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Application of Film Bulk Acoustic Wave Resonator for Sensitive Mass Sensor

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Film Bulk Acoustic wave Resonator (FBAR) is one of the band pass filters employed for high frequency devices. In order to apply FBARs to sensitive mass sensor, quality factor defined by the ratio of the resonance frequency to the full width at half maximum for the frequency characteristics is required to be large. In this study, operating characteristic for the FBAR was analyzed using the commercialized software Ansys (Ansys Inc.) which solves electric field-structure coupled problems using a 3 dimensional finite element method. A change in resonance frequency for the FBAR due to additional weight was confirmed by the simulation, and the FBAR was estimated to show the 10 Hz of the change in the resonance frequency for 2 GHz band operation when 2 pg of additional weight was loaded. Thereby the FBAR was considered to work as a sensitive mass sensor. The electrode materials were found to affect quality factor, and the highest quality factor was also found to be obtained when the electrode is TiN compared with Mo, Ru, Rh and W.

Key words: Film bulk acoustic wave resonator, Quality factor, Piezoelectric film, Electrode

1. INTRODUCTION

Film Bulk Acoustic wave Resonator (FBAR) which is utilized for wireless communication devices, is one of the band pass filters and is applied as a duplexer, resonator for oscillators. A conventional FBAR is composed of a piezoelectric film sandwiched by two electrodes. The thickness of piezoelectric film must be equivalent the half of the wavelength of RF signals in order to utilize FBAR as a band pass filter. AlN is mostly used as a piezoelectric material for FBAR[1-2], because the acoustic velocity of AlN is very high and the thickness for GHz operation is easily obtained by the sputtering method. The RF signals through the piezoelectric film when RF frequency corresponds to the resonance frequency for the piezoelectric film. The resonance frequency strongly depends on weight loaded on the electrodes. The behavior that the resonance frequency is sensitive to the weight loaded on the electrode, is considered to be available as a mass sensor by locating a sensitive membrane to gases and so on[3]. High quality factor, Q, is required to detect the change in resonance frequency with high resolution in order to utilize FBAR as a sensitive mass sensor. In this study, the effect of geometric properties on Q was estimated and the change in resonance frequency for FBARs due to the additional weight to electrodes was also estimated by a 3 dimensional finite element method.

2. CALCULATION MODEL

Typical structure of FBAR is shown in Fig. 1. Air cavity is placed below the lower electrode not to suppress the vibration of the piezoelectric thin film. The piezoelectric film vibrates in the z-direction, when the voltage of RF signals is applied to electrode. The material for the piezoelectric thin film and the substrate are assumed to be AlN and Si, respectively, in this calculation. The thickness of the AlN film is 3.32 μm, which corresponds to 1.7 GHz of the resonance frequency. The electromechanical coupled coefficient, acoustic velocity and density for the AlN were set to 6.5, 11300 m/s and 3255 kg/m^3, which are the typical values for the AlN. The anisotropic elastic, piezoelectric and dielectric matrixes for the AlN included in the calculation are expressed as below.

$$(\text{Anisotropi c elastic matrix}) = \begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ 0 & C_{11} & C_{13} & 0 & 0 & 0 \\ 0 & 0 & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & (C_{11}/C_{12})/2 \end{pmatrix}$$

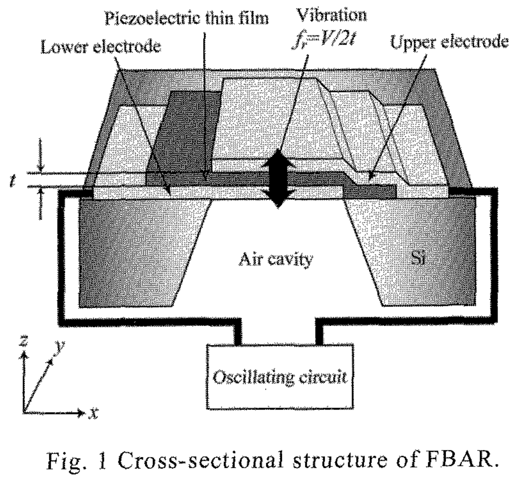
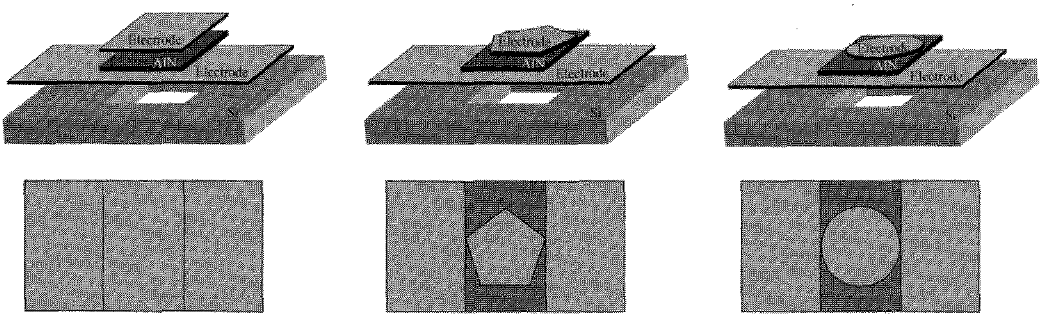


Fig. 1 Cross-sectional structure of FBAR.



