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Simulation of a ceramic resonator using overtone vibration of a single plate and a double layer plate

J. H. Cho*, Y. H. Lee, B. Y. Choi, M. P. Chun and B. I. Kim

Department of Ceramic Building Materials Research, Korea Institute of Ceramic Engineering and Technology, Seoul 153-801, Korea

Various vibration modes used in ceramic resonators which have been commercialized recently, and they have been mainly used in generating frequencies greater than 10MHz with the 3rd overtone vibration (TE3 mode vibration) and 2nd vibration (TE2 mode vibration) generated by laminating two layers. In the case of the TE2 mode vibration, it is known that it can give the better features for temperature and higher Qm than those of the TE3 mode vibration and there is no problem of a spurious response generated in the TE3 mode vibration. In this study, we simulated the TE3 mode vibration and TE2 mode vibration using the FEMLAB program. $PbTiO_3$-based ceramics were used in this experiment and their standard dimensions were 2.0 ×2.5×0.36 mm and 0.5×1.5×0.2 mm for the each TE3 mode and TE2 mode respectively, which simulation revealed that the TE2 mode generated vibration in a more local area than TE3 mode. Moreover the result for the TE2 mode was analyzed with variables of overlap length/thickness and the width of the element. It was found that a 2.0 ratio of overlap length per thickness was less influenced by a spurious response for the TE2 mode vibration, and it was expected that the TE2 mode vibration would be more dominant rather than other vibrations in samples 0.5 mm width.

Key words: C.Piezoelectric properties, D.Perovskite, E.Functional application, Simulation

Introduction

Ceramic oscillators use the mechanical resonant behavior of piezoelectric ceramics, and they use various vibration modes of the resonant frequency. To generate a frequency above 10MHz from them, the 3rd overtone vibration (TE3 mode vibration) has mainly been used, and SMD (Surface Mounted Device) type products generally use this. This is because piezoelectric ceramic materials that exhibit the energy trapping phenomenon of the TE3 mode vibration have better temperature characteristics and higher Q_m than those of the fundamental thickness vibration. However, resonators that use the TE3 mode vibration exhibit spurious responses of the TE1 mode vibration, the 5th-harmonic thickness extensional vibration etc.

Recently the use of the TE2-mode vibration has been studied to minimize the resonator and elevate its functional features, in addition it was reported that the TE2-mode could promote the temperature feature and give a higher Qm.[1,2]

In this study, we comparatively analyzed the characteristics of resonators generating vibrations of each TE3-mode and TE2-mode using a FEMLAB simulation program, in particular, the results for the TE2 mode were simulated with variables of overlap length/thickness and the width of the element.

Concept of Design

Figures 1 and 2 show the fundamental structures used in this paper. Figure 1 describes the structure of the resonator with the TE3-mode vibration, and (a) shows the 3-dimensional features and (b) the 2-dimensional features. Figure 2 shows the structure of the resonator for the TE2-mode vibration, which also shows both 3 and 2-dimensional features. The resonator is structured to be attached to the electrodes in both the upper and lower parts of the piezoelectric ceramics plate and the TE2-mode resonator also has a laminated structure with the electrode on its center. The sizes of ceramic sample have designed based on commercial products and their outer size and electrode size are given on each figure. The electrode are designed with a standard 10 μm thickness which is thicker than practical for convenience.

Simulation

$PbTiO_3$-based materials [3] were used for the simulations, and it was supposed that the poling direction is paralleled to the thickness. The simulations were designed to have a 20MHz oscillating frequency, and their results were compared with the impedance of real resonators [1]. The 2nd model was used in analyzing the basic vibrations and in studying the influence of the ratio of the thickness to electrode length, and the 3rd model was used in simulating that of electrode width.

