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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 271-272
18-20 November, 2009

Contour-mode AlN Resonator with High Coupling Factor
大きい k^2 を有する輪郭振動型 AlN 振動子

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1. Introduction

Piezoelectric resonators are widely used as frequency-selective devices such as filters and oscillators. High-Q high coupling factor (k^2) resonators are necessary for both low insertion and high isolation in filter applications and both high precision frequency and low resonant impedance in oscillator applications.

The demand for miniaturization and integration in IC chips is strong for these resonators. Recently, several high-Q contour-mode MEMS (micro electro mechanical systems) resonators have been reported [1-4] that can be miniaturized and that have good compatibility with CMOS (complementary metal oxide semiconductor) fabrication. However, their k^2s are slightly too low to apply these technologies to filters or oscillators.

In this paper, MEMS type contour-mode resonators with k^2 of several percent are discussed. We report on a radial-extensional resonator with a high k^2 and a high Q value, which is suitable for filter and oscillator applications.

2. Simulation

Figure 1 shows the structure of a radial extensional AlN-film resonator, which consisted of one piezoelectric layer and two metal layers. The two metal layers act as the top and bottom electrodes, which apply an electric field to the piezoelectric layer. The resonant part was precisely patterned as a circle by using a dry etching process. The resonant frequency mainly depends on the radius of the resonant part so that extremely precise control of the film thicknesses is not necessary because the radius is precisely controlled by a photo mask pattern.

Figure 2 shows the k^2 of the radial extensional resonator calculated by using a three-dimensional finite-element method [1]. The relative top electrode thickness (horizontal axis) was defined as a ratio of the top electrode thickness to the total thickness. The material of the electrodes

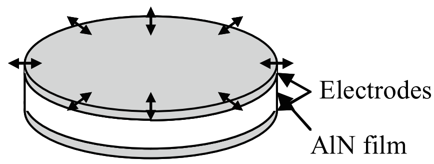

Fig. 1. Radial extensional resonator.

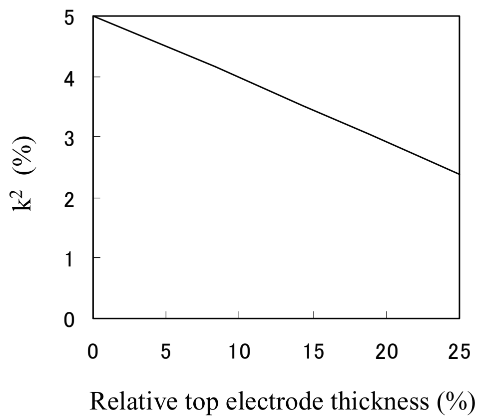

Fig. 2. k^2 of radial extensional resonator using an AlN film.

was molybdenum. Because the vibration was generated by transverse effect, the k^2 was calculated from a transverse-effect formula as

$$\frac{k^2}{1-k^2} = \frac{\pi}{2}\frac{f_P}{f_S}\tan\left(\frac{\pi}{2}\frac{f_P - f_S}{f_S}\right) , \quad (1)$$

where f_S and f_P are the series resonant frequency and the parallel resonant frequency respectively.

When the relative top electrode thickness is less than 25 %, the value of k^2 is greater than 2 %, which is an attractive value for filter and oscillator applications because a high k^2 leads to low insertion loss and low motion resistance.

