2E4-3

Double-parabolic-reflectors ultrasonic transducer with long and flexible waveguide for therapeutic ultrasound

Kang Chen[1†‡], Takasuke Irie[2], Takashi Iijima[3], and Takeshi Morita[3] ([1]Grad. School Frontier Sciences, The Univ. of Tokyo; [2]Microsonic Co., Ltd.; [3]Tokyo Univ. of Science)

1. Introduction

In order to deliver powerful ultrasound through waveguide for minimally invasive treatment (MIT), we invented Double Parabolic refLectors wave-guided high-power Ultrasonic tranSducer (DPLUS) [1-4]. As shown in Fig. 1, DPLUS waveguide has two parabolic reflectors to focus and guide ultrasound. In this work, we examine the use of long and flexible waveguide.

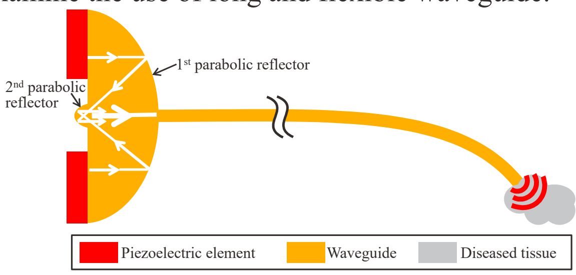

Fig. 1. DPLUS waveguides for ultrasound-based MIT.

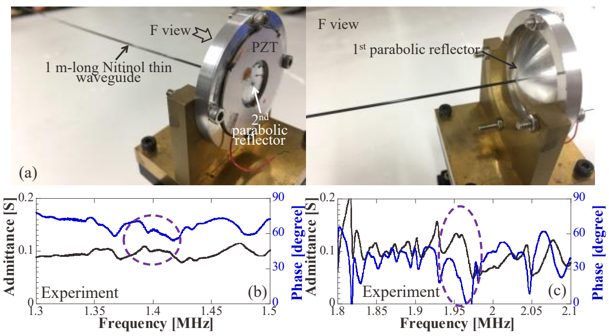

Fig. 2. DPLUS prototype and admittance measurement.

2. Methods and Results

A DPLUS prototype is shown in Fig. 2(a). The structure and material except thin waveguide part are based on our previous study [1-4]. Nickel titanium (Nitinol) material (The Nilaco Corporation, Tokyo, Japan) was selected for thin and flexible waveguide. The diameter (1 mm) and length (1 m) were designed based on Pochhammer-Chree wave theory. Focal lengths of two parabolic reflectors are 10 and 0.5 mm; material of DPLUS main body (without thin waveguide) is A2017. Piezoelectric element was selected as PZT 5H with large d_{33} from NGK Spark Plug Co., Ltd. The ring-shape PZT is 18 mm in inner diameter, 40 mm in outer diameter, and 1.1 mm in thickness. PZT and thin waveguide were both glued to DPLUS main body.

Admittance of DPLUS was measured and two ranges are shown in Figs. 2(b)-(c). Near 1.96 MHz is close to the thickness mode resonant frequency of PZT in DPLUS. Around 1.4 MHz is a resonance determined by the shape of parabolic reflectors structure. At these two resonances, incident wave is guided by two parabolic reflections, and they are suitable for generating large vibration-amplitude wave to thin waveguide.

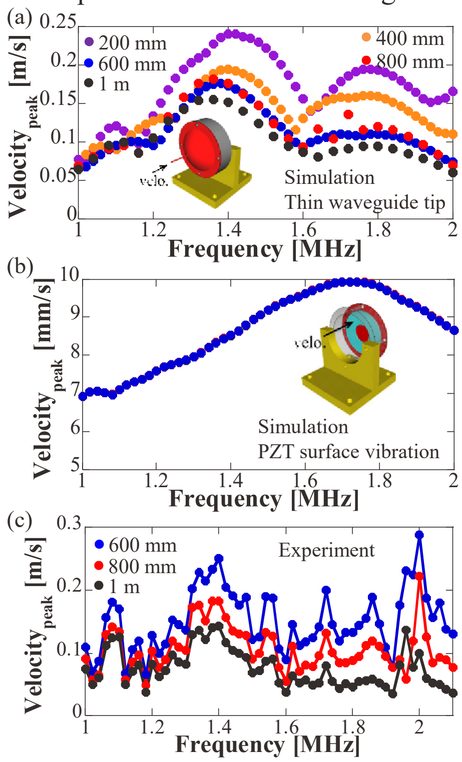

Fig. 3. Vibration velocity under different thin waveguide lengths. Simulation results at (a) thin waveguide tip and (b) PZT surface under 5 cycles short burst excitation. (c) Measurements at thin waveguide tip under 100 cycles.

Vibration velocity at the thin waveguide tip under different thin waveguide lengths were simulated by PZFlex (Weidlinger Associates, Los Altos, CA, USA) and measured by a vibrometer (LV-1800, Ono Sokki Co., Ltd., Japan). In simulation, lossless Nitinol was used, and it is shown that even neglecting material loss in thin waveguide, vibration amplitude can be changed under different lengths. This is caused by wave dispersion. Under 5 cycles short burst, two velocity peaks can be obtained as shown in Fig. 3(a), which correspond to the frequencies mentioned in admittance results. From the vibration amplitude at PZT surface in Fig. 3(b), one can deduce that thickness mode vibration of PZT contributes to the vibration peak at around 1.8 MHz in Fig. 3(a). Experimental results in Fig. 3(c) indicate larger change of vibration amplitude with length. They mainly come from two sources: wave dispersion and material loss. Since simulation results indicate limited vibration amplitude change between 1.3 and 2 MHz due to wave dispersion, experiments prove that material loss is the dominant source.