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*Corresponding author:
Tel : +82-2-3282-2424
Fax: +82-2-3282-7816
E-mail: goedc@kicet.re.kr

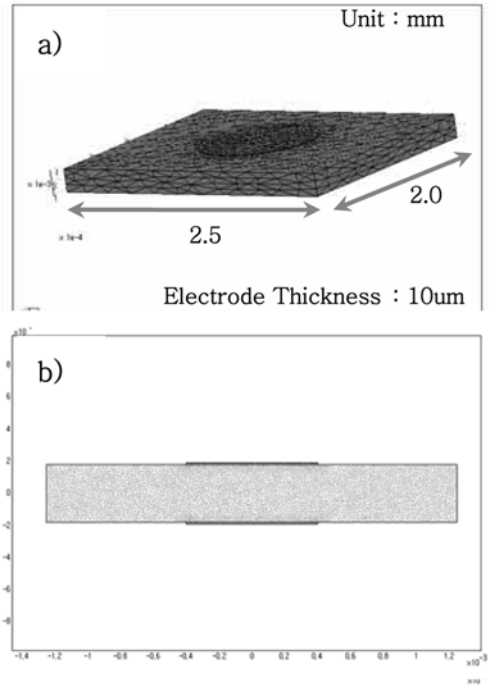


Fig.1. Structure of TE3-mode Resonator.

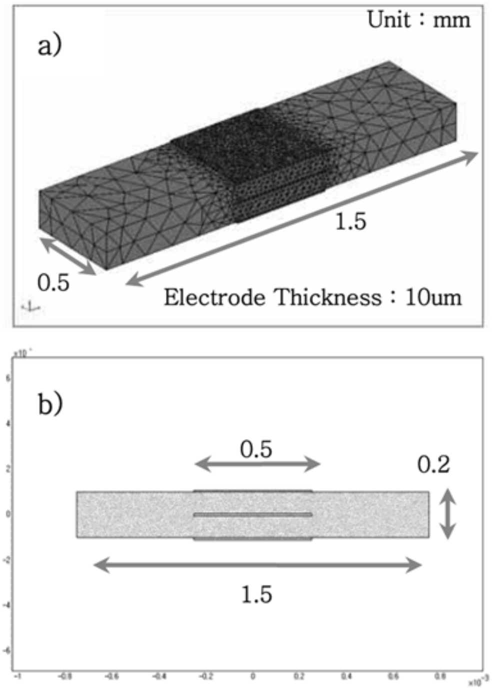
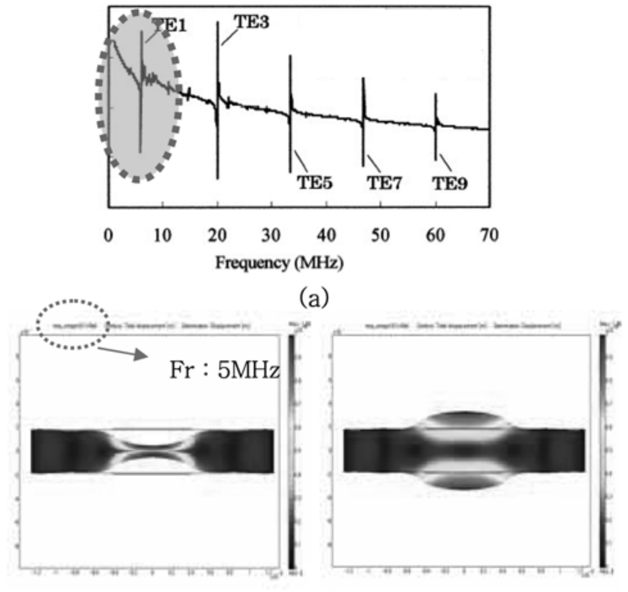