(a) Rectangular (b) Pentagon (c) Circle

Fig. 2 Calculation model of FBAR. Shapes of upper electrodes are (a) rectangular, (b) pentagon and (c) circle.

$$(\text{Piezoelectric matrix}) = \begin{pmatrix} 0 & 0 & e_{31} \\ 0 & 0 & e_{31} \\ 0 & 0 & e_{33} \\ 0 & e_{15} & 0 \\ e_{15} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$(\text{Dielectric matrix}) = \begin{pmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{11} & 0 \\ 0 & 0 & \varepsilon_{33} \end{pmatrix}$$

Here, C_{11}, C_{12}, C_{13}, C_{33} and C_{44} are set to 3.96×10^{11}, 1.37×10^{11}, 1.08×10^{11}, 3.73×10^{11} and 1.16×10^{11} [Pa][4]. e_{31}, e_{33} and e_{15} are -0.54, 1.56 and 0.42 [C/m^2][4]. ε_{11} and ε_{33} are 8.0×10^{-11} and 9.5×10^{-11} [F/m][5].

3. RESULTS AND DISCUSSION

3.1 Influence of the shape for the upper electrode on the quality factor

Influence of the shape for the upper electrode is evaluated in terms of quality factor, Q, and spurious response. The models of the FBARs in the calculation are simplified as shown in Fig. 2 and the upper electrodes are modeled by rectangular, pentagonal and circler shapes. The material for the electrode is assumed to be molybdenum, which is widely used as an electrode for the FBARs. The thickness of the upper and lower electrodes are fixed to 2 μm.

Figure 3 shows the reactive force of the AlN films placed in the FBAR generated by AC electric field. The peaks for the reactive force correspond to the resonance of AlN film. The resonance frequency are about 1.74 GHz for the FBAR with the rectangular shaped upper electrode, 1.76 GHz for those with the pentagonal and circular shaped upper electrodes. The difference in resonance frequency for the FBARs among the three kinds of shapes for the electrode is due to the weight of the electrode because the area for each upper electrode is different. When the upper electrode is rectangular and circular shape, the relatively large spurious resonance appears below the resonance frequency. On the other hand, spurious resonance is considered to be suppressed in the case of the pentagonal shaped upper electrode. This may imply

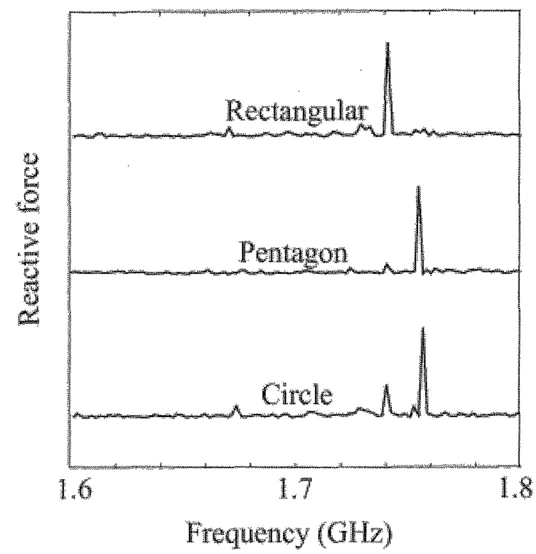


Fig. 3 Frequency characteristics of reactive force for FBARs with rectangular, pentagonal and circular shaped upper electrodes.

that the spurious resonance appears in the in-plane direction for the rectangular and circler shaped upper electrodes because of symmetric shapes of the upper electrodes. Figure 4 shows the quality factor, Q, as a function of the area for the upper electrode. Quality factor, Q, increases with increase in the area for the upper electrode, which is explained by the electric capacitance of the FBAR because the FBAR is also considered as a capacitor. Q for the FBAR with the pentagonal shaped upper electrode is strongly dependent on the area of the upper electrode compared with that with circular shaped upper electrode. Therefore, the pentagonal shape is considered to be preferable for the upper electrode to obtain high Q, although the reason is unclear.

The relationship between the quality factor, Q, and the thickness of the upper and lower electrodes are also investigated for the FBAR with the pentagonal shaped upper electrode that the highest Q is obtained when the thickness is 2 μm.

