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S_0-Like Lamb Mode Resonator on $LiNbO_3/SiO_2/SiC$ Structure

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1. Introduction

Kimura, et al, proposed use of the 0-th order symmetric (S_0)-like Lamb mode on the LN thin plate mounted on the Bragg reflector (see Fig. 1(a))[1] because of its high phase velocity V_p, is insensitivity to plate and electrode thicknesses, and large electromechanical coupling factor K^2. In addition, S_0-like mode resonators can tune resonance frequencies by IDT period p_I. This feature is advantageous than XBAR[2] for mass production although achievable K^2 is smaller. Note that the Bragg reflector is used to suppress energy leakage to the Si base substrate.

Although higher K^2 is achievable by using a free standing LN thin plate[3], the device structure is inferior in terms of power handing and physical strength[4].

Recently, Zhou, et al, proposed use of SiC as the base substrate for S_0-like resonators (see Fig. 1(b)).[5] SiC is known to possess very high acoustic wave velocity, and the energy leakage can be suppressed for a wide frequency range without using the Bragg reflector.

The original S_0 mode exists in thin plates when both the top and bottom surfaces are mechanically free. In contrast, large acoustic impedance of SiC clamps the LN bottom surface and their direct bonding is expected to degrade achievable device performances.

In this paper, the author proposed to sandwich the SiO_2 layer between LN thin film and SiC plate to enhance the device performances (see Fig. 1(c)).

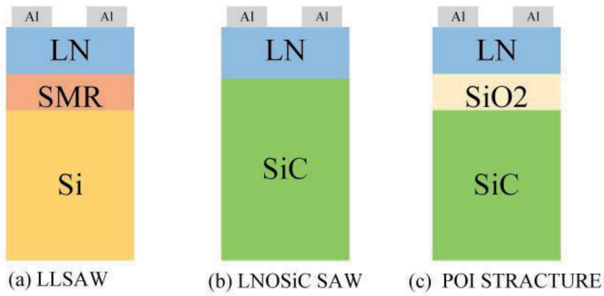

Fig. 1 S_0-like mode resonator structures.

2. Properties of S_0 Mode in LN Thin Plate

First, basic properties of the S_0 Lamb mode are retrieved for the LN thin plate. Since it is known that properties of the S_0 mode are not sensitive to the LN plate thickness t_{LN}, we fix it at $0.2p_I$ in the following calculations.

Fig. 2 shows variation of K^2 of S_0 and SH_0 modes with the propagation direction α on the X-cut LN thin plate. It is seen that K^2 of the SH0 mode is small and that of the S_0 mode is large (~27%) when α is 40°. Note V_p of the S_0 and SH_0 modes are circa 6,100 m/s and 4,000 m/s, respectively, and are relatively insensitive to α.

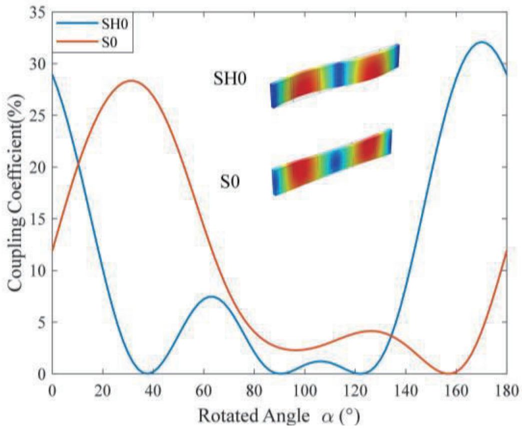

Fig. 2 Change of K^2 for S_0 and SH_0 modes with α.

Fig. 3 shows change of K^2 and V_p with the Al electrode thickness t_{Al} when t_{LN} and the metallization ratio MR are set at 0.2 p_I and 0.4, respectively. Due to the mass loading, V_p decreases monotonically with t_{Al} while K^2 takes a maximum at t_{Al}~$0.04p_I$ and then decreases monotonically with t_{Al}. This dependency can be understood as t_{Al} increase enhances concentration near the top surface and results in K^2 increase at first, further t_{Al} increase makes wave field asymmetry significant and results in K^2 decrease.

