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Abstract

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Fabrication and Analysis of Butterfly-type Piezoelectric Actuators

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A noble butterfly-type piezoelectric actuator was designed to meet the demand of a tiny motor in mobile devices. To predict the actuation motion, we utilized the ATILA software and investigated the effects of the material properties on the impedance spectrum and the elliptical displacement. The increase of mechanical loss made the impedance peaks broader and tilted the elliptical displacement leading to asymmetry along the directions of motion. However, the decrease in the piezoelectric constant and the increase in the dielectric loss gave information about the small peak and made the shape of the elliptical displacement closer to the measured result. Even though there is discrepancy in the magnitude of value, the simulation by revising the piezoelectric constant and the dielectric loss was more effective in predicting the actuation behavior of the butterfly-type actuator.

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I. INTRODUCTION

The piezoelectric actuators have many applications, due to their compact size, low noise, fast and precise response, and lower power consumption. Recently, corresponding to the expansion of the mobile device market, piezoelectric actuators with a larger displacements and more compact sizes are being widely developed [1–6]. In developing new actuators, if larger displacements are to obtained, research is usually used in the singular new materials with larger piezoelectric constants or new structures with effective amplification should be developed. Even though there has been much research on new piezoelectric materials, $Pb(Zr,Ti)O_3$ based materials are still the most popular due to having a larger piezoelectric constant than any other materials. However, researchs on new structures to achieve large amplification is being actively reported and commercialized in the market place [6].

For new actuators, that which are basically composed of a piezoelectric ceramic, an elastic body for displacement amplification, and a moving element, the fabrication of real actuators will be expensive money and highly time consuming. Therefore, prediction of actuation behavior before fabrication is inevitable in developing a new structure of actuators. Recently, Piezo-tech developed the butterfly-type actuator and disclosed the patent [7–9]. Though the butterfly-type actuator has several ad-

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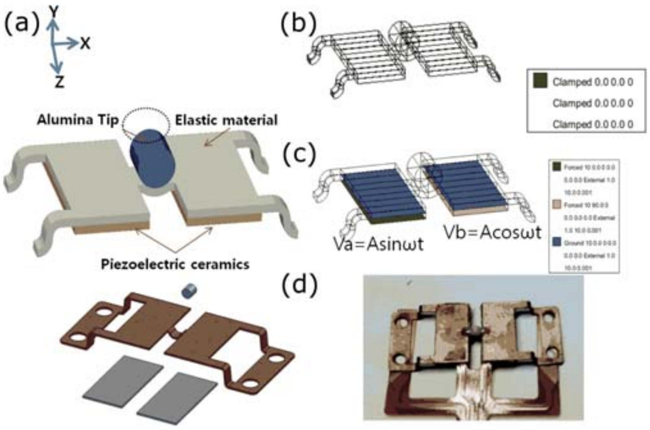

Fig. 1. (Color online) (a) Schematic, (b) boundary condition, (c) driving condition, and (d) photo of the butterfly-type actuator.

vantages, such as easy alignment and large displacement, its actuation behavior has barely been reported or presented [9].

This paper describes a novel butterfly-type piezoelectric actuator, its operation principle and its performance. The design principle, which utilized harmonic motion with a 90 degree phase difference on two piezoelectric plates, is described first. This is followed by a presentation as the analysis results obtained using the ATILA software. Finally, we fabricated and characterized a real butterfly-type actuator and compared the results with the calculated data.

II. ACTUATOR DESIGN AND BASIC PRINCIPLE

In principle, piezoelectric ceramics expand and shrink periodically under an AC field through the converse piezoelectric effect, and the displacements of piezoelectric ceramics are extremely small. In general actuator applications a special design is needed in order to amplify the tiny displacement and to convert the periodic standing wave vibration into continuous movement. Figure 1 illustrated the design and presents a photo of the butterfly-type actuator. Two piezoelectric ceramics were fixed on an elastic body of bronze at each face. Here, to obtain the amplification, the center of elastic elements was machined to have a narrow bridge and four feet at the end of the elastic body were tightened to the frame. When transferring the elliptical motion at the center of the elastic body into a moving element, which is not shown here, the alumina tip with high stiffness was fixed onto the center of the elastic body. This alumina tip would transfer the motion with sufficient friction and secure long life time without severe wear.

To generate the motion of the alumina tip, a harmonic electric field was applied to the piezoelectric plates with 90 degree phase difference. Simply, elliptical motion was generated when one side of elastic body was moving upward and the other side of elastic body was moving downward due to the 90 degree phase difference. As the alumina tip was a cylindrical shape, the contact shape between the moving element was not pointed but linear and this linear contact made parallel adjustment simple.