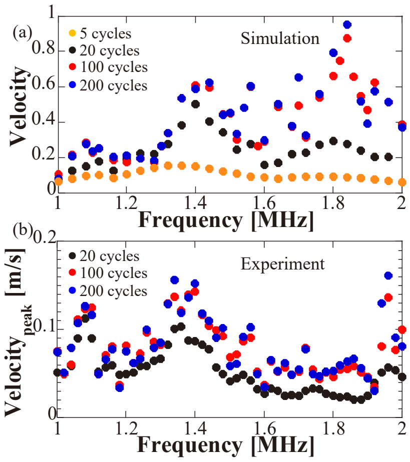

Fig. 4. Vibration velocity at 1 m-long thin waveguide tip under different burst cycles.

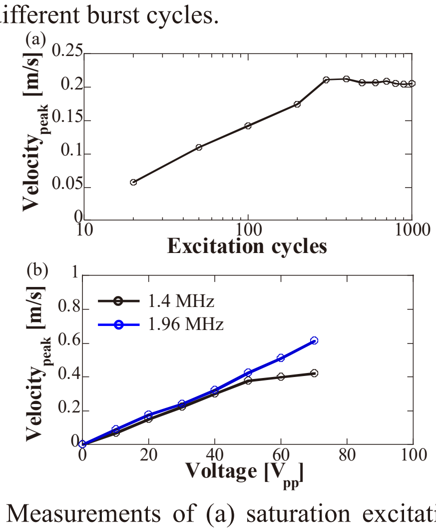

Fig. 5. Measurements of (a) saturation excitation cycle and (b) vibration amplitude limit.

Under short burst, incident wave propagates simply by double parabolic reflections; under long burst, vibration amplitude in the thin waveguide relies on resonant frequencies of DPLUS. Vibration velocity under different burst cycles were examined. Results were plotted in Fig. 4. With increasing excitation cycles, there are again two main velocity peaks corresponding to the frequencies discussed in admittance results. Velocity peak frequencies are similar for short and long burst excitation. Further examination to measure the mechanical output limit was conducted. Excitation cycle for saturated vibration amplitude was measured as shown in Fig. 5(a). The saturation cycle is around 300 cycles. Then, vibration under large input voltage was measured under 200 burst cycles. As shown in Fig. 5(b), around 0.6 m/s can be estimated which is sufficient based on our previous demonstration [3].

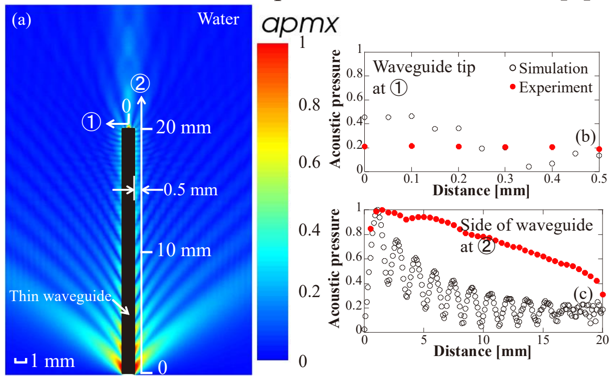

Fig. 6. Wave transmission when waveguide tip is immersed into water. Immersion depth is 20 mm. Acoustic pressure was normalized separately in experiment and simulation since simulation values are more than 5 times of experiment.

Acoustic output was measured to show wave transmission in target medium. Simulation and experiment were separately normalized as shown in Fig. 6. In experiment, thin waveguide was 1 m long, and acoustic pressure at directions ① and ② were measured at 1.96 MHz by a needle-type hydrophone (HY05N, Toray Engineering, Japan). To accurately capture the variation of acoustic pressure shown in simulation, hydrophone with sufficiently small effective diameter is required. Results indicate that side direction emission is much stronger than forward direction.

3. Conclusion

In this work, we studied powerful ultrasound delivery by DPLUS with a long and flexible thin waveguide. At a 1 m-long Nitinol thin waveguide tip, large vibration between 1 to 2 MHz could be measured. Acoustic measurement indicated that ultrasound mainly flows to the target from the side direction. Results are important for improvements of DPLUS and tissue destruction demonstration.

Acknowledgment

This work was supported by JSPS Kakenhi (20H02097) and Japan Keirin Autorace foundation.

References

1. K. Chen, T. Irie, T. Iijima, T. Morita: *Appl. Phys. Lett.*, **114**, (2019).
2. K. Chen, T. Irie, T. Iijima, T. Morita: *IEEE Trans. Ultrason. Ferroelectr. Freq. Control.*, 60 (2020).
3. K. Chen, T. Irie, T. Iijima, T. Morita: *Sci. Rep.*, **9** (2019).
4. Q. Liu, K. Chen, J. H, T. Morita: *Jpn. J. Jpn. J. Appl. Phys.*, **59** (2020).