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Use of Periodic 2D Pillar Array for Performance Enhancement of AlN-based SMR BAW Resonators

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1. Introduction

Bulk acoustic wave (BAW) resonators based on the thin-film technologies are widely used in modern communication equipment [1]. Solidly mounted BAW (SMR-BAW) resonators possess several advantages such as good power durability compared with free-standing BAW resonators called FBAR [2].

However, SMR-BAW resonators also have some demerits. One is reduction of the effective coupling factor $k_{\rm eff}^2$ due to penetration of acoustic waves into the Bragg reflector [3]-[4]. Second is necessity of certain number of layers for the acoustic mirror to achieve enough acoustic reflectivity [5].

This paper discusses enhancement of $k_{\rm eff}^2$ and acoustic reflectivity of the acoustic mirror by the use of periodic 2D pillar array as the first layer of acoustic mirror in AlN-based SMR BAW resonators.

2. Basic Structure

Fig. 1(a) shows basic configuration of the periodic 2D pillar array discussed in this paper. The portion framed by dotted red lines is the unit cell of a period. Gaps among pillars are vacant, i.e., vacuum. When the periodicity is set much smaller than the lateral acoustic wavelength, the structure looks like uniform, and its properties are simply given by ensemble average of those of employed pillar material and air [6]. Furthermore, owing to the periodicity, scattering does not occur except reflection due to impedance mismatch intrinsically, which means this configuration is ideally acoustic lossless.

Fig. 1(b) shows a model of the AlN-based SMR-BAW resonator for 3D periodic FEM where the SiO_2 2D pillar array is given as the first layer of the acoustic mirror composed of SiO_2 and W with thicknesses of 0.7 µm and 0.6 µm, respectively. Thicknesses of Ru electrodes and AlN are set at 0.3 µm and 1 µm, respectively. Periodic boundary conditions are given to side edges, and the perfect matching layer is given to the Si bottom surface.

Fig. 1(c) shows the cross sectional view where design parameters of pillar width w, thickness h and periodicity P are defined. Due to in-plane isotropy of AlN, P and w for the x-direction are set equal to those for the y-direction. Then the configuration will exhibit the 4mm crystallographic symmetry.

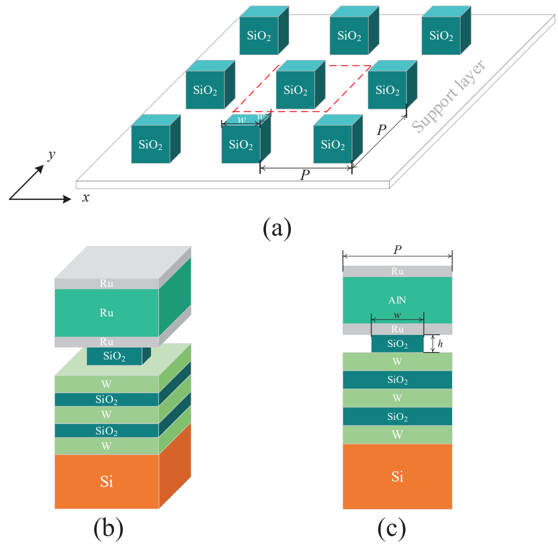

Fig. 1 (a) Structure of periodic pillar array; (b) Periodic 3D FEM model; (c) Cross sectional view.

3. k_{eff}^2 Enhancement

First, P is set very tiny (10 nm) to making it look like uniform. The effective coupling coefficient $k_{\rm eff}^2$ defined as

$$k_{\rm eff}^2 = \frac{\pi^2}{8}\frac{(f_{\rm a}^2 - f_{\rm r}^2)}{f_{\rm a}^2}$$

is estimated as functions of h and w/P. In the equation, $f_{\rm r}$, $f_{\rm a}$ are the resonance and anti-resonance frequencies, respectively.

Fig. 2 shows variation of $k_{\rm eff}^2$ with $h/t_{\rm AlN}$ and w/P. It is seen that $k_{\rm eff}^2$ changes parabolically with $h/t_{\rm AlN}$ and takes a maximum when $h/t_{\rm AlN}$~0.6. On the hand, $k_{\rm eff}^2$ increases monotonically with a decrease of w/P, and becomes insensitive to $h/t_{\rm AlN}$. Note that $k_{\rm eff}^2$ in this configuration is 8.01% for the free standing

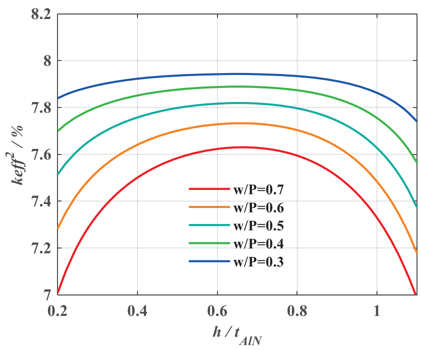

Fig. 2 Variation of $k_{\rm eff}^2$ with h and w.