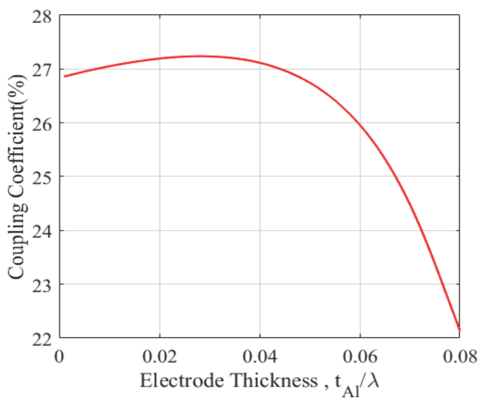

Fig.3 Change of K^2 and V_p with Al electrode thickness.

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3. Properties of S_0-like Lamb Mode in $LN/SiO_2/SiC$ Configuration

Next, properties of the S_0-like mode in the $LN/SiO_2/SiC$ configuration are studied. Fig.4 shows variation of K^2 and V_p with the SiO_2 thickness t_{SiO2} when t_{Al}, t_{LN} and MR set at $0.05p_I$, $0.2p_I$ and 0.4, respectively. As we expected, impact of SiO_2 is significant: K^2 increases from 15.6% to 23% with insertion of SiO_2 of $t_{SiO2}=0.08p_I$. As a trade-off, V_p decreases a lot.

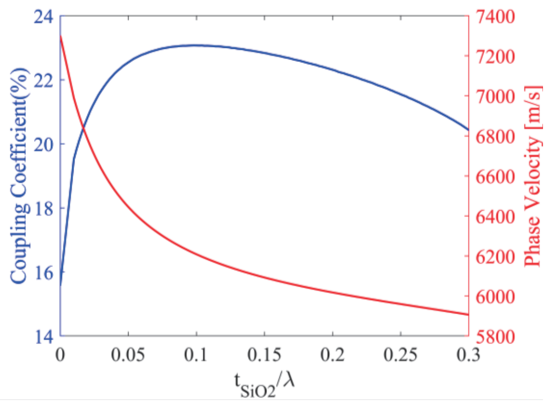

Fig. 4 Variation of K^2 and V_p with SiO_2 thickness.

Fig. 5 compares calculated admittance Y and conductance G of two S_0-like Lamb mode resonators, i.e, with and without sandwiched SiO_2 layer ($t_{SiO2}=0.1p_I$) when t_{Al}, t_{LN}, p_I, and MR set at $0.05p_I$, $0.2p_I$, 2 μm and 0.4, respectively. It is seen that the SiO_2 layer expands separation between resonance and anti-resonance frequencies significantly. Although it reduces V_p given by f_r/p_I, the value is still very high (~6,300 m/s).

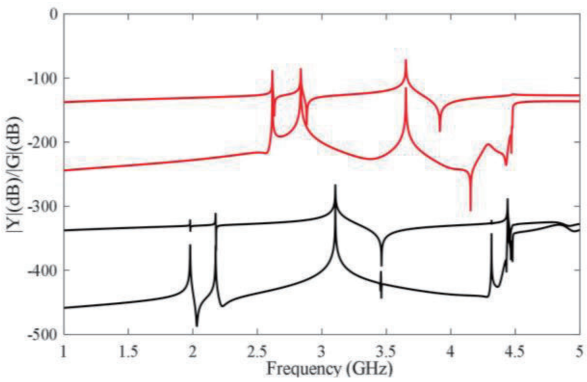

Fig. 5 Comparison of admittance and conductance between two resonators with and without SiO_2 layer.

The cutoff of bulk radiation is seen at 4.5 GHz, which is determined by the velocity of slow-shear wave in SiC. Theoretically, the leaky loss is zero below this frequency and finite G is due to tiny losses added in these calculation.

Two spurious resonances are seen below the main resonances, and those at 1.9 GHz and 2.1 GHz are due to Rayleigh and SH0-like modes, respectively. They may be able to be further suppressed in some extent by finely adjusting both the rotation and cut angles of the LN plate.

Only when SiO_2 is added, two spurious resonances are also seen near the bulk wave cutoff. They are due to higher-order plate modes. Although these resonances can be shifted to higher frequencies by reducing t_{LN} and/or t_{SiO2}, they will also give impacts to achievable performances and/or manufacturability.

4. Conclusion

This paper discussed the influence of bulk wave radiation on S0 mode and the methods to suppress and avoid it. A new structure has been proposed. Compared with the conventional structures, it has several advantages.

It's shown that the inserting SiO_2 isolation layer can not only further separate bulk wave radiation frequency and main mode frequency but also enhance K^2 significantly. Besides, SiO_2 has a negative temperature coefficient which can provide additional temperature compensation.

For the next step, the authors will discuss the suppression of transverse modes.

Acknowledgment

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5.References

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