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An electrostatic field sensor operated by self-excited vibration of MEMS-based self-sensitive piezoelectric microcantilevers

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ABSTRACT

We have developed MEMS-based electrostatic field sensors (MEMS-EFS) composed of probe to detect electrostatic field and self-sensitive piezoelectric microcantilevers. The self-sensitive piezoelectric microcantilevers have $Pb(Zr,Ti)O_3$ (PZT) thin films for sensor and actuator. The MEMS-EFS were fabricated through sol–gel deposition of PZT thin films and MEMS microfabrication process. An output voltage of the PZT thin films for sensor was found to be proportional to the displacement of the microcantilevers. Self-excited vibration of the microcantilevers has been achieved by amplifying and forwarding the output voltage of the PZT thin films for sensor with a band pass filter circuit. The developed MEMS-EFS can evaluate an electrostatic field of −3 to 3 kV with good linearity.

1. Introduction

Electrostatic field sensors (EFS) are mainly applied for monitoring the electrostatic field on the exposure drum of copy machines and on the semiconductor wafers and flat panels processed in clean rooms. Miniaturization of EFS through MEMS technology can realize arrayed EFS, which enables 2D-mapping of electrostatic field. MEMS-EFS also realize integration with temperature, humidity and particle sensors, which are capable of multi-sensing wireless sensor nodes for monitoring clean rooms. Although MEMS-EFS based on thermal or electrostatic actuation have been developed [1,2], thermal noise and high voltage derived from such actuation interfere precise measurement of an electrostatic filed. Thus, MEMS-EFS should be based on piezoelectric actuation as well as commercially available ones.

EFS have probes to detect electrostatic field. The relation between the voltage of electrified bodies V_s, the surface of the probes S and the charges induced on the probe Q_s is expressed as

$$Q_s = \varepsilon_{air}\varepsilon_0 \frac{S}{L} V_s, \quad (1)$$

where $\varepsilon_{\rm air}$ and ε_0 are permittivity of air and vacuum, L is the distance between the probes and electrified bodies. Since it is difficult to measure Q_s under DC condition, EFS measure V_s by modulating S or L. Commercially available EFS modulate S by the shutter driven by $Pb(Zr,Ti)O_3$ (PZT) ceramics.

In the previous study, we reported MEMS-EFS, which integrate the probes to detect electrostatic field and PZT thin films for actuator into microcantilever [3]. Using the developed MEMS-EFS, we demonstrated the measurement of electrostatic field by modulating L with vibration of the microcantilevers driven at their resonant frequency. Since the resonant frequency can be varied by the intensity of electrostatic filed and environmental conditions such as temperature and humidity, the microcantilevers should be operated by self-excited vibration [4] so that the microcantilevers follow the variation in resonant frequency.

We have already developed self-sensitive piezoelectric microcantilevers, which have PZT thin films for sensor and actuator (sensor PZT and actuator PZT) [5,6]. Then, we have developed MEMS-EFS composed of the probes to detect electrostatic field and the self-sensitive piezoelectric microcantilevers. We have also developed the electronic circuit for self-excited vibration using a band pass filter. By using the band pass filter circuit, we have achieved self-excited vibration of the piezoelectric microcantilevers. Since the piezoelectric microcantilevers reported in the previous study [3] are driven by forced vibration, it was impossible to distinguish plus and minus of electrostatic field. In the present study, however, we have successfully demonstrated the measurement of the electrostatic field of −3 to 3 kV by synchronous detection of the output voltage from the sensor PZT modulated by the band pass filter and the voltage derived from electric charges induced on the probes.

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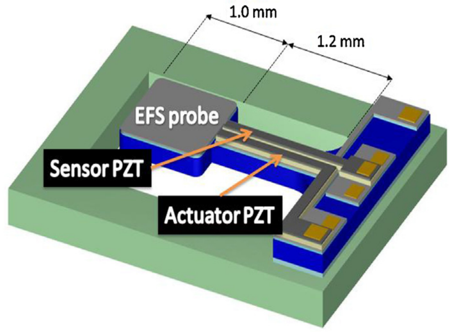

Fig. 1. Design of the MEMS-EFS developed in the present study, which integrate sensor PZT, actuator PZT and probes to detect electrostatic field into microcantilevers. EFS probes are 1 mm-square and cantilever is 1.2 mm long.

2. Design and working principle

Fig. 1 illustrates the design of the MEMS-EFS developed in the present study. The MEMS-EFS consist of the probes to detect electrostatic field (EFS-probe) and the self-sensitive piezoelectric microcantilevers. The microcantilevers have sensor and actuator PZT. The surfaces of the EFS-probe are located toward electrified bodies as shown in Fig. 2. When the distance L is varied at the amplitude of l and frequency of f by the actuator PZT, the charges generated on the EFS-probe Q_m are also varied as

$$Q_m = \varepsilon_{air}\varepsilon_0 \frac{S}{L + l\sin 2\pi ft} V_s. \quad (2)$$