3. Experiment

Figure 3 shows a photograph of a fabricated resonator. Although the radial extensional resonator

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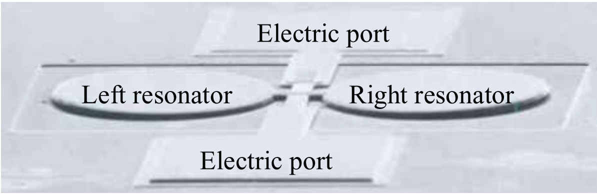

Fig. 3. Photograph of fabricated tuning fork type resonator consisting of two radial extensional resonators.

has a null point at the center of the resonant part, it is difficult to connect an electric lead line to the top electrode using conventional AlN-film fabrication processes [5]. We adopted a tuning fork type structure, which consisted of two radial extensional resonators. Because the tuning fork type resonator has a null point between the radial extensional resonators, it is easy to connect the electric lead line at the null point. The radii of the radial extensional resonators are 50 μm, and the thicknesses of the top electrode, the AlN film, and the bottom electrode are 100, 1000, and 100 nm respectively. There is a 1-μm gap between the radial extensional resonator and Si substrate.

Figure 4 shows the absolute impedance of the fabricated tuning fork type resonator shown in figure 3. The measured k^2 was lower than the calculated one because the amorphous starting layer [6] was present in the AlN film and we neglected the effect of the amorphous layer in the calculation.

We observed an excellent resonant response for the radial extensional vibration in air, which exhibited minimum and maximum impedance values of 25 Ω and >100 kΩ. respectively. The fabricated resonator showed high Q values (defined in [7]) of 3060 at the resonant frequency and 4050

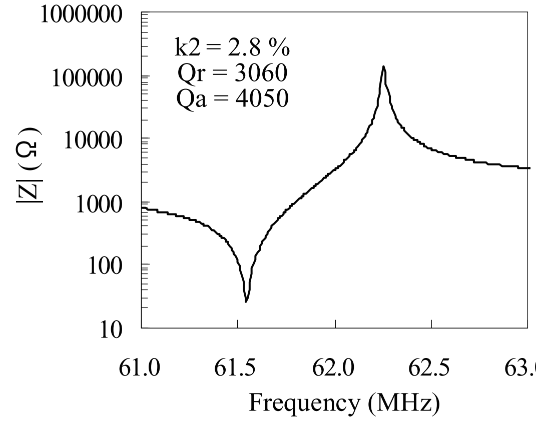

Fig. 4. Impedance of a fabricated tuning fork type resonator.

at the anti-resonant frequency respectively, and it showed a k^2 of 2.8 %, which is higher than those for conventional film-type contour-mode resonators such as width-extensional resonators [2], ring resonators [2], and hollow-disk resonators [3].

4. Conclusion

A tuning fork type resonator that consisted of two radial extensional resonators has been presented. A fabricated resonator exhibited a high coupling factor and high Q values, which was suitable for filter and oscillator applications, because the figure of merits, defined as the ratio of the Q value and the capacitance ratio, was 71 at the resonant frequency and 94 at the anti-resonant frequency, which were the highest values of the AlN-film contour-mode resonators.

Acknowledgment

The authors express their gratitude to Prof. M. Hikita of Kogakuin University, and Prof. K. Hasegawa of Muroran Institute of Technology for their helpful contributions to this work.

References

1. A. Isobe, K. Asai, H. Matsumoto and N. Shibagaki: Proc. IEEE Ultrason. Symp. (2006) 560.
2. G. Piazza, P. J. Stephanou, M. B. J. Wijesundara and A. P. Pisano: Transducers'05, 2065.
3. S. Li, Y. Lin, Y. Xie, Z. Ren and C. T. C. Nguyen: IEEE MEMS2004, 821.
4. H. Matsumoto, A. Isobe and K. Asai: Proc. IEEE Freq. Cont. Symp. (2005) 797.
5. H. Matsumoto, K. Asai, N. Kobayashi, S. Nagashima, A. Isobe, N. Shibagaki, and M. Hikita: Jpn. J. Appl. Phys. **43** (2004) 8219.
6. R. Aigner: Proc. Third International Symposium on Acoustic Wave Devices for Future Mobile Communication Systems, (2007) 85.
7. A. Isobe, M. Hikita, and K. Asai: IEEE Trans. Ultrason. Ferroelectr., Freq. Control., **52** (2005) 1812.