resonators with $\lambda$ of 6.4 μm. The resonators have different apodization ratios (AR) of 0% (i.e. no apodization), 60% and 100%, where AR is defined as 1 – (minimum aperture)/(maximum aperture). For example, the IDT shown in Fig. 2 has AR of 60%. Ripples between $f_r$ and $f_a$ were suppressed, when AR was 60% and 100%, whereas ripples were found without apodization as observed for the low frequency resonator. In exchange, the apodization needs to pay a small penalty for bandwidth and impedance ratio.

Figure 4 shows the frequency characteristics of 4 kinds of high frequency resonators shown in Table I with AR of 100%. Although the bandwidth and impedance ratio decreased slightly by apodization, as already mentioned, the impedance ratio as high as 80 dB and a wide bandwidths of 22% were achieved without ripples at high frequency ($f_r$ = 440~560 MHz). To our best knowledge, this performance is the best achievement in this frequency range.

Although ripples between $f_r$ and $f_a$ due to transverse modes disappeared, spurious responses were observed in a frequency range higher than $f_a$, as shown in Figs. 3 and 4. Such spurious responses were not found in the low frequency resonator [7], and thus we inferred that the spurious responses were caused by a lack of the finger number of the grating reflectors. The plate wave might not reflect completely at the grating reflectors and partially reflect at the substrate edges, resulting in the spurious responses. It is expected that the bandwidth and impedance ratio would be also improved by optimizing the reflectors as well as the IDT. In addition, further improvement in the bandwidth is expected using IDT/$LiNbO_3$/IDT structure, but the fabrication is a challenging problem left for the future study.

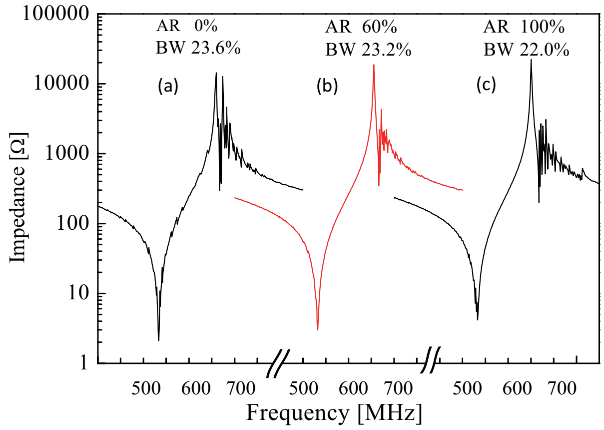


Fig. 3 Frequency characteristics of resonators with 3 kinds of apodization, (a) AR = 0%, (b) AR = 60% and (c) AR = 100%.

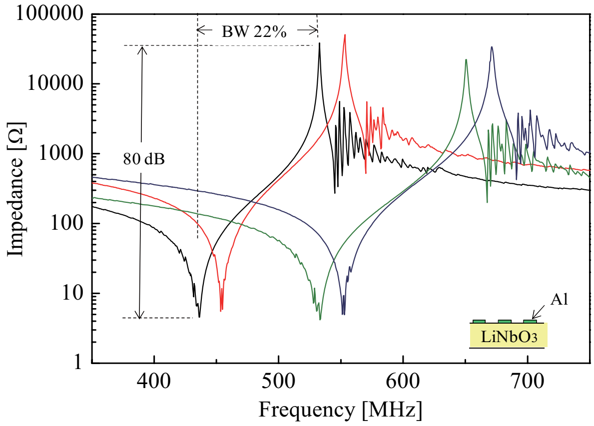


Fig. 4 Frequency characteristics of high frequency resonators shown in Table I.

## 4. Conclusion

In our previous study, macroscale $SH_0$ mode plate wave resonators with an ultra-wide bandwidth and a large impedance ratio were designed, prototyped and evaluated. Based on the result, the following 3 issues were addressed in this study; (1) low frequency operation, (2) ripples due to transverse modes, and (3) reflection at free plate edges, which cannot be used for high frequency resonators. Our approaches are thinning a $LiNbO_3$ plate from 200 μm to 0.5 μm in thickness for (1), apodizing IDTs for (2), and using grating reflectors for (3). The fabricated high frequency resonators for TV white band ($f_r$ = 430~560 MHz and $f_a$ = 450~670 MHz) showed a wide bandwidths of 22% and a large impedance ratios of 80 dB and without ripples between $f_r$ and $f_a$.


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