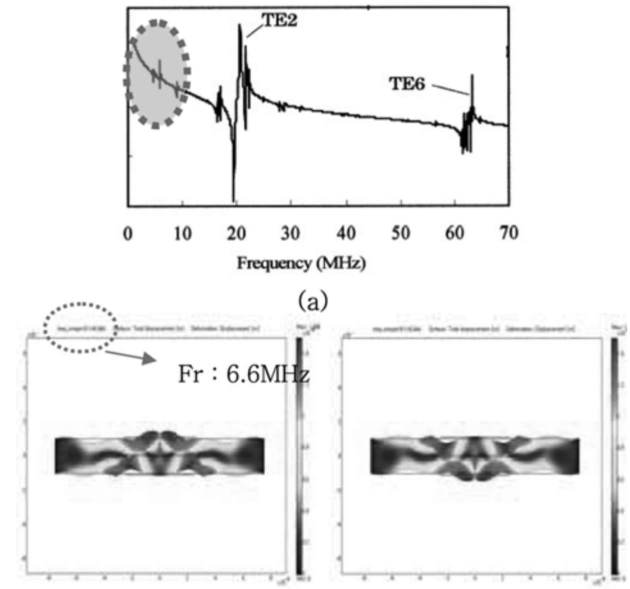
Fig. 2. Structure of TE2-mode Resonator



(a)

(b)

Fig.3 (a) Features for the 1st vibration impedance of practically manufactured TE3-mode resonator [1)] (b) The 1st vibration type of TE3-mode resonator



(a)

(b)

Fig. 4. (a) Features for the 1st vibration impedance of practically manufactured TE2-mode resonator[1)] (b) The 1st vibration type of TE2-mode resonator

Results and Discussions

Resonant Frequency and Vibration Shape

The 1st vibrations for the TE3-mode resonator and the TE2-mode resonator appeared around 5MHz and 6.6MHz, respectively, and the behavior of these are shown in Figures 3 and 4. In the case of TE3-mode, a relatively simple vibration pattern is seen but it is more complicated than that of the TE2-mode. Figure 5 shows the vibration features for the 3rd vibration of the TE3-mode and the displacement of the resonator as a function of frequency. It can be seen that displacement is widely distributed including an exceptional part of electrode, in addition a similar sized vibration from the 1st to 7th was found which means it agrees with the

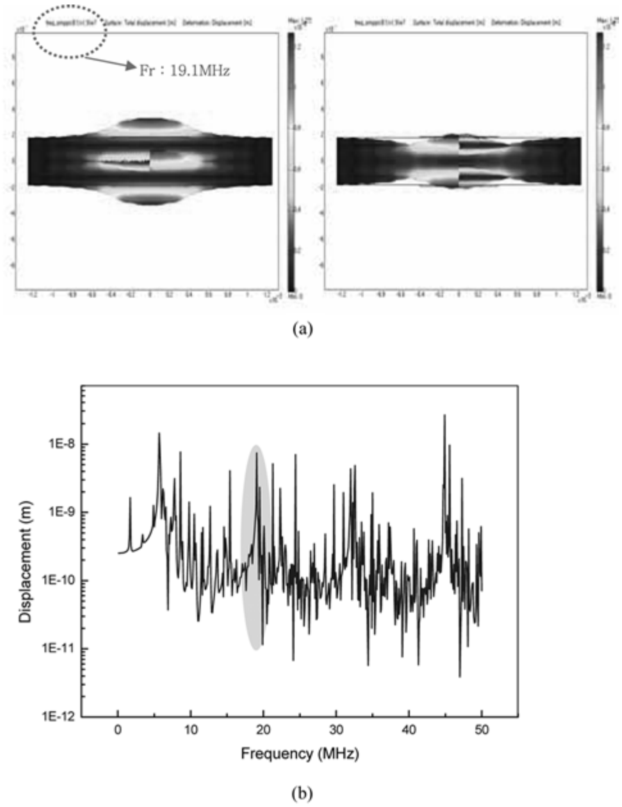


Fig. 5. (a) The 3rd vibration type of TE3-mode resonator (b) Displacement of TE3-mode resonatoras a function of frequency.