Assuming $L >> l$, Eq. (2) can be approximated as

$$Q_m = q\sin 2\pi ft + Q_s. \quad (3)$$

This equation means that the charges on the MEMS-EFS are modulated at the amplitude of q. Assuming $q = rQ_s$, Eq. (3) is expressed as

$$Q_m = rQ_s \sin 2\pi ft + Q_s. \quad (4)$$

Thus, the amplified output voltage of MEMS-EFS V_{EFS} is expressed as

$$V_{EFS} = \frac{ArQ_s \sin 2\pi ft}{C_{total}} + \frac{AQ_s}{C_{total}}, \quad (5)$$

where A is an amplifier gain and C_{total} is the total capacitance of all of the components. The amplitude of Eq. (5), $V_{EFS,pp}$ is given as

$$V_{EFS,pp} = \frac{ArQ_s}{C_{total}}. \quad (6)$$

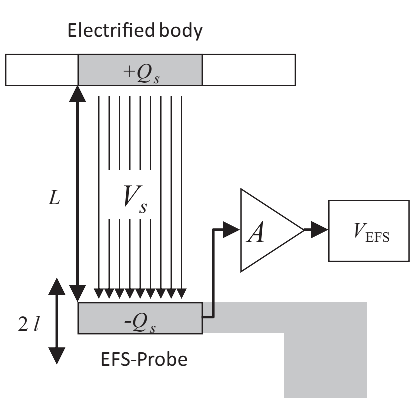

Fig. 2. Schematic of the arrangement of the MEMS-EFS and electrified bodies. The surfaces of the EFS-probe are located toward electrified bodies.

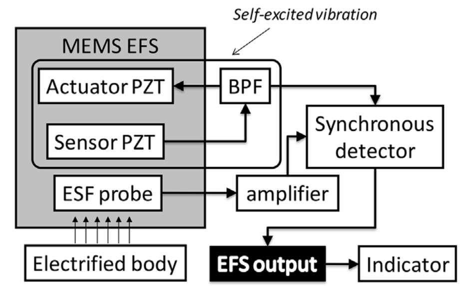

Fig. 3. Block diagram of the MEMS-EFS and electronic circuits for self-excited vibration.

Using Eq. (1), Eq. (6) is rewritten as

$$V_{EFS,pp} = Ar\frac{\varepsilon_{air}\varepsilon_0 S/L}{C_{total}} V_s. \quad (7)$$

Eq. (7) clearly represents that the amplitude of the AC output voltage obtained by amplifying the charge on the EFS-probe is proportional to the voltage of electrified bodies. Thus, the voltage of electrified bodies can be evaluated by measuring the amplitude of V_{EFS}.

As described above, MEMS-EFS should be operated by self-excited vibration so that the microcantilevers follow the variation in the resonant frequency due to change in the intensity of electrostatic filed and environmental conditions such as temperature and humidity. Fig. 3 illustrates the block diagram of the MEMS-EFS and electronic circuits for self-excited vibration. In order to realize self-excited vibration, we have employed band pass filters

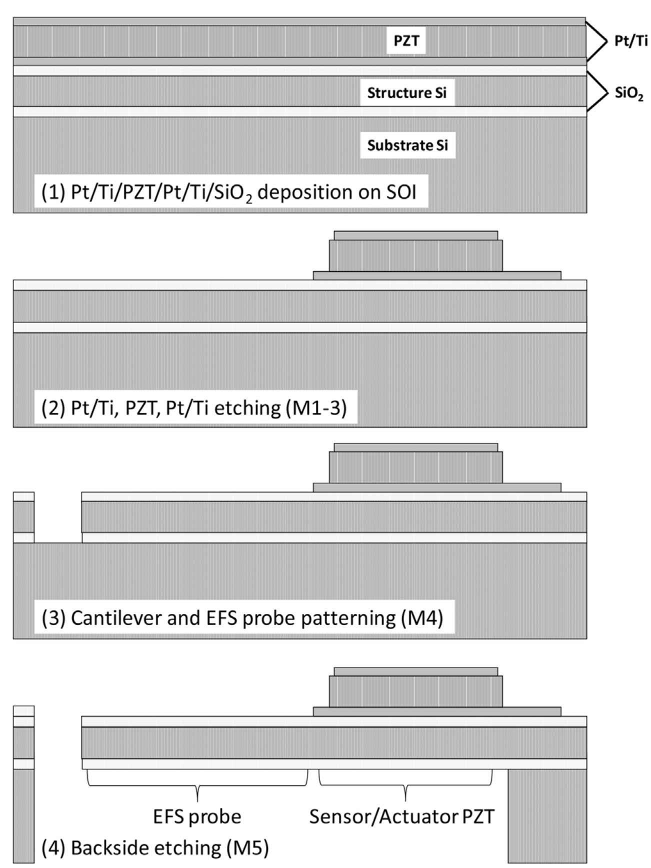

Fig. 4. MEMS microfabrication process for MEMS-EFS. (1) Pt/Ti/PZT/Pt/Ti/SiO_2 deposition on SOI wafer, (2) Pt/Ti, PZT, Pt/Ti etching (Masks 1–3), (3) Cantilever and EFS probe patterning (Mask 4) and (4) Backside etching (Mask 5).