A Flat Type Touch Probe Sensor Using PZT Thin Film Vibrator

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Abstract
We have fabricated a touch probe sensor, which has a flat configuration and using PZT thin film vibrator. This sensor is for high-precision surface shape measuring, for example, SPM. The sensor consists of a oscillator vibrating in the longitudinal direction. The vibration was exited and detected by a hydrothermaly deposited PZT thin film device. The length of the vibrator was 9.8 mm, and its resonance frequency was 304.35 kHz. The sensitivity and the resolution were evaluated by experiments. The vertical resolution was estimated to be 2.4 nm.

Introduction
Touch prove sensors have been used as probe of surface shape measuring tools. For example, vibrating cantilevers are used as such probe in scanning probe microscopes (SPM) including atomic force microscopes (AFM)[1]. Most of them are using bending vibrating cantilevers. However, a longitudinally vibrating probe has been proposed as the probe of such measuring tools[2,3]. This is because longitudinal vibrator has much higher Q value, and not so influenced by the damping ratio of air viscosity compare to bending vibrator. In addition, longitudinal vibrator has much higher resonance frequency than cantilevers. So quick scanning of the probe can be realized.

We fabricated a touch probe sensor using a longitudinal vibrator. The vibration was generated by the hydrothermaly deposited PZT thin film[4]. This previous sensor consisted of a rod vibrating in the axial direction. Its length was 27.8 mm and its resonance frequency was 116 kHz. The resolution was higher than 67 nm. However, the pick-up voltage contained offset value. So the sensitivity will be improved by reducing the offset.

figure 1: Principle of the measurement using the touch probe sensor.
In this paper, in order to obtain much higher sensitivity, we have fabricated a much smaller and flat-type sensor.

**Principle and Structure**
The schematic view of the measurement using the touch probe sensor is shown in Fig.1. The sensor consist of a half wave length longitudinally vibrating oscillator. An exponential horn enlarges the amplitude of vibration. When the tip end of the horn touches the surface of the workpiece, the resonance frequency of the vibrator shifts. By continuously detecting the contact along the surface, the surface shape of the workpiece can be obtained.

The structure of the touch probe sensor is shown in Fig.2. The vibrator length was 9.8 mm. The step-up ratio of the exponential horn was 3.2. The base material of the vibrator was titanium substrate. The thickness of this substrate was 100 μm. On the surface of the Ti substrate, we deposited PZT thin film by the hydrothermal method[5,6]. The thickness of PZT film was about 7 μm each side. The electrodes deposited on the surface of the PZT film were used for the drive and the pick-up.

In order to reduce the influence of the offset, we use and a differential amplifier. This is because the offset would be mainly due to the leakage between the supply and the pick-up wires. As shown in Fig.3, the pick-up voltage was defined as the deference between the voltage of the pick-up electrode and that of the reference electrode. The differential amplifier circuit gain was 10.
Experiments

To evaluate the relationship between the vibration amplitude and the pick-up voltage, the velocity of the vibrator tip and the output voltage of the amplifier were measured. The driving voltage was $3 \, \text{V}_{\text{p-p}}$. The results are shown in Fig.4. The plots of the pick-up voltage are the values of measurement results divided by amplifier gain. The amplitude and the pick-up voltage had a peak at 304.35 kHz. At that frequency, the amplitude was $126 \, \text{nm}_{\text{p-p}}$ and the mechanical Q value was 705. The pick-up voltage was $3.36 \, \text{mV}_{\text{rms}}$. From the plots of the pick-up voltage, the offset value was small enough. And it can be said that the resonance frequency can be detected from the peak value of the pick-up voltage.

To evaluate the sensitivity and the resolution of the sensor, we measured the relationship between the pick-up voltage and the tip-workpiece displacement. The results are shown in Fig.5. The pick-up voltage was measured when the workpiece was brought close to the vibrator tip. The plots of pick-up voltage has not divided by the amplifier gain. The plots describes the force curve. From the left hand of the graph, each area corresponds to (A) the freely vibration, (B) the tapping vibration, and (C) the contact.

From the change of the relationship between the displacement and the pick-up voltage, as shown in Fig.5 (B), the sensitivity and the resolution of this sensor is obtained. The sensitivity can be defined as the tangent of the tapping mode in Fig.5. This equals to the change of the pick-up voltage, $\delta V$ in Fig.6, divided by the change of the amplitude of vibration, $\delta d$ in Fig.6. From the slope of the curve in Fig.5, the sensitivity was $2.0 \times 10^{-2} \, \text{mV}/\text{nm}$. The resolution equals to the minimum detectable voltage divided by the sensitivity. The minimum detectable voltage is defined as the
equivalent noise level of the amplifier at the input terminal. From the measurement of the noise level and the sensitivity, the resolution was 2.4 nm.

**Conclusion**

We fabricated the touch probe sensor using hydrothermally deposited PZT thin film, and evaluated its sensitivity and resolution. The resonance frequency and the tip-amplitude at the resonance were 126 nm-o-p and 304.35 kHz. The sensitivity and the resolution were $2.0 \times 10^2$ mV/nm and 2.4 nm. We could achieve higher sensitivity and resolution by miniaturizing the vibrator and using the flat configuration.

**References**