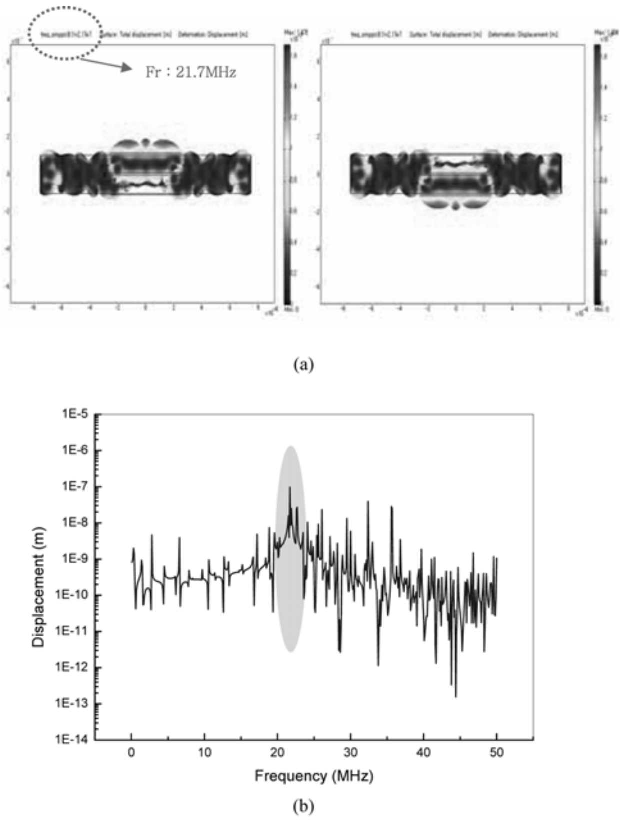


Fig. 6. (a) The 2nd vibration type of TE2-mode Resonator (b) Displacement of TE2-mode resonator as a function of frequency.

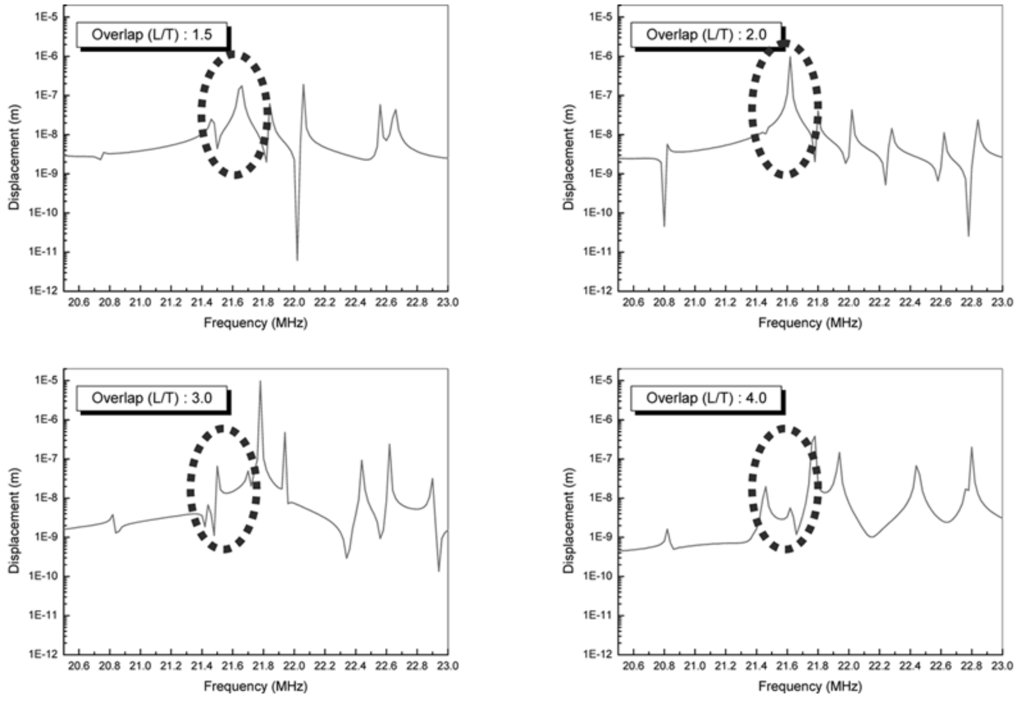


Fig. 7. Displacement changes of TE2-mode resonator by L/T.

