Thin Plate Longitudinal Vibrator Touch Probe Sensor using PZT Thin Film

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Abstract - Using PZT thin film, a vibro touch sensor was fabricated. The sensor is for measurement of material surface roughness and surface structure of micro devices such as VLSI up to sub nano meter order resolution without any damages to work piece. The sensor element has flat shape. Base material was titanium thin plate whose thickness was 100 µm. On both sides of the titanium, PZT film was deposited 10 µm. The sensor element had half wave length longitudinal vibration mode. The resonance frequency of the sensor was about 304 kHz. The sensitivity of the device is the tangential of the pickup voltage decrease. In the experiment, the tangential was 0.018 mV/nm. From the sensitivity and the noise level, the resolution of the sensor was 2.4 nm.

INTRODUCTION

For quick scanning and higher sensitivity to measure surface roughness and surfaces texture of micro devices without damage, a longitudinally vibrating probe sensors have been proposed [1]-[3]. We are improving the material performance and developing touch probe sensors for this purpose.

To fabricate micro transducers and micro systems, piezoelectric material is very effective for transduction. This is because the electro mechanical coupling factor is large and the device design is so simple. Especially, at the resonance operation condition, the driving voltage is low and the sensitivity is high.

For application of PZT film to actuators and sensors, we introduced a deposition process of the hydrothermal method [4],[5]. This process has merits of thick film thickness, free of deposition surface shape, not requiring annealing process, automatic polarization, low hysteresis and tight bonding force to base material.

HYDROTHERMAL METHOD PZT FILM

For fabrication of micro actuators and sensors, a hydrothermal method was investigated to deposit PZT film. Hydrothermal method utilizes the chemical reaction between titanium base metal and the melted ions at high temperature. The chemical reaction is carried out in the solution as shown in Fig. 1. To sum up other merits of hydrothermal method, thick deposited PZT film, automatic polarization, and unnecessary of annealing process are attractive characteristics.

The process has two steps. Both processes are curried out in an autoclave at high temperature and high pressure. The first step is called nucleation process. During this process, nuclear crystals of PZT are deposited on the titanium base. The process temperature is 140 degree Celsius. The solution of this process contains a few amount of titanium ion as shown in Table I. Titanium is also provided from the base, therefore,
the titanium ion concentration of the first step is low. For tight bonding of the film to the base material, the mechanism of crystal generation using the base material has an advantage. We proposed the improved process [5]. The reaction conditions which were adopted for transducer fabrication is shown in Table I. The original process did not contain titanium ion at the 1st step.

The second step process was carried out at lower temperature of 120 degree Celsius as indicated at Table I. Concentrations of each ion were adjusted to obtain proper ingredient ratio. During the second process, PZT crystal are expected to grow up. The thickness of the film increased by repeating the crystal growth process. After the two processes, we obtained 10 µm thick film for each side of the titanium base.

The piezoelectric factor $d_{31}$ of deposited film was estimated. From the measurement of the vibration amplitude at low frequency drive, deformation was estimated. The piezoelectric factor $d_{31}$ was estimated to be -34 pC/N from the measurement. The factor of bulk material is 3 times higher than these values.

**PERFORMANCE OF THE PZT FILM TRANSDUCER**

A rectangular shaped longitudinal transducer which was 7.9 mm long, 1 mm width, and 114 µm thick was fabricated. The vibration mode was half wave length longitudinal vibration. The PZT film was deposited 7 µm on both side of 100 µm titanium base. The measurement of the vibration velocity was carried out with a laser Doppler vibrometer.

We obtained the maximum vibration velocity of 0.53 m/sec by the longitudinal vibrator as indicated in Fig. 2. The vibration velocity was linearly increased against the driving voltage and did not saturate, but the device brake down due to high electric field. The maximum vibration level of bulk PZT elements was 0.3 m/sec [6]. In case of single crystal material such as

