A Cylindrical Ultrasonic Micro Motor Based on PZT Thin Film

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Abstract — We introduced a hydrothermal method to deposit the PZT thin film on a titanium tube to make a stator transducer for an ultrasonic motor. The titanium tube was 2.4 mm diametral, 10 mm long and 0.25 mm wall thick. On the side wall, the thin film was formed about 8 μm in thickness. Four driving electrodes were painted on the PZT film. The electrodes were strip shaped and they divided 4 parts in circumference of the side wall. Two pairs of the strip electrodes facing each other were connected to individual RF power supplies to excite degenerated fundamental bending vibration modes. Two generator has 90 degree phase difference to excite mode rotation. The transducer was driven at the resonance about 106 kHz. The driving voltage from 20 to 33 V_{p-p}, we obtained rotation of 0 to 300 rpm.

INTRODUCTION

For a micro electro mechanical system, a direct drive actuator is important device. An ultrasonic motor is one of the most promising actuator for this purpose. In a cm-order diameter, it is already demonstrated that ultrasonic motors generate ten to thirty times torque than electromagnetic motors. This advantage will be preserved at mm-order and sub mm-order diameter motor.

Micro ultrasonic motors whose stator vibrators were composed of piezoelectric thin film[1],[2] were all flat profile. However, for a purpose of a high torque motor, cylindrical motors are superior to the flat ones. In a cm-order diameter, such a motor has been proposed[3], and then, been put into commercial production[4], already. Therefore, a cylindrical type has been adopted for this investigation.

There are several ways to deposit piezoelectric thin film. Sol-gel process is rather popular. This method has already tried to make the micro

ultrasonic motor. But a problem of this method is a difficulty to get thick material such as 10 μm . In order to take out enough force, thick film is required for a stator transducer. Accordingly, we have introduced a hydrothermal synthesis to deposit lead zirconate titanate (PZT) film. The process of this method is carried out in a liquid, hence, the shape of a transducer is rather free. This method for PZT film had developed by Tsurumi et al[5]. They deposited 20 μm thick film. On this account, we introduced the hydrothermal synthesis method to fabricate the PZT film.

The stator transducer was made with a titanium pipe on which PZT film was deposited.

MATERIALS AND VIBRATION MODE

For a micro ultrasonic motor, a stator transducer should be simplified. In such a case, thin film of PZT is suitable, although, a sandwich transducer which uses bulk material is superior to a high power application. To fabricate a superior performance small stator transducer for an ultrasonic motor, we require the several μm thickness PZT film which has good electromechanical characteristics. Also a substrate material is important to make low mechanical loss transducers.

A hydrothermal synthesis method for PZT has been developed. This method is available to fabricate enough thickness film and high linearity response actuator[5]. One more distinctive feature is that the deposited PZT film does not require the polarization process. The PZT film is automatically polarized during the synthesis process, therefore, the actuator may have superior linearity. The high linearity suggests possibility of the low mechanical vibration loss. The deposit process is carried out in high pressure liquid, so that the base material shape is free. Fortunately,

Fig. 1 Schematic shape of a stator vibrator for a micro ultrasonic motor.

Fig. 2 Principle of the micro ultrasonic motor using degenerated bending mode.

the substrate material is limited to titanium or titanium oxide. Titanium possesses high tensile strength and high mechanical Q factor. Hence, this substrate material is suitable for a stator transducer.

We have fabricated a cylindrical shape stator transducer as shown in Fig.1. The base material is titanium tube and the PZT film is deposited on the side wall. The polarization of the PZT film is the thickness direction. By the transverse effect, the bending vibration of the tube is excited.

As same as the other mode rotation type ultrasonic motors, the vibration of the stator transducer is transformed to the rotation motion through the friction force as shown in Fig.2. The rotor turns opposite direction by alternating the mode rotation direction.

Fig. 3 Fabrication process of the stator transducer.

FABRICATION OF STATOR TRANSDUCER

Fabrication process of the stator transducer has four steps. Each step is indicated in Fig.3. They are,

- (1) cut the titanium pipe in appropriate length and polish the side wall,
- (2) deposit the PZT film by the hydrothermal process,
- (3) paint the silver past for driving electrodes,
- (4) connect the copper wire to supply the RF electricity.

The hydrothermal method of PZT film is suitable for this stator fabrication. Because the process is carried out in the high temperature and high pressure liquid as shown in Fig.4. Hence, a particular skill is not required, even though the deposit subject is not a flat surface but a curved surface or some other complex shape.

The deposit process was carried out in an autoclave which has capacity of 30 ml. The required materials are solution of $\text{Pb}(\text{NO}_3)_2$, ZrOCl_4 , KOH and a solid titanium. The titanium, a component of the PZT, is supplied from the substrate. The autoclave was kept at 160°C for 48 hours. The atmospheric pressure was about 6 atm. To avoid the pin hole uncoated area, the autoclave was rotated during the process at several revolutions per minutes.

The PZT film was successfully deposited on the curved side wall of the titanium pipe. The thickness of the film was about 7 to 9 μm. To confirm that the film was actually PZT, a 20 μm titanium flat foil was also put in the autoclave to examine XRD afterward. The result is shown in Fig.5.

The feeding wires for RF power supply were fixed at the nodal position of axial-vertical vibration component. Because this position is suitable not to disturb the bending vibration. These wires were also utilized to hold the motor.

EXPERIMENTS

The resonance condition was measured by monitoring the bending vibration velocity at the end using a Laser Doppler vibrometer as shown in Fig. 6. The driving voltage was 25 Vp-p. The resonance frequency was about 106 kHz. From

Fig. 4 Scheme of the process of PZT thin film.

Fig. 5 XRD pattern of deposited thin film of titanium substrate.

the frequency response indicated in the figure, the mechanical Q factor was about 200. Due to the large loss of the electrodes and the wire connection, the mechanical loss might have increased. In a result, rather high driving voltage was required to get enough vibration velocity.

The operation test of the motor was carried out using a screw as a rotor. The photograph of the motor is shown in Fig. 7. The cone shaped head screw was used to make the rotor contact with the stator at the inner side edge of the cylinder. The diameter and the weight was 1.7 mm and 0.05g. The rotor was put on the stator so that the pre load was only the weight of the screw. The rotation speed changed from 0 to 295 rpm with the driving voltage from 20 to 33 Vp-p as shown in Fig. 8.

CONCLUSION

We have proposed a cylindrical micro ultrasonic motor. To fabricate the stator transducer of the motor, the hydrothermal method for the PZT thin film was applied. The PZT film deposited on the round surface of the titanium pipe. The fabricated transducer worked as expected.

For the next step, the quality of the stator transducer should be improved. The electrodes and the power supply wires caused the vibration loss. The construction should also be improved to get out of the mechanical output power efficiently. The rotor shape, the driving surface and the motor

Fig. 6 Vibration amplitude of stator transducer against applied frequency.

Fig. 7 Photograph of the fabricated micro ultrasonic motor.

Fig. 8 Rotation speed versus driving voltage.

At high vibration amplitude, the characteristics of the deposited PZT film should be examined. To estimate the performance of the motor, these information is important.

As the film is thin such as $10\ \mu\text{m}$, the actually required driving voltage would be low. Hence 2 or 3 volt will be enough for driving the motor.

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