Table 1. Summary of the calculated and the measured values at 268 kHz for a butterfly actuator.

Condition	Impedance (Ω)	Displacement along Y direction (nm)
Measured	857	35
$\tan\delta_m = 0.002$ $d_{33} = 289$ pC/N $\tan\delta = 0.004$	340	559
$\tan\delta_m = 0.02$ $d_{33} = 289$ pC/N $\tan\delta = 0.004$	802	203 (at X = 0)
$\tan\delta_m = 0.002$ $d_{33} = 28.9$ pC/N $\tan\delta = 0.004$	560	56
$\tan\delta_m = 0.002$ $d_{33} = 289$ pC/N $\tan\delta = 0.04$	548	56

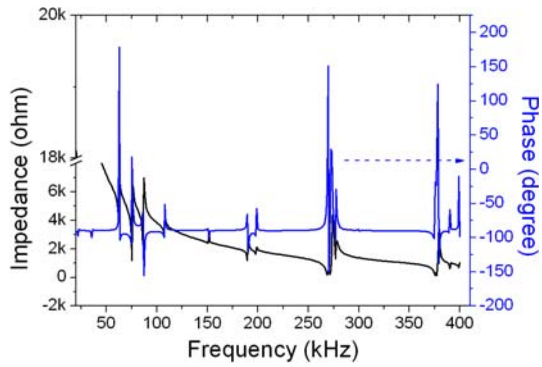

Fig. 2. (Color online) Calculated impedance and phase change of a butter-fly type actuator as functions of the frequency. For this simulation, a mechanical loss of tanδ_m = 0.002, a piezoelectric constant of d_{33} = 289 pC/N, and a dielectric loss of tanδ = 0.004 were employed.

III. PREDICTION OF THE BUTTERFLY ACTUATOR IS BEHAVIOR

A finite element model with ATILA software was initially used in order to predict the actuation behavior and to deduce optimal dimensions of the butterfly-type actuator prior to fabrication. Figure 2 illustrates the modal result of the analysis in the 20 ~ 400 kHz frequency range

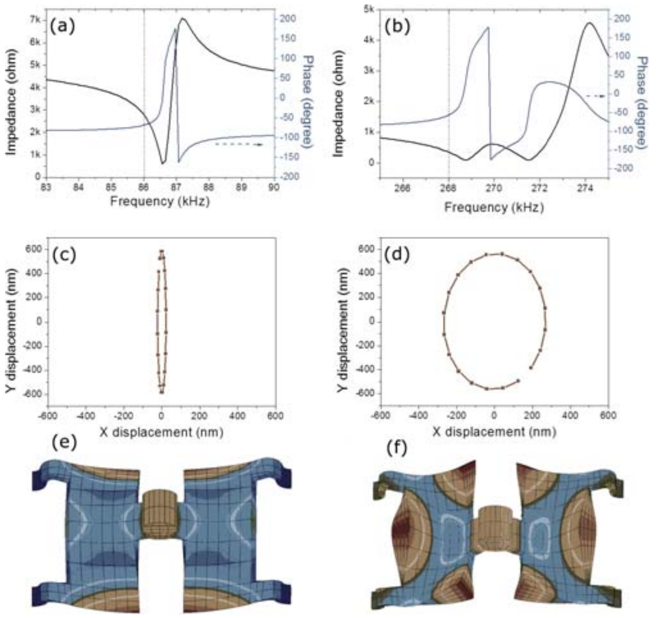

Fig. 3. (Color online) (a) and (b) Calculated impedance and phase change, (c) and (d) calculated displacement, and (e) and (f) harmonic analysis of a butterfly actuator at 86 and 268 kHz, respectively. For this calculation, tanδ_m = 0.002, d_{33} = 289 pC/N, and tanδ = 0.004 were employed, and the driving voltage was 10 Vp-p.