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FBAR and that of SMR-BAW with uniform SiO_2 is 7.17%.

Fig. 3 shows admittance Y characteristics of SMR BAW resonators with and without slotted SiO_2 with w/P=0.4 and h/t_{AlN}=0.7. The slotted pillars can enhance k_{eff}^2 without generating spurious resonances.

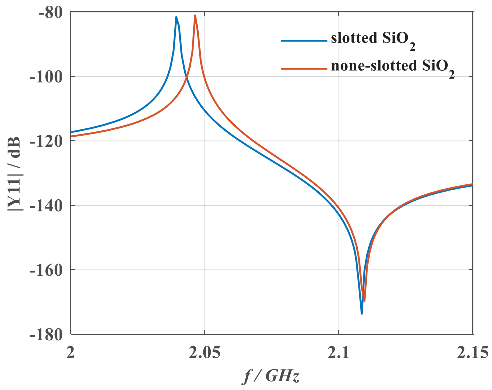

Fig. 3 Y of SMR BAW resonators. Blue: structure with slotted pillars, and orange: structure without slotted pillars.

Next, w/P and h/t_{AlN} are fixed at 0.3 and 0.7, respectively, and variation of with P is investigated. **Fig. 4** shows the result. With an increase in P, a spurious resonance appears close to the main resonance, and overlaps with it. This spurious response is caused by coupling between the thickness resonance and that of the pillars. This spurious resonance seems insignificant when P is set smaller than 1 μm.

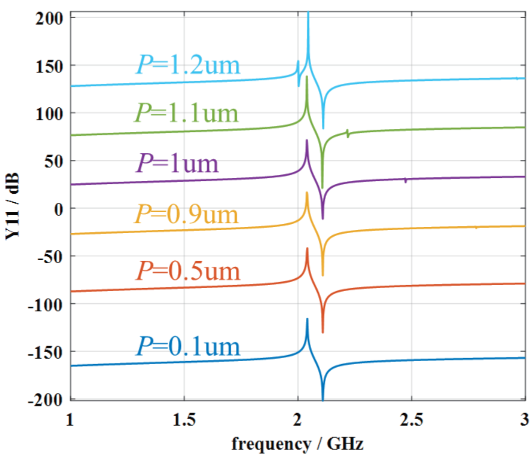

Fig. 4 Variation of Y with P.

4. Reflectance Enhancement

Since slotted SiO_2 is expected to possess lower acoustic impedance than non-slotted one[6], application of slotted SiO_2 is expected to enhance reflectance of the Bragg reflector.

Fig. 5 shows variation of Bode Q with the number N of Bragg reflector layers. Two types of calculations are shown: a) with the slotted SiO_2, and b) without the slotted SiO_2. In these calculations, P, h and w/P are equal to 0.7 μm, 0.7 μm, and 0.5, respectively. The Q enhancement is obvious. Namely, relatively high Q close to 5,000 can be achievable even at N=2 when the slotted SiO_2 is applied while N=4 is necessary to get reasonable Q when the slotted SiO_2 is not applied.

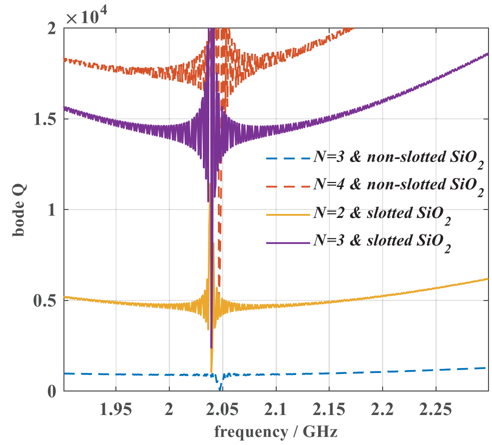

Fig. 5 Variation of Bode Q with the number of Bragg reflector layers.

5. Conclusion

This paper discussed applicability of periodic 2D pillar array to the AlN-based SMR BAW resonators. It was shown that k_{eff}^2 can be enhanced close to that of FBAR when w/P is set small. It is also shown that use of the 2D pillar array also enhances reflectivity of the Bragg reflector.

The periodic 2D pillar array can also control anisotropy of plate wave propagation along the surface, and the anisotropy gives significant impact to transverse mode resonances. Detailed discussions will be given at the Symposium.

Acknowledgment

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