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Double-parabolic-reflectors acoustic waveguides (DPLUS) for minimally invasive treatments

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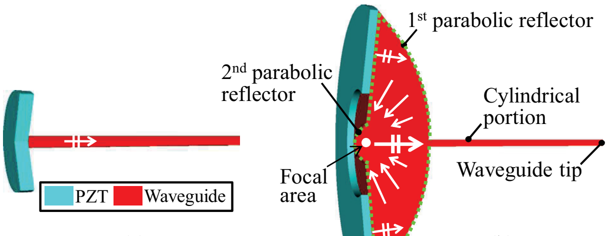
1. Introduction

High Intensity Focused Ultrasound (HIFU) treatments have been widely used to noninvasively treat various types of primary tumors and metastasis. However, it losses certain accuracy in localized therapy for deep tissues and may potentially induce undesirable bioeffects including side burnings by thermal-based therapies and significant hemorrhage by mechanical-based therapies. An alternative way for localized deep tissue ablation is minimally invasive treatment (MIT). MIT is an energy based treatment, it inserts the thin needle directly to the lesion to deliver different types of energy for treatments so as to limit the size of required incisions, localize the therapeutic region, and shorten the wound healing time, associated pain and risk of infection.

Acoustic waveguide that remotely delivers ultrasound to the lesions is one of the promising techniques for localized therapeutics. However, powerful ultrasound emission at the thin waveguide tip is difficult because of the limited energy source (large diameter difference between PZT and thin waveguides) and enregy loss during transmission[1]. Although some attempts have been explored to generate larger ultrasound, powerful ultrasound transmission is still not available due to undesirable reflections of ultrasound and constrained dimension of piezoelectric elements[2, 3].

2. Acoustic waveguides with double parabolic reflectors

In this work, we invented Double Parabolic refLectors wave-guided high-power Ultrasonic tranSducers (DPLUS) to realize powerful ultrasound generation. Comparison of conventional waveguides and the waveguide of DPLUS is shown in **Fig. 1**. For conventional configuration, large diameter difference exists between PZT and thin waveguides, which limits the amount of energy being directly transmitted to the waveguides. Thus, high-power transmission is impossible. For our invented waveguide, a ring-shape PZT with large surface area is attached to a double-parabolic-reflectors waveguide with large end surface, which indicates that more energy can be directly introduced to the waveguide. The 1st parabolic reflector is to increase the contact surface area with PZT and to focus ultrasound. The 2nd parabolic reflector is to transfer the focused ultrasound to an enhanced plane-wavefront ultrasound. Two parabolic reflectors share the same focal point and the resulted ultrasound is guided to the thin waveguide for high-power transmission. In our previous work[1], we have proved that the proposed acoustic waveguide can generate powerful ultrasound that is over one order-of-magnitude of conventional configuration in acoustic pressure and over two order-of-magnitude in power, which positively support the effectiveness of generating powerful ultrasound.



(a) (b)

Fig. 1. Configurations of the piezoelectric element and waveguides for (a) conventional models and (b) the proposed DPLUS.

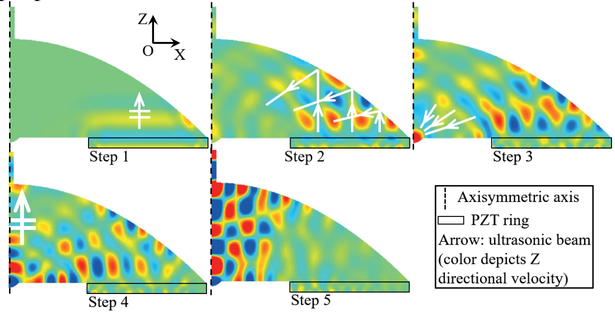


Fig. 2. Working principle of DPLUS waveguides.

The working principle of DPLUS waveguide is shown in **Fig 2**. PZT works in the thickness mode vibration. The working processes can be divided into five steps. Step 1: Plane-wavefront ultrasound is emitted by PZT and propagated into the waveguide. Step 2: Plane-wavefront ultrasound is reflected by the first parabolic reflector. Step 3: Reflected ultrasound is focused to the focal area.

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Step 4: Focused ultrasound is reflected by the second parabolic reflector and transferred to the enhanced plane-wavefront ultrasound. Step 5: The enhanced plane-wavefront ultrasound is propagating through the thin waveguide.

3. Frequency responses of DPLUS

A prototype of DPLUS was fabricated as shown in **Fig. 3**(a), the waveguide was made of duralumin and the fixture was made of brass. PZT was a soft type PZT C-62 from Fuji Ceramics Co., Ltd. with the thickness of 1.1 mm and inner/outer radius of 8/20 mm. The thin cylindrical waveguide radius was 0.5 mm, focal lengths of the 1st and 2nd parabolic reflectors equaled 10 and 0.5 mm, respectively. Experimental setup to obtain the frequency response of DPLUS was shown in Fig. 3(b) and the results were shown in **Fig. 4**. The admittance curves of DPLUS were flattened compared with admittance from single PZT ring without attaching to the waveguide and more admittance peaks appeared. Frequencies with large mechanical vibration exactly correspond to the obvious admittance change when the waveguide tip is immersed into water. Besides, large mechanical vibration can be observed from 0 to 2.5 MHz, which offers flexible selection of frequencies with large vibration for effective tissue destruction. To further characterize the vibration velocity, we select several frequencies, including low frequencies (62.1, 187.9, 305.1, and 438.1 kHz) and high frequencies (0.811, 1.346, 1.530 and 1.705 MHz).