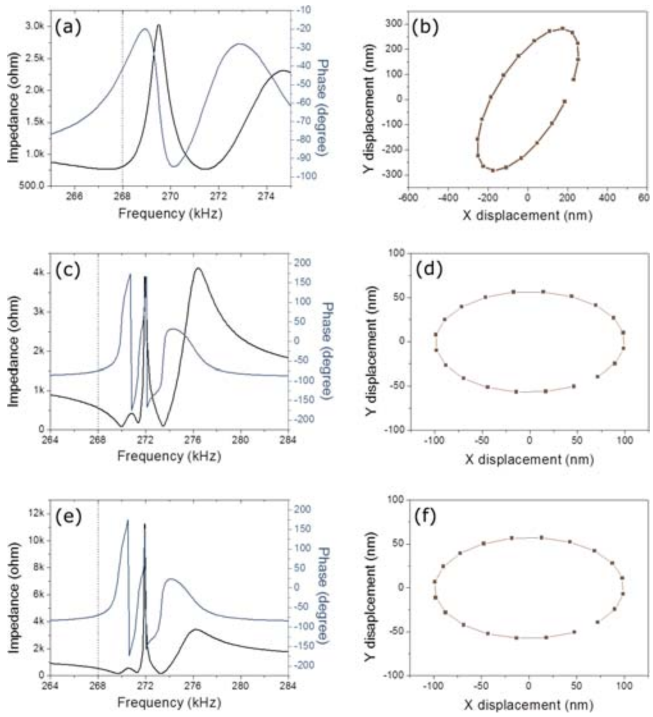

Fig. 4. (Color online) Calculated (a), (c), and (e) impedance and phase change and (b), (d), and (f) displacement at 268 kHz for different material properties. (a) and (b) tanδ_m = 0.02, d_{33} = 289 pC/N, and tanδ = 0.004; (c) and (d) tanδ_m = 0.002, d_{33} = 28.9 pC/N, and tanδ = 0.004; (e) and (f) tanδ_m = 0.002, d_{33} = 289 pC/N, and tanδ = 0.04. It should be noted that tanδ_m, d_{33}, and tanδ were changed for comparison.

with the material properties as mechanical loss (tanδm) of 0.004, piezoelectric constant (d_{33}) of 289 pC/N, a dielectric loss (tanδ) of 0.002, and hard PZT properties. For elastic body, we utilized beryllium copper (BeCu, UNS C17200). Several peaks, came from various kinds of modes, implying a complex structure in terms of electromechanical coupling. Among the resonance peaks, we conducted modal analysis and highlighted two frequencies, are each near 86 and 268 kHz. Figure 3 shows the impedance and phase change, the displacements along the X and Y directions, and a harmonic analysis of the butterfly-type actuator. From the harmonic analysis in Figs. 3(e) and 3(f), the motions near 86 and 268 kHz seems similar at a glance, but the elliptical motions in Figs. 3(c) and 3(d) are actually quite different. From the operation principle, a larger displacement along the X direction will give a larger movement of the moving element, resulting in a smaller actuator. Meanwhile, the displacement along the Y direction will affect the friction between the alumina tip and the moving element. For insufficient displacement along the Y direction, the alumina tip can not exert enough frictional force to push the moving element. In this regard, the elliptical motion at 86 kHz is not adequate for a miniaturized actuator, so we choose 268 kHz for the operation frequency. For simulations in general, piezoelectric material properties under free conditions are adopted, but in real situations, the dielectric and the piezoelectric properties change when the materials are attached to on elastic body. To investigate how material properties affect actuation behaviors, mechanical loss the piezoelectric constant or the dielectric loss was. Compared, with Fig. 3, the mechanical loss tanδm increased from 0.002 to 0.02, a 10 times increase, and impedance vs frequency and the elliptical displacement are presented in Figs. 4(a) and (b), respectively. The resonance peak became clearer and sharp, and the elliptical motion was tilted showing an nonsymmetrical shape along the X and the Y directions. With the 10 times smaller piezoelectric constant (d_{33} = 28.9 pC/N) than in Fig. 3, Fig. 4(c) shows three resonance peaks, including an additional small peak near 271 kHz. Compared with Fig. 3, the displacements along the X and the Y directions in Fig. 4(d) were diminished in a different ratio, giving a longer displacement along the X direction than the Y direction. Figures 4(e) and 4(f) represented the results calculated with the dielectric loss (tanδ = 0.04) being 10 times larger than that of Fig. 3. The overall impedance shape and the displacement are similar to these in Figs. 4(c) and 4(d). Even though, we could not do a numerical calculation due to the structural complexity of the butterfly actuator, and the ATILA result implied that a decrease in the piezoelectric constant and an increase in the dielectric loss had a similar influences on the simulation results. In Table 1, simulation results with different material properties are summarized.

Table 2. Piezoelectric material property for butterfly-type actuator.

	Materials (KP14, Kyoungwon ferrite Co. Ltd)
Dimension (mm × mm × mm)	4 × 8 × 0.2
Relative Dielectric Constant (at 1 kHz)	1300
Dielectric Loss (at 1 kHz)	0.004
Piezoelectric Constant (d_{33}, pm/V)	289
Piezoelectric Voltage Constant (g_{33}, $\times 10^{-3}$ m/N)	28
Quality Factor	1600
Density (g/cm^3)	7.5