<table>
<thead>
<tr>
<th>Table I Reaction conditions of the hydrothermal method for PZT film.</th>
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<tbody>
<tr>
<td><strong>1st Process</strong></td>
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<tr>
<td>ZrOCl$_2$·8H$_2$O        0.507[g] melted into 2[ml] H$_2$O</td>
</tr>
<tr>
<td>TiCl$_4$              0.35[ml] 1.603[mol/l] TiCl$_4$</td>
</tr>
<tr>
<td>Pb(NO$_3$)$_2$         1.204[g] melted into 7[ml] H$_2$O</td>
</tr>
<tr>
<td>KOH                  2.693[g] melted into 11[ml] H$_2$O</td>
</tr>
<tr>
<td>Temperature :140 degrees Celsius</td>
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<tr>
<td>Reaction time :24 hours</td>
</tr>
<tr>
<td><strong>2nd Process</strong></td>
</tr>
<tr>
<td>ZrOCl$_2$·8H$_2$O        0.761[g] melted into 2[ml] H$_2$O</td>
</tr>
<tr>
<td>TiCl$_4$              0.53[ml] 1.603[mol/l] TiCl$_4$</td>
</tr>
<tr>
<td>Pb(NO$_3$)$_2$         1.806[g] melted into 7[ml] H$_2$O</td>
</tr>
<tr>
<td>KOH                  2.693[g] melted into 11[ml] H$_2$O</td>
</tr>
<tr>
<td>Temperature :120 degrees Celsius</td>
</tr>
<tr>
<td>Reaction time :24 hours</td>
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</tbody>
</table>

Fig. 2. Vibration velocity of the rectangular transducer; longitudinal vibration of 7.9mm x 1mm element.

Fig. 3. Frequency response of the rectangular transducer at high driving voltage.

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LiNbO$_3$, this limit is 3 m/sec [6]. The hydrothermal PZT material is intermediate of ceramics and single crystal.

Under the condition that the driving voltage was constant, the vibration velocity was measured with changing driving frequency. In the case of bulk materials, it is well known that the response curves are distorted and jumping phenomenon are observed. In the case of hydrothermal PZT film devices, however, the response curves were smooth and continuous as shown in Figs 3. Therefore, the element is good for sensor and superior than bulk PZT which has strong non-linearity.

It is concluded that the hydrothermal PZT has fine linearity and high intensity mechanical output. They seem to be based on polycrystal structure of the material.

TOUCH PROBE SENSOR

Using the PZT thin film, a vibro touch sensors were fabricated. The sensors are for measurement of material surface roughness and surface micro construction of micro devices such as VLSI up to sub nano meter order resolution without any damages to work piece. This device is scanning probes sensor as shown in Figs. 4. The probe sensor is intended to measure the surface profile at tiny contact force.

The sensor element has flat shape as shown in Fig. 5[7]. Base material was titanium thin plate whose thickness was 100 µm. On both sides of the titanium, PZT film was deposited 10 µm. Electrodes were deposited on both sides for drive and pickup. The sensor element had half wave length longitudinal vibration mode. At the nodal part of the vibration mode, the element was supported by a flame. One quarter wave length bar was for the drive and pickup. The other quarter wave length was an exponential horn to enlarge the vibration amplitude.

The resonance frequency of the sensor was about 304 kHz as indicated in Fig. 6. From the pickup output voltage, vibration amplitude is monitored. To avoid electromagnetically coupling, the sensor electrical circuit had balanced input stage. The amplifier gain was about 20 dB. The equivalent noise level at input terminal including the sensor element was 0.042 mV.

We measured the change of the output voltage from the pickup electrode when we made the sensor approach to a work piece. The sensor pickup voltage diminished due to touch to the work piece at the tip. The measured result is shown in Fig. 7 at the resonance frequency drive. The cyclic contact to the work piece limited the vibration amplitude, then, the pickup voltage decreased.

If we maintain the decrease of the vibration amplitude by monitoring the pickup voltage, the cyclic contact condition of the sensor tip maintained uniformly. With this servo mechanism, the sensor tip trace the surface shape of work piece. The resolution of the sensor system is limited by the sensitivity of the element and the noise level of the element and the amplifier. The sensitivity of the device is the tangential of the pickup voltage decrease as indicated in Fig. 7 by a solid line.

Fig. 4. Schematic measurement way for operation of vibro touch sensor.

Fig. 5. Vibro touch sensor and its connection to electric driver and sensor output.
In the case of this experiment, the tangential was 0.018 mV/nm. From the sensitivity and the noise level, the resolution of the sensor was 2.4 nm.

The resolution of the system depends on the quality of the piezoelectric film. The piezoelectric factor $e_{31}$ was 0.13 C/m². From an analytical approach, we know that the resolution is proportional to the piezoelectric factor. Hence, if the PZT film had high piezoelectric factor as same as bulk material, namely $e_{31}=3$ C/m², the resolution would go up to 0.1 nm.

**SUMMARY**

We fabricated touch probe sensors using the hydrothermal method PZT film. The touch probe sensor had resolution to measure 2.4 nm sensitivity. The performance of these devices such as the resolution depend on the piezoelectric factor of $e_{31}$. The performance will be better by improving the PZT film quality.

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**REFERENCES**