4. Vibration characteristics

For the selected frequencies, we measured the vibration velocity as shown in **Fig. 5**. Vibration velocity at the waveguide tip showed an initial linear increase and a subsequent saturation for 1.346 and 1.53 MHz and a continuous increase for 0.811 and 1.705 MHz. Theoretical curves were provided by numerical simulation at 1.29 MHz under continuous and 5-cycles burst excitation. It is important to highlight that at megahertz frequencies, DPLUS can realize extremely large vibration velocity at the waveguide tip, 4.8, 1.015, 2.080, and 2.315 m/s peak value of vibration velocity can be achieved at around 0.807, 1.3454, 1.530 and 1.702 MHz under the exciting voltage of 120, 90, 90 and 70 V_{pp}, respectively. These results proved the high mechanical vibration of our DPLUS at megahertz range. At low frequencies, it can be observed that 62.1 kHz offers the largest potential to increase the vibration velocity, 7 m/s at 10 V_{pp} can be easily achieved, while other frequencies showed smooth increase of vibration velocity, around 4.4, 2.2, and 3.9 m/s can be realized under 80 V_{pp} at 187.6, 306, and 438 kHz, respectively.

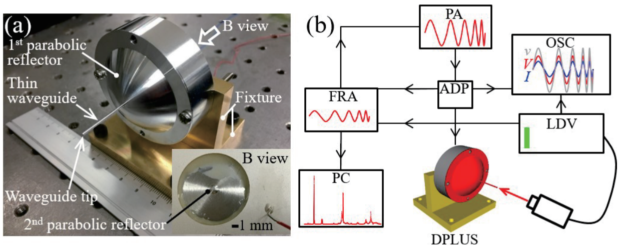

Fig. 3. (a) Prototype and (b) experimental setup. PC personal computer, FRA frequency response analyzer, PA power amplifier, ADP adaptor, OSC oscilloscope, LDV laser doppler vibrometer.

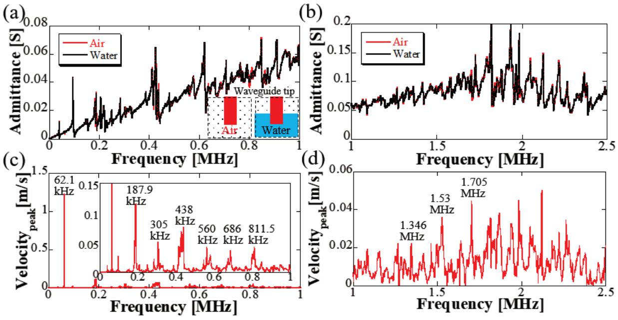

Fig. 4. Frequency response of DPLUS. Admittance curves of DPLUS in air and water from (a) 0 to 1 MHz and (b) 1 to 2.5 MHz. Vibration velocity curves of DPLUS in air from (c) 0 to 1 MHz and (d) 1 to 2.5 MHz.

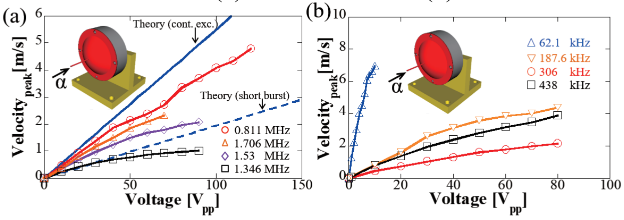

Fig. 5. Vibration velocity characteristics at (a) high frequencies from 1 to 2 MHz and (b) low frequencies from 0 to 0.5 MHz.

5. Conclusion

In this work, we presented the invention of DPLUS and the basic performances that can be utilized for thermal and mechanical ultrasound therapeutics. Simulation and experiments positively support the high-power ability of our DPLUS, which is promising for further practical applications.

Acknowledgment

This work was supported by Japan Keirin Autorace foundation (JKA).

References

1. K. Chen, T. Irie, T. Iijima, and T. Morita: *Appl. Phys. Lett.* **114** (2019) 072902.
2. T. Moriya, Z. Q. Hu, Y. Tanahashi and Y. Seki: *Jpn. J. Appl. Phys.* **42** (2003) 3262.
3. T. Irie, N. Tagawa, M. Tanabe, T. Moriya, M. Yoshizawa, T. Iijima, K. Itoh, T. Yokoyama, H. Kumagai, and N. Taniguchi: *J. Ultrasound Med.* **38** (2011) 119.