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Contour-Mode AlN Resonator with High Q Factor
輪郭振動型 AlN 振動子の高 Q 化

Kengo Asai† ,and Atsushi Isobe (Central Research Lab., Hitachi Ltd.)
浅井 健吾†，礒部 敦 （日立製作所 中央研究所）

1. Introduction

It has recently been reported that MEMS-type contour-mode resonators fabricated by the CMOS process are suitable for megahertz-band devices and that disc-type resonators with a top electrode, a AlN film, and a bottom electrode can strongly excite a radial extensional (RE) vibration mode [1-4]. In this study, we experimentally investigated the relationship between the Q value and the structure of the RE resonator and developed a tuning-fork-type structure that achieved high Q value.

2. RE Resonator Structure

Figure 1 shows the simple disc-type RE resonator on the silicon substrate, which consists of one piezoelectric layer and two metal layers. The two metal layers act as top and bottom electrodes, which apply an electric field to the piezoelectric layer in parallel to the polarization of the piezoelectric film. The RE resonator is supported with the supporting beams at two points around the resonant part. The resonant part is 50 μm in radius, and the top electrode, piezoelectric film, and bottom electrode are 160, 1500, and 160 nm thick, respectively. There is a 1μm gap between the resonant part and the substrate. The piezoelectric material is AlN.

Figure 2 shows the relationship between the measured impedance property and the width (*W*) of the supporting beam of the fabricated RE resonator. The vertical axis indicates the absolute value of the impedance, which was calculated from measured two-port S parameters. The horizontal axis indicates frequency normalized with the series resonant frequency of each resonator. The impedance values of the series resonant resistances were 2270, 1740, and 470Ω, and the parallel resonant resistances were 7.2, 12.7, and 53.8kΩ, respectively. These figures clearly shows that the resonant property gradually strengthened as the width narrowed. The Q value, which was calculated from the impedance property [5], is described in each figure. The Q value is inversely proportional to the width of the supporting beams. This result means that the Q value deterioration is mainly due to the vibration energy leaking into the silicon substrate through the supporting beams. Setting them narrower to improve the Q values is difficult because the supporting beams do not fail during the fabrication process. Therefore, we proposed the tuning-fork-type RE resonator for High Q value.

Figure 3 shows the structure of the fabricated tuning-fork-type RE resonator, which consists of two resonant parts, one connecting part, and two supporting beams. Both resonant parts vibrate in the same phase because they are electrically connected in parallel. As a result, this structure has a null point at the center of the connecting part

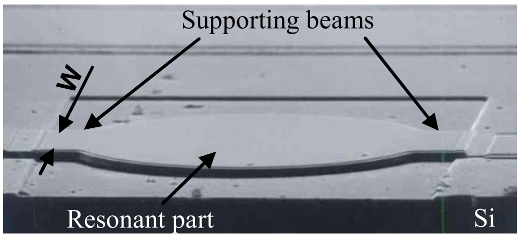
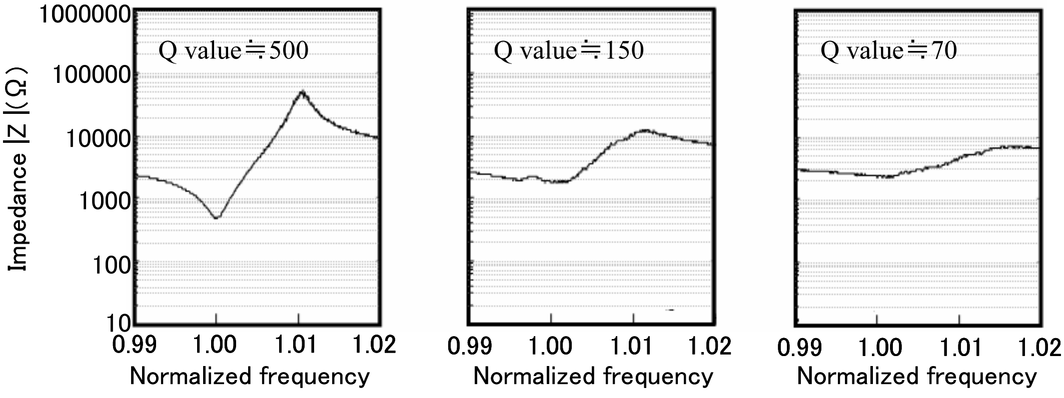


Fig. 1. Photograph of simple disc-type RE resonator



(a) W=20 μm (b) W=40 μm (c) W=60 μm

Fig. 2. Measured impedance property vs. width of supporting beam (W)

E-mail : kengo.asai.cq@hitachi.com

configuration. Because the supporting beams, which also act as electric lead lines, are connected at the null point, the vibration energy of the resonant parts does not leak into the silicon substrate through the supporting beams.

