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Suppression Rayleigh Wave Spurious Signal in SH-SAW Devices Employing PMN-33%PT crystals

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1. Introduction

The (001)-poled ferroelectric PMN-xPT crystals are known to have ultrahigh electromechanical coupling factors (k_{33}>90%) near the morphotropic phase boundary (MPB)[1-2]. Nakamura et al.[3] theoretically studied acoustic properties of the crystals, and inidicated existence of an shear-horizontal (SH) surface acoustic wave (SAW) with a large coupling factor k^2 of ~50% on rotated YX PMN-33%PT over a wide range of cut angles. This value is a few times larger than that achievable on rotated Y-cut $LiNbO_3$. The high coupling factor seems very attractive for realization of wideband SAW filters, however no further discussion has been reported until now.

This paper theoretically studies how main and spurious responses change with choice of the substrate rotation angle and the electrode material and height. The results show that the spurious signals can be suppressed successfully under their proper combination without badly sacrificing k^2 for the main response. It is also shown how wideband filters can be realized by using the optimized configuration.

2. Simulation results

Fig. 1 shows the effective permittivity $\varepsilon(V^{-1})$ of 40°YX-PMN-33%PT substrate. The horizontal axis is normalized by $\varepsilon(\infty)$. There is a strong pole with large difference between V_f=1502.0 m/s giving $\varepsilon(V_f^{-1})$=0 and V_m=1099.7 m/s giving $\varepsilon(V_m^{-1})$=0. This is due to the SH SAW. There is another pole with relatively small difference between V_f=1907.7 m/s and V_m=1861.9 m/s. This is due to the Rayleigh SAW. Since its velocity is not so different from that of the SH SAW, the Rayleigh SAW response must be suppressed sufficiently.

First, we investigated how k^2 of these modes changes when a uniform metal layer is deposited on the surface. We estimated k^2

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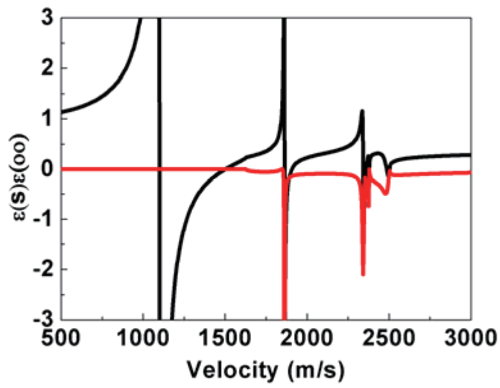

Fig.1 Effective permittivity $\varepsilon(V^{-1})$ as a function of velocity for 40°YX-PMN-33%PT

from their residue[4]. Figure 2 shows k^2 as a function of the rotation angle θ for YX-PMN-33%PT. In the calculation, electrode is gold (Au) and the thickness (h/λ) is selected to be 6.0%.

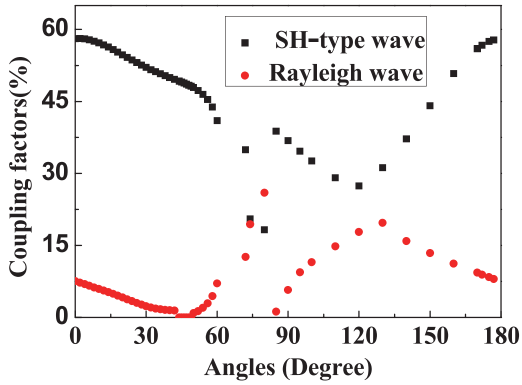

Fig.2 Dependence of Mechanical coupling factors on rotated angles

It is seen that k^2 for the Rayleigh SAW is close to 0 when θ equals to 48°, where k^2 for the SH SAW is about 48%. This value is about 20% smaller than the value (60%) achievable using the substrate material (θ≈0° and h=0).

There is a sudden change in k^2 at θ≈75°, which is due to the coupling between SH-type and Rayleigh SAWs. When h/λ<6.0%, the bulk wave cut-off frequency is close to the anti-resonance frequency. On the other hand, when h/λ>6.0%, although minimum k^2 for the Rayleigh SAW is almost zero, while k^2 for the SH SAW becomes also small.

