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Finite element analysis and fabrication of an ultrasonic system for microchip cooling

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Abstract

Recently, microchip cooling using ultrasonic wave is being researched actively elsewhere [1-3]. But previous researches are focused on increasing passive cooling effect by enhancing the convective heat transfer coefficient. In this work, an ultrasonic waveguide for microchip cooling that is operated by 40 kHz operating frequency, was designed and fabricated for active cooling. To develop the system, finite element analysis using ANSYS software was performed to design the waveguide. The predicted anti-resonance frequency for a piezoelectric actuator was 34.8 kHz, which was in good agreement with the experimental result of 34.7 kHz with 0.3% error. After manufacturing the system, impedance characteristics were measured and compared. As a result, the predicted anti-resonance frequency for the ultrasonic waveguide was 39.3 kHz, which coincided with the experimental value of 39.8 with 1.3% error. Considering these results, it is thought that the developed ultrasonic waveguide will be applicable in microchip cooling.

Keywords: Ultrasonic; Finite element method (FEM); Microchip cooling

1. Introduction

Recently, microchip cooling using ultrasonic wave is being researched actively elsewhere [1-3]. But previous researches are focused on increasing passive cooling effect by enhancing the convective heat transfer coefficient.

In this article, an ultrasonic waveguide for microchip cooling that is operated by 40 kHz operating frequency, was designed and fabricated for active cooling. To develop the system, finite element analysis using ANSYS software was performed. The anti-resonance frequency for a piezoelectric actuator was predicted, the result was compared with the experimental result. After manufacturing the system, impedance characteristics were measured and compared. The predicted anti-resonance frequency for the ultrasonic waveguide was compared with the experimental value. At the end, the application probability of the developed ultrasonic waveguide to microchip cooling is discussed.

2. Ultrasonic waveguide for microchip cooling

2.1. Structure and working principle

The 40 kHz ultrasonic waveguide for microchip cooling is mainly composed of two parts, the ultrasonic unit and the electric generator. The ultrasonic waveguide system is shown in Fig. 1. The ultrasonic waveguide has a thin cylindrically shaped aluminium (Al) waveguide with a lead zirconate titanate (PZT) actuator attached on the top. Inside of the waveguide, there are a resonator and stacks that can refrigerate. When power is supplied to the PZT actuator, the actuator vibrates and the displacement is transferred through the waveguide to the resonator part for cooling.

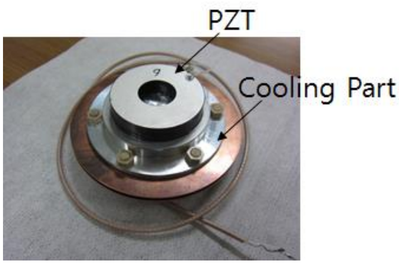


Figure 1. Ultrasonic waveguide for microchip cooling

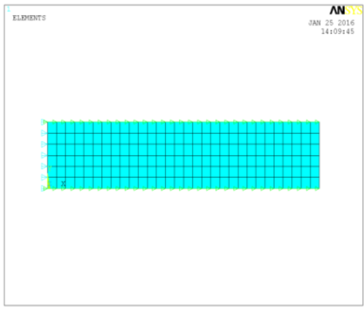


Figure 2. FEM analysis model

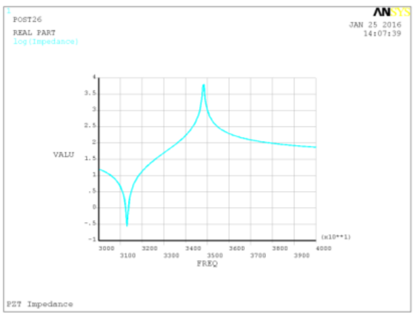


Figure 3. FEM analysis result of the impedance graph

2.2. FEM Analysis

The ultrasonic system was designed by FEM analysis using Ansys, which is commercial FEM software. At first, the PZT actuator was modeled with the analysis tool. The analysis model was axis-symmetric and the nodes of the top and bottom electrodes were coupled to apply voltages, as shown in Fig. 2. And a series of calculations were performed from 30.0 kHz through 40.0 kHz. As a consequence, the highest impedance value was 34.8 kHz as shown in Fig. 3, which was decided as a design frequency.