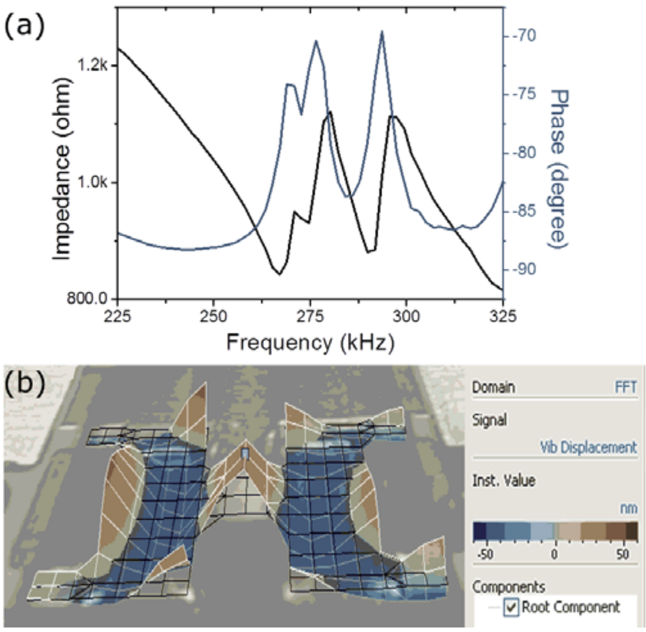

Fig. 5. (Color online) (a) Impedance and phase spectrum and (b) displacement along the Z direction at 268 kHz. When 10 V_{p-p} was applied to the butterfly actuator, movement was detected as a 3-D laser vibrometer change of the butterfly-type actuator.

IV. FABRICATION AND CHARACTERIZATION OF A BUTTERFLY-TYPE ACTUATOR

Despite the relevance of the results obtained by using finite element modeling, many choices can be undertaken only through a repeatable experimental procedure simply because some parameters cannot be modeled. We fabricated and characterized a butterfly actuator. The piezoelectric ceramics in Table 2 were fixed onto an elastic body of bronze by using the epoxy glue and an alumina tip was fixed onto the center of the bridge of the elastic body. The impedance and the phase spectrum of the butterfly type actuator were measured using an HP4194A impedance analyzer. The spectrum, shown in Fig. 5(a), shows there broad peak. Those three peaks were located over a wide frequency range, implying a lower mechanical quality factor for the butterfly structure. Figure 5(b) shown a 3-dimensional image captured for applying 10 V_{p-p} onto the butterfly-type actuator. Even though there is a difference in the magnitudes of the displacement, the overall contour image matches well with Fig. 2(f), and this similarity implies that the operating principle works well for butterfly-type actuators. When we measured the displacement along the Y direction, a maximum value of 35 nm was obtained. The discrepancies in the spectral shape and the magnitude of displacement mean that, in order to simulate the butterfly actuator more precisely, more parameters should be considered in the simulation process.

V. CONCLUSION

A noble butterfly-type piezoelectric actuator was designed and fabricated. Before fabrication, we analyzed the actuator properties with the ATILA software and investigated the effects of the material properties, mechanical loss, piezoelectric constant, and dielectric loss, on the impedance spectrum and the elliptical displacement. The increase in the mechanical loss made the impedance peaks broader and tilted the elliptical displacement leading to asymmetry along the directions of the motion. The decrease in the piezoelectric constant and the increase of in the dielectric loss had similar effects on the impedance spectrum and the elliptical motion. Compared with measurement results, the simulation by revising the piezoelectric constant and the dielectric loss was more effective in predicting the actuation behavior of a butterfly-type actuator.

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REFERENCES

[1] K. Uchino and J. R. Giniewicz, *Micromechatronics* (CRC/ Dekker, New York, 2003).
[2] H.-P. Ko, S.-S. Kim, S.-N. Borodinas, P.-E. Vasiljev, C.-Y. Kang and S.-J. Yoon, Sens. Actuator, A **125**, 477 (2006).
[3] ATILA, *V6.0.0 Operational Manual* (Micromechatronics Inc., State College, PA, 2007).

[4] S.-H. Park, J. Agraz, S. Tuncdemir, Y.-D. Kim, R. Eitel, C. Randall and K. Uchino, Jpn. J. Appl. Phys. **47**, 313 (2008).
[5] T. Hemsel and J. Wallaschek, Ultrasonics **38**, 37 (2000).
[6] B. Watson, J. Friend and L. Yeo, Sens. Actuator, A **152**, 219 (2009).
[7] C.-Y. Kang, S.-J. Yoon, D.-Y. Jung, H.-J. Kim, P.-E. Vasiljev and J.-W. Choi, Linear Motor, Korea Patent 10-0817470, 2010.
[8] Piezotechnology Ind., www.piezo-tech.com
[9] W.-H. Lee, C.-Y. Kang, D.-S. Paik, B.-K. Ju and S.-J. Yoon, Sens. Actuator, A **168**, 127 (2011).