We also examined use of Cu and Al as metal layer. However, we could not find combinations of h and θ giving sufficient suppression of the Rayleigh SAW without badly reducing k^2 for the SH SAW.

Fig. 3 shows the calculated input admittance $Y(f)$ per period of infinitely long IDTs on θ=0° with a Au grating of 0.12p thickness as a function of the relative frequency fp/V_B, where p is the grating period and V_B is the slow shear bulk wave velocity (1626.6 m/s). The vertical axis is normalized by ωε(∞). The resonance (f_r) and anti-resonance (f_a) frequencies giving $\hat{Y}(f)^{-1}$=0 and $\hat{Y}(f)$=0 are seen at 0.288 and 0.466, respectively, for the SH SAW.

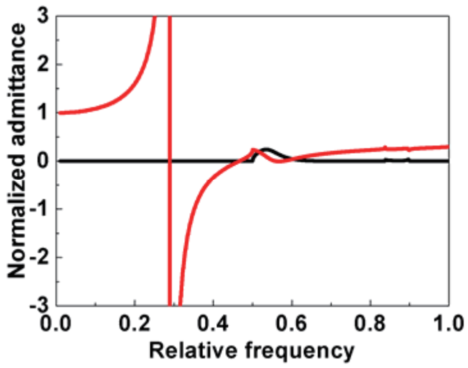

Fig.3 Input admittance per period of infinitely long IDTs when θ= 0°

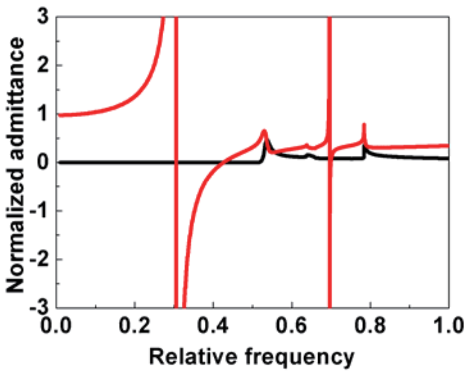

Fig.4 Input admittance per period of infinitely long IDTs when θ=48°

Fig.4 shows the calculated Y(ω)/ωε(∞) on θ=48° under the same conditions for Fig. 3. In the case, f_r and f_a locate at 0.30 and 0.422, respectively. Compared to θ=0°, the location of Rayleigh wave moves away from main resonance and the coupling becomes weaker. We have also calculated the capacitance ratio γ of the two cut types which are 0.62 and 1.02, respectively, which are much smaller than 3.3 for 15°YX-$LiNbO_3$. Smaller γ is feasible to obtain wider tunable range for the tunable filters [5].

Applicability of these materials to the ladder filter was examined. Simulation was performed by regarding $Y(f)$ shown in Figs. 3 and 4 as impedance of resonators in the filter configuration. Fig. 5 shows the result. For θ=48°, -3 dB bandwidth is about 47%. The spurious response due to the Rayleigh SAW is small and locates at relatively far from the passband. For θ=0°, on the other band, -3 dB bandwidth is wider. However, the filter characteristics is seriously deteriorated by the Rayleigh SAW and bulk waves.

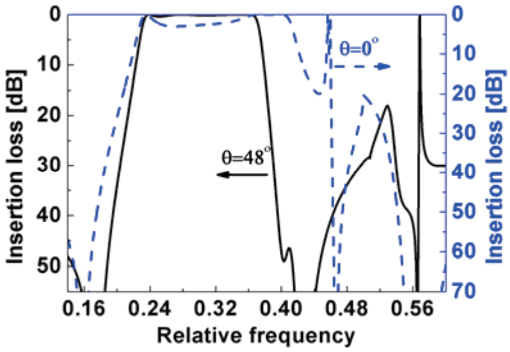

Fig.5 Frequency response of ladder-type filters when θ=0° (dot line) and 48° (solid line)

3. Conclusions

It was shown that spurious signals in rotated YX-PMN-33%PT are successfully suppressed without badly reducing k^2 by proper setting of the metal layer thickness and the rotation angle. With θ=48°, k^2 for the SH SAW is 48%, while that for the Rayleigh SAW is almost zero. This implies that the fractional –3 dB bandwidth of 47% is achievable when the ladder-type filter is composed.

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