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Development of 3 dimensional shapes piezoelectric films for ultrasonic devices.

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1. Introductions

In general, cavitation is triggered by tiny cavitation nuclei in liquids, and this phenomenon has been observed in vivo. Ultrasound frequencies of around 20 kHz-10 MHz are used for cavitation generation, depending on the purpose, but for further innovation in treatment technology, control of powerful ultrasound at high frequencies above 10 MHz is desired.

However, the relationship between the sound pressure to generate cavitation and the frequency at which it occurs is inversely proportional, and it has been found that the sound pressure to generate cavitation is exponentially higher at frequencies above 10 MHz. For example, a sound pressure of 40 atmospheres (4 MPa) is required at a frequency of 10 MHz, and there are almost no reported cases of ultrasonic devices that can continuously irradiate such a high sound pressure in water. If continuous irradiation at 40 atmospheres of sound pressure at 10 MHz is possible in water, the diameter of cavitation would be less than 1 μm, which would enable fine treatment with a resolution at the cellular level, which has not yet been realized.

In this study, we fabricated a prototype ultrasonic transducer that can continuously irradiate high acoustic pressure at 10 MHz or higher using hydrothermally synthesized $KNbO_3$ piezoelectric single-crystal films that have good acoustic matching with water and can transmit high power ultrasound in a wide bandwidth, and conducted basic evaluations of this transducer.

Therefore, We will evaluate the transducers by generating acoustic nonlinear phenomena in water using strong ultrasonic waves, and discuss possible applications. In addition, by making the ultrasonic transducer in 3D shape, we will spatially control the strong ultrasonic sound field at high frequencies and control the waveforms by utilizing the wide bandwidth.

2. Fabrication of 3D shapes-piezoelectric $KNbO_3$ films.

Hydrothermally synthesized $KNbO_3$ piezoelectric single-crystal films[1-3)], which have good acoustic matching with water and can transmit high-power ultrasonic waves over a wide bandwidth, are used as the main material for ultrasonic transducers that can continuously emit high sound pressure in the high frequency band. The film formation procedure in this study is as follows: The Nb-$SrTiO_3$ substrate is machined to create a concave surface on the substrate surface. $KNbO_3$ piezoelectric single-crystal films are formed along the concave surface by hydrothermal synthesis.

After film formation, the $KNbO_3$ piezoelectric single-crystal film is peeled off from the substrate, electrodes are formed on the top and bottom of the resulting film, and the film is connected to a coaxial cable as ground and signal lines. The shape of the acoustic aperture surface of the ultrasonic transducer using the concave piezoelectric film is shown in Figure 1.

When ultrasonic waves are focused in water, the concave side is used as the aperture surface. When ultrasonic waves are diffused in a wide-directional manner, the convex side is used as the aperture surface.

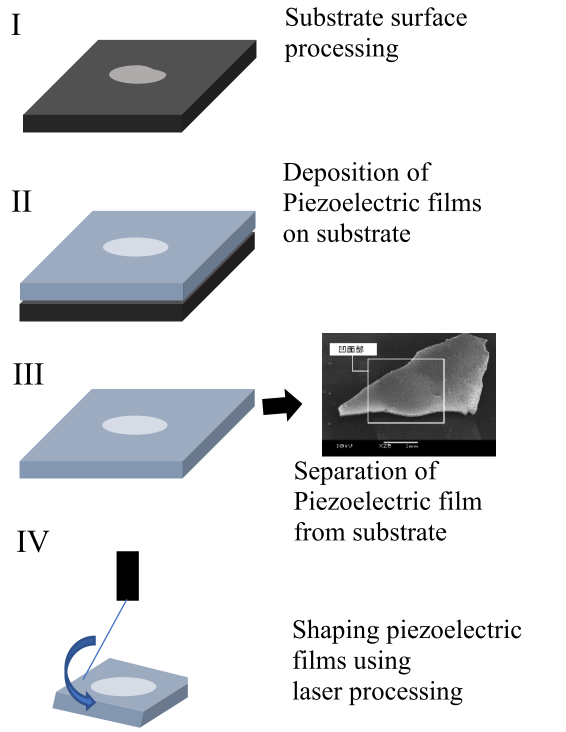


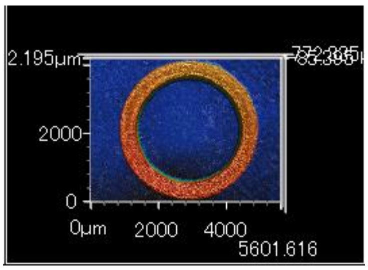
Fig.1 Schematic of concave piezoelectric film formation

Concave or groove machining was performed on the substrate to obtain a piezoelectric film on its surface. After the piezoelectric film was peeled off from the substrate, it was shaped using a laser cutting machine to improve the yield as an ultrasonic transducer material. With regard to the piezoelectric crystal film by this method, it has also been found that various shapes can be designed and realized with high accuracy by shape processing using a laser processing machine, as shown in Figure 2. In both cases, the electrodes are already formed on surface of $KNbO_3$ piezoelectric films.

Star shaped

Ring shaped

Profiling with Contour Lines of Ring shaped



Cross section of profiling of Ring shaped

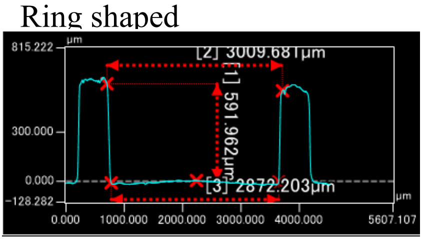


Fig.2 Photographs and profiling of 3D shapes $KNbO_3$ piezoelectric films

3. Ultrasonic transducers using 3D shapes $KNbO_3$ films

The maximum vibration velocity of a hollow structure epitaxial $KNbO_3$ film ultrasonic transducer (hereinafter referred to as the transducer of this method) when driven at its resonant frequency was measured, and large amplitude characteristics were obtained near the natural frequency in the radial direction due to the piezoelectric transverse effect. The piezoelectric crystal film part of the transducer using this method has a thickness of 0.5 mm, an outer diameter of approximately 3 mm, and an inner diameter of approximately 1.2 mm. The natural frequency in the radial direction is approximately 350 kHz, and the limit of the maximum vibration velocity exceeds 0.5 m/s.

It was found that ultrasonic transducers using shaped piezoelectric crystal films also have high output characteristics. In the future, we plan to design a shape to control the sound field in underwater operation, and measure the frequency response, output sound pressure, directivity, and other sound fields of ultrasonic transducers using 3D-shaped piezoelectric crystal films.

Acknowledgment

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