Next, the waveguide with the PZT actuator was modelled as shown in Fig. 4. The highest impedance value was 39.3 kHz as shown in Fig. 5.

2.3. Displacement analysis

At this time, displacement analysis was performed. Firstly, the PZT actuator and the waveguide were modeled. Modal analysis was performed and structural motion could be predicted. The FEM displacement analysis result at the operating frequency of 20.0 kHz is shown in Fig. 4. The red and bright part means high displacement, whereas, the blue and dark part low displacement.

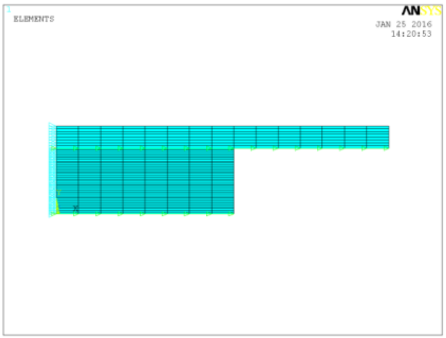


Figure 4. FEM analysis model

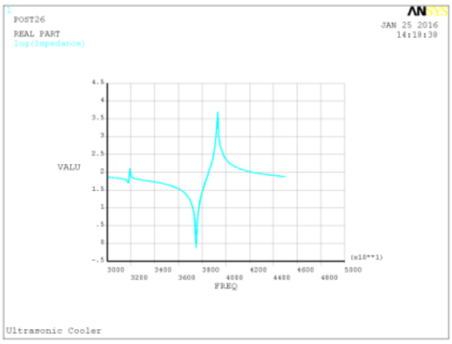


Figure 5. FEM analysis result of the impedance graph

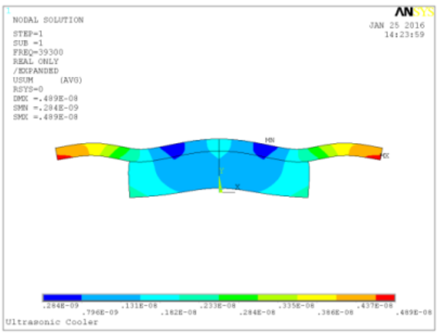
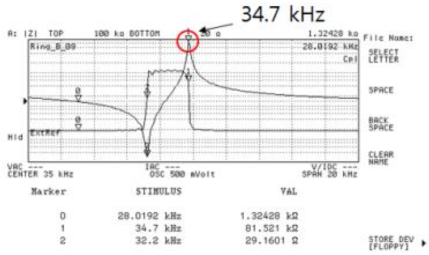


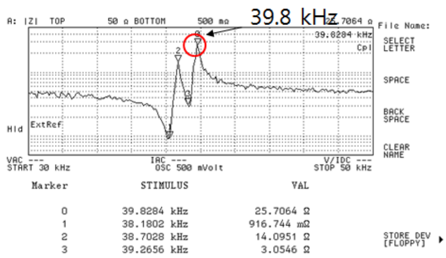
Figure 6. FEM analysis result of the impedance graph

3. Experiments

Using the analysis results, ultrasonic system was fabricated. The peak frequency value of impedance was measured to be 34.7 kHz of the PZT alone and 39.8 kHz of the system, which agreed well with predicted value with 0.3% and 1.3% error, as shown in Figs. 7 (a) and (b), respectively.



(a)



(b)

Figure 7. Experimental results of the impedance graph of (a) PZT and (b) ultrasonic system

4. Conclusions

In this work, an ultrasonic waveguide for microchip cooling that is operated by 40 kHz operating frequency, was designed and fabricated for active cooling. To develop the system, finite element analysis using ANSYS software was performed to design the waveguide. The predicted anti-resonance frequency for a piezoelectric actuator was 34.8 kHz, which was in good agreement with the experimental result of 34.7 kHz with 0.3% error. After manufacturing the system, impedance characteristics were measured and compared. As a result, the predicted anti-resonance frequency for the ultrasonic waveguide was 39.3 kHz, which coincided with the experimental value of 39.8 with 1.3% error. Considering these results, it is thought that the developed ultrasonic waveguide will be applicable in microchip cooling.

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