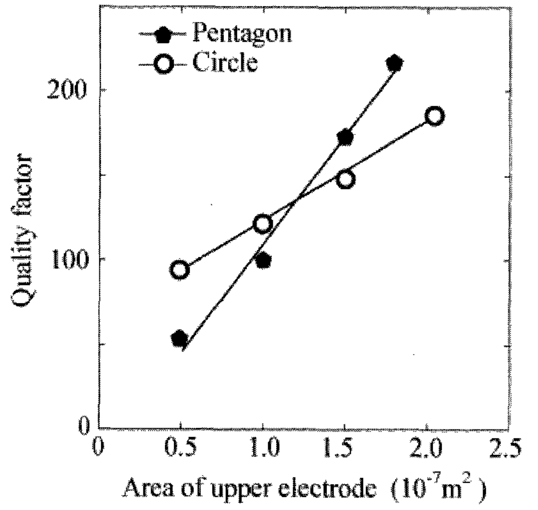


Fig. 4 Quality factor as a function of area for upper electrode.

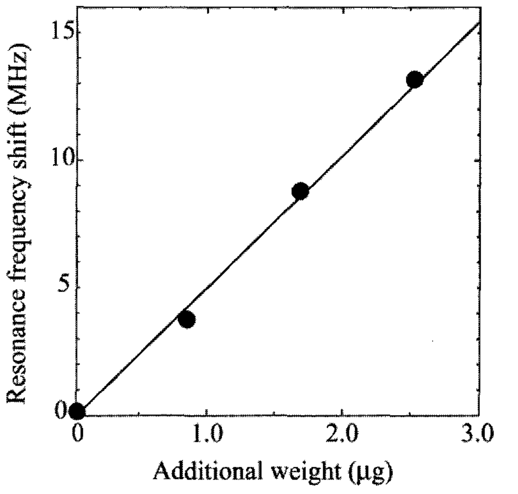


Fig. 5 Dependence of resonance frequency on additional weight.

3.2 Change in resonance frequency by additional weight

Resonance frequency for the FBAR is known to lower with increasing the additional weight. Figure 5 shows the dependence of the resonance frequency for the FBARs on additional weight. The obtained data are for the FBAR with the 2-μm-thick pentagonal shaped upper electrode. The dependence of the resonance frequency on additional weight is estimated by increasing the density of the electrodes. Reduction in the resonance frequency is expressed by the positive number of the resonance frequency shift in the figure. The resonance frequency linearly changes with the additional weight, and the gradient of the linear line shown in Fig. 5 is about 6 MHz/μg. On the assumption that equipment for measurement of the resonance frequency has a resolution of 10 Hz in frequency, FBARs are concluded to detect 2 pg of weight, and sensitive mass sensors are considered to be realizable.

3.3 Material of electrodes

Influence of the material employed as the electrodes on quality factor is evaluated. The shape of the upper electrode is pentagonal and the thickness of the electrode is 2 μm. A shape of the air cavity and the tapered angle for the substrate at the air gap are preliminary optimized in order to increase Q value. The materials considered in this calculation are Mo, Ru, Rh, W and TiN. Mo and Ru are widely used as an electrode for FBARs[6-9]. The material parameters are shown in Table 1. Young's modulus, Poisson's ratio and density for the AlN are 300 [GPa], 0.27 and 3300 [kg/m^3], respectively. The reason why those materials are considered in this study is that the electrode must be conductive and the material parameters are similar to that for the AlN, because the material of which the parameters similar to the AlN is considered not to restrict the vibration of the AlN film, resulting in high quality factor.

Obtained quality factor, Q, for Mo, Ru, Rh, W and TiN are 416, 581, 398, 246 and 642, respectively. TiN

Table 1 Material parameters

Material	Young's modulus [GPa]	Poisson's ratio	Density [kg/m^3]
Mo	324	0.32	10200
Ru	414	0.30	12370
Rh	359	0.30	12450
W	345	0.28	19300
TiN	590	0.30	5400

is considered to be available as an electrode for FBAR, although conductivity for the TiN is relatively smaller than that for the other material considered in this study. Consequently, TiN is estimated to be preferable material for the electrode of the sensitive mass sensor utilizing FBARs.

4. CONCLUSIONS

Application of film bulk acoustic wave resonator for a sensitive mass sensor was discussed using the commercialized simulator based on three dimensional finite element method. FBAR is considered to be able to detect 2 pg of weight loaded on the electrodes as 10 Hz of change in the resonance frequency assuming that a measurement system has a resolution of 10 Hz in frequency. The material employed as electrodes for the FBAR is evaluated that TiN is the most preferable concerning a quality factor.

5. ACKNOWLEDGMENT

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