3. Fabrication Process

It is important to form the disc geometry in high precision, because the resonance frequency and resonant property are decided for the RE resonator in accordance with the radius of the resonant parts.

Figure 4 shows two fabrication processes of the resonant part that consists of the laminated RE resonator: an individual process method that processes the resonant structure of each single-layer in Fig. 4(a), and a batch process method that processes the resonant structure by one process in Fig. 4(b). We selected the individual process method because it is difficult to form the resonant part as a circle precisely enough by utilizing the effect of the sidewall polymer generated in dry-etching process in the batch process method.

The two resonant parts should be precisely formed to be the same shape to avoid any deterioration of the electric property. Figure 5 compares the frequency dependencies of the Q value by the difference of the process method of the RE resonator. The top electrode, the AlN film, and the bottom electrode were 100, 1000, and 100 nm thick, respectively. The Q value of the tuning-fork-type RE resonator was improved because the leakage of the vibration energy was suppressed. The tuning-fork-type RE resonator fabricated using individual process method has high Q values, specifically, 3000 at the series resonant frequency and 4000 at the parallel resonant frequency, and coupling factor(k^2) of 2.8%. The resonant property of the tuning-fork-type RE resonator fabricated by the individual process was clearly superior to that of the batch process.

4. Conclusion

We clarified that the resonant property degraded due to substrate leaks from the resonant part into the silicon substrate through the supporting points. The tuning-fork-type RE resonator fabricated using the individual process does not leak vibration energy from its resonant part into the silicon substrate and exhibits a high coupling factor and high Q values. Its figure of merit is 71 at the series resonant frequency and 94 at the parallel resonant frequency.

References

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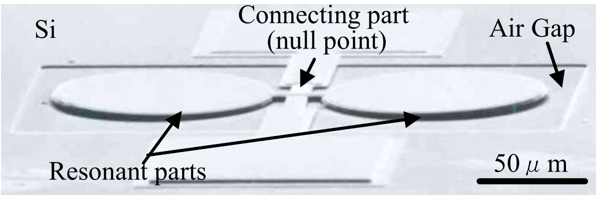
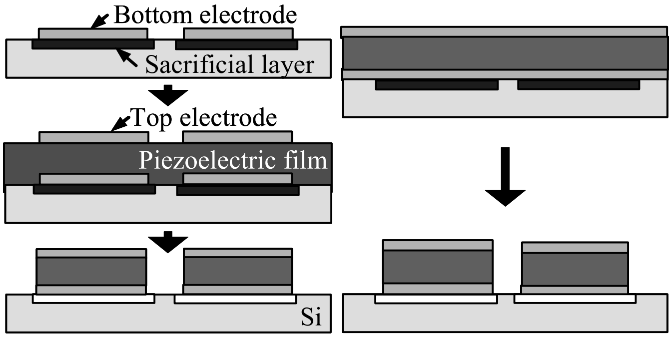
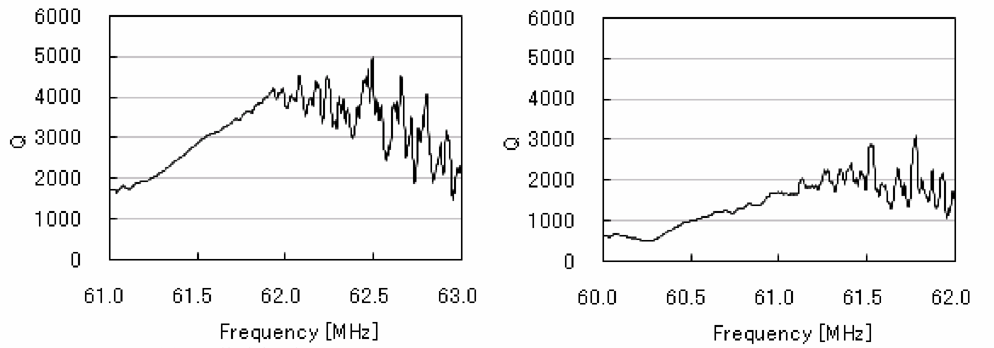


Fig. 3. Photograph of tuning-fork-type RE resonator



(a) Individual process (b) Batch process

Fig. 4. Fabrication process of RE resonator



(a) Individual process (b) Batch process

Fig. 5. Q values of tuning-fork-type RE resonator