impedance of resonator in Figure 3. Figure 6 shows the 2nd vibration of the TE-mode and its displacement as a function of frequency. It can be seen that the vibration is restricted to only the area of the electrode and the displacement on the 2nd resonance point is dominant rather than other displacements as a function of

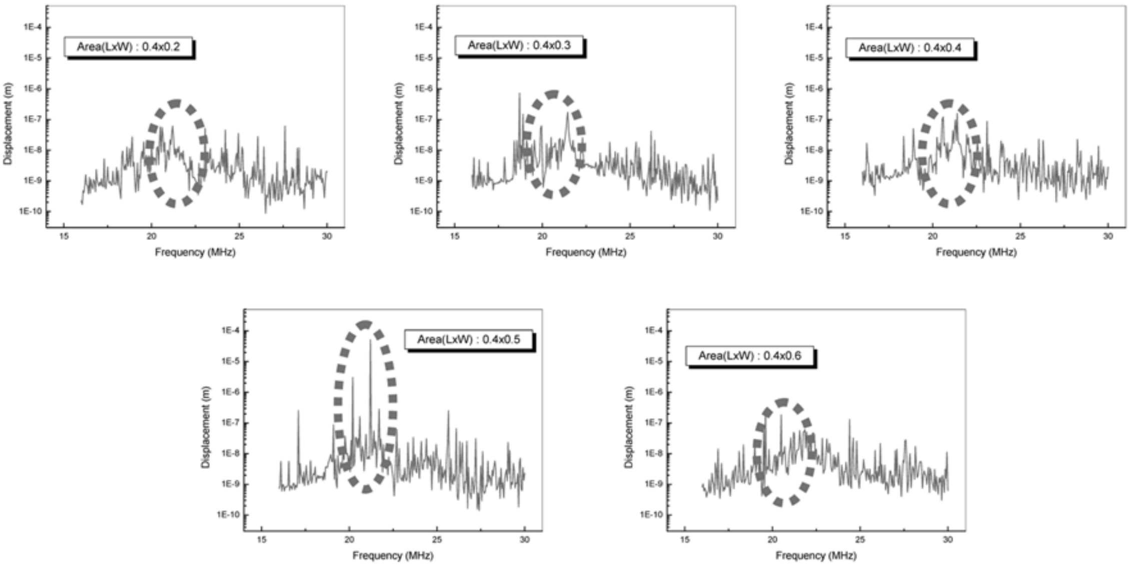


Fig. 8. Displacement changes of TE2-mode resonator by W.

frequency. This also agrees with the impedance in Figure 4.

The Effects of Variables

The most important variables in a resonator using the TE2-mode are the ratio (L/T) of the electrode length (L) to ceramic plate thickness (T) and the width of the electrode(W). Therefore, we used the above two variables in analyzing through simulation.

By fixing the thickness of the ceramic plate to 0.2 mm, the displacement as a function of frequency was analyzed by changing the value of L to 0.3, 0.4, 0.6, and 0.8mm to show the influence of L/T. Figure 7 shows the results of the simulation. For L/T = 2.0, that is when the value of the electrode length is twice the thickness, it was expected that the TE2-mode vibration near to 20MHz would be less influenced by other spurious vibrations.

The caseIt was simulated for the influence of electrode width (W) by fixing L = 0.04 mm and increasing W by 0.1 mm unit from 0.2 mm to 0.6 mm. The results are given in Figure 8. It may be considered that the interaction between spurious vibrations for the 3rd model is more complex than for the 2nd model, and also that the TE2-mode vibration may be dominant where W is 0.5 mm.

Conclusions

TE3-mode and TE2-mode vibrations were simulated using a FEMLAB program. The influences of L/T ratio and W of TE2-mode resonator were analyzed. In the results, it was discovered that the displacement for the TE2-mode vibration appeared in a more local region than that of the TE3-mode vibration. Also it was seen that the TE2 mode would be less influenced by spurious vibrations in a L/T ratio of 2.0 where the electrode length was twice its width in a manufactured resonator. When L = 0.4 mm for W, it was expected that the TE2-mode vibration would be dominant compared to other spurious vibrations if W is a little wider than 0.5 mm.

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