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High-power ultrasonic transducers using polymer materials and their applications to functional ultrasonic devices

ポリマー材料を用いた 強力超音波振動体とその機能デバイスへの応用

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Summary of thesis

(論文要約)

To achieve lightweight ultrasonic transducers for mass production, in this thesis, we applied low-mechanical-loss polymer materials as the vibrating bodies in ultrasonic transducers, and evaluated the performance of the polymer-based functional ultrasonic devices.

In Chapter 1: "Introduction," we reviewed the developments of piezoelectric transducers and ultrasonic motors, and their commonly-used materials. To achieve the lightweight and mass production, which are the requirements of the transducers for next generations, it will be meaningful to employ functional polymers to fabricate high-power ultrasonic transducers and devices.

In Chapter 2: "Measurement of mechanical quality factors of polymers in flexural vibration for high-power ultrasonic application," we devised a method for evaluating the mechanical loss in high-amplitude ultrasonic vibration on the basis of the original definition of the mechanical quality factor (*Q* factors), and estimated the *Q* factors of several commonly-employed functional polymers when the vibration amplitude and the frequency were varied. The *Q* factor is defined as the ratio of the reactive energy stored on a vibrating body to the dissipated energy when the wave propagates on vibrating body in a period. The reactive energy is calculated from the vibration velocity distribution, and the dissipated energy is obtained from the reduction in the acoustic power when the wave flows into and out of the vibrating body. In addition, to obtain a high precision, the optimal dimensions of the polymer samples are discussed. The *Q* factors of polymers decreases as the frequency and vibration amplitude become higher. At 28.30 kHz, the *Q* factors of poly phenylene sulfide (PPS) reached approximately 460, the highest value among the tested polymers. Clearly, PPS is potentially applicable as the vibrating body in ultrasonic transducers.

In Chapter 3: "Polymer-based airborne ultrasonic transducer," we employed PPS as the vibrating body to fabricate an airborne ultrasonic transducer, and optimally designed its structure. The transducer included a longitudinal vibrator, where the piezoelectric ceramics were sandwiched between the PPS vibrating bodies, and a PPS thin film for enlarging the vibration velocity. Through the simulation, we discussed the optimal vibration mode, and adjusted the dimensions of each part. The experimental results show that the rated sound pressure reached 38.9 Pa, which was 3.5 times the value of the commercial transducer under the same electric-field intensity, and the ratio of the sound pressure to the weight of the polymer-based airborne ultrasonic transducer was 1.8 times the values of the commercial transducers. We anticipate that the practical application of the polymer-based airborne ultrasonic transducer, which exhibits high sound pressure and lightweight, can be achieved.

In Chapter 4: "Structural parameter study on polymer-based ultrasonic motor," we explored how the shape parameters, particularly the vibrator thickness, affected the performance of the PPS-based vibrators, and compared it with the metal-based vibrators with the same structures. As the PPS-based vibrators

become thicker, the force factors of the vibrators become higher, and enhance the output torques of the motors. However, the radial vibration components, which never contributes to the rotations of motors, also increase as the vibrators become thicker. The undesirable vibration components lead to high frictional loss, of which the negative effect on output torques of motors offsets the positive effect caused by the increase in the force factor. Since polymer materials and piezoelectric ceramics have great difference in mechanical constants, the polymer vibrating body should be much thicker than the piezoelectric ceramics to yield a force factor comparable to the metal-based vibrators. Thus, the optimal thicknesses of the polymer-based motors are higher than the values of metal-based motors with the same diameters, and the maximum output torques and power of polymer-based ultrasonic motors are lower than those of the metal-based motors. To improve the motor performance, we employ a triple-layered vibrator consisting of a thin alumina plate sandwiched between the PPS vibrating body and the piezoelectric ceramic plate, to increase the force factor. It is experimentally verified that the output torques of the motors are enhanced using the triple-layered vibrators.

In Chapter 5: “Performance improvement of polymer-based ultrasonic motor through utilization of high-order vibration mode,” for the first time, we investigated a high-order vibration mode in the polymer-based ultrasonic motor because it exhibited a higher electromechanical coupling factor than the bending mode, and provided a horizontal nodal line that facilitates the vibrator fixing. The experimental results show that the output torques and power of the polymer-based motors are improved under the high-order vibration modes.

In Chapter 6: “Conclusions,” we summarized the characteristics of polymer-based transducers and USMs, and pointed out the future works.

Last but not least, in Appendices, we introduced a magnetic field sensor on the basis of a polymer-based cantilever. Owing to the low elastic modulus and low density, the polymer-based cantilever provides a higher vibration velocity, which leads to a higher sensitivity, than the aluminum-based cantilever. Besides, a method for analyzing the force factors and the elliptical motion shapes of the vibrators used in traveling-wave USMs is introduced.