

Characterization of BiFeO₃ Thin Film for Tactile Sensor Using Microcantilevers with Piezoelectric Capacitor and Strain-Gauge

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Abstract— Lead-free BiFeO₃ thin films for tactile sensor using microcantilevers have been prepared on Pt and SrRuO₃/Pt thin films on a SiO₂/Si substrate by RF sputtering, and the electrical characteristics have been optimized by controlling the substrate temperature, gas pressure, and oxygen partial pressure in deposition process. The BiFeO₃ thin film (thickness: 300 nm) deposited on SrRuO₃ (thickness: 80 nm) deposited at substrate temperature of 500°C in gas pressure of 0.6 Pa and oxygen partial pressure of 0.24 Pa has good crystallinity, ferroelectricity, and piezoelectric property. Therefore, it is demonstrated that BiFeO₃ thin film can be a good sensing material as a detection part of tactile sensor. Furthermore, a cantilever structure with piezoelectric capacitor and strain gauge has been fabricated and different time-dependent outputs from them can be obtained.

Keywords—tactile sensor, BiFeO₃ piezoelectric thin film, cantilever

I. INTRODUCTION

In recent years, texture design of products such as automobiles and electric appliances becomes more and more important to add value. To characterize texture of the object, the surface properties including roughness, slipperiness, and hardness are measured by using the tactile sensing similarly to human active-touching. In our previous works, tactile sensors with strain gauge on microcantilevers have been developed to detect multi-axial force.[1] However, human tactile sense has mechanoreceptors with 2 types (slow and fast) of adaptation, therefore, multiple detection parts with different time responses are required to obtain texture information recognized by human.[2] Therefore, we have proposed the tactile sensor using microcantilevers with strain gauge and piezoelectric films, which depend on the force intensity and time differentiation of the force, respectively, as shown in Fig. 1. BiFeO₃ thin film is employed for a piezoelectric material, because of its giant ferroelectricity and lead-free material. We have already obtained BiFeO₃ thin film with piezoelectric and ferroelectric properties by RF sputtering, however, further improvement of electric properties and confirmation of time dependence of the output are needed. In this work, the crystalline structure and electrical property of BiFeO₃ thin film has been optimized by changing deposition conditions and inserting a buffer layer.

Furthermore, the time-dependent outputs from the piezoelectric capacitor and strain gauge integrated on a single cantilever structure have been characterized.

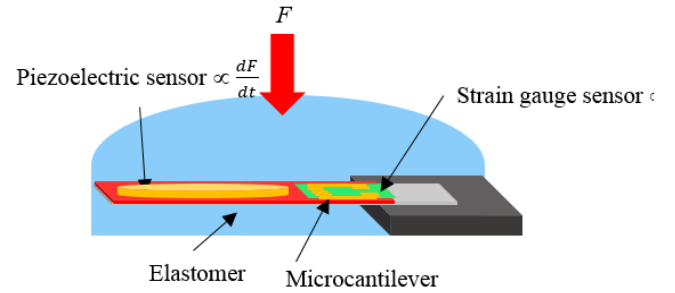


Fig. 1. A schematic illustration of proposed tactile sensor.

II. EXPERIMENTAL

BiFeO₃ thin film was deposited on Pt and SrRuO₃/Pt thin films on a SiO₂/Si substrate by RF-magnetron sputtering in Ar/O₂ plasma using a Bi_{1.1}FeO₃ ceramic target. RF power was 300 W and substrate temperature 500°C. At first, BiFeO₃ thin film were deposited by changing substrate temperature, gas pressure, and oxygen partial pressure and their material properties were characterized. Furthermore, to improve the crystalline structure and electric characteristics of BiFeO₃ thin film, SrRuO₃ thin film matched to lattice constant of BiFeO₃ was used as buffer layer on bottom electrode. Piezoelectricity of BiFeO₃ thin films was characterized by vibrating a cantilever structure with BiFeO₃ capacitors.

III. RESULTS AND DISCUSSION

A. Characterization of BiFeO₃ Thin Film

Fig. 2 shows electric field dependences leakage current density of BiFeO₃ thin films with and without SrRuO₃ buffer layer on the Pt bottom electrode (thickness: 100nm). It is found that leakage current is reduced by using SrRuO₃ buffer layer.

Crystalline structures of BiFeO₃ thin film were characterized by X-ray diffraction (XRD), as shown in Fig. 3. The XRD pattern of the sample with SrRuO₃ buffer layer has sharp peaks corresponding to (100) and (110) of BiFeO₃ ferroelectric crystal phase and few other peaks corresponding to nonferroelectric phase. Fig. 4 shows P-E hysteresis loops measured by Sawyer-Tower circuit of BiFeO₃ thin film deposited in different O₂ partial pressure. It is found that the polarization at zero electric field E , $P(E=0)$ increases with increasing of O₂ partial pressure. Moreover, $P(E=0)$ and electric field (at zero polarization) of BiFeO₃ with SrRuO₃ buffer layer are the largest value and smaller than that without buffer layer, respectively.

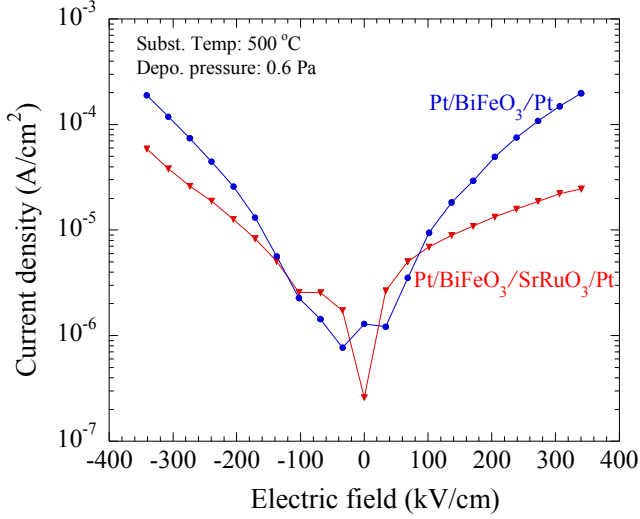


Fig. 2. Current density of Pt/BiFeO₃/Pt, and Pt/BiFeO₃/SrRuO₃/Pt thin films as a function of electric field.

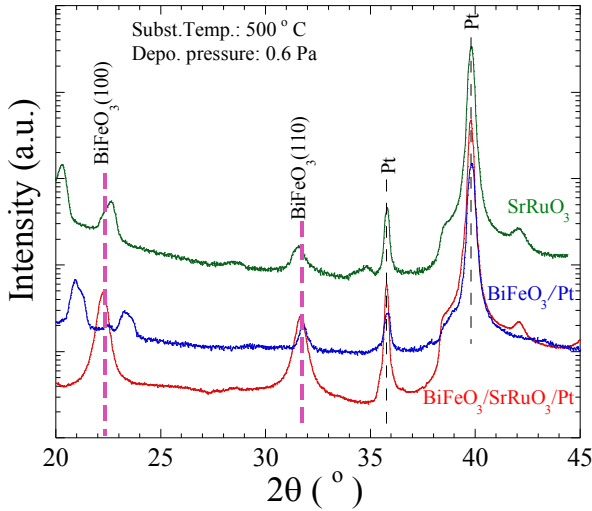


Fig. 3. XRD patterns of SrRuO₃/Pt, BiFeO₃/Pt, and BiFeO₃/SrRuO₃/Pt thin films on SiO₂/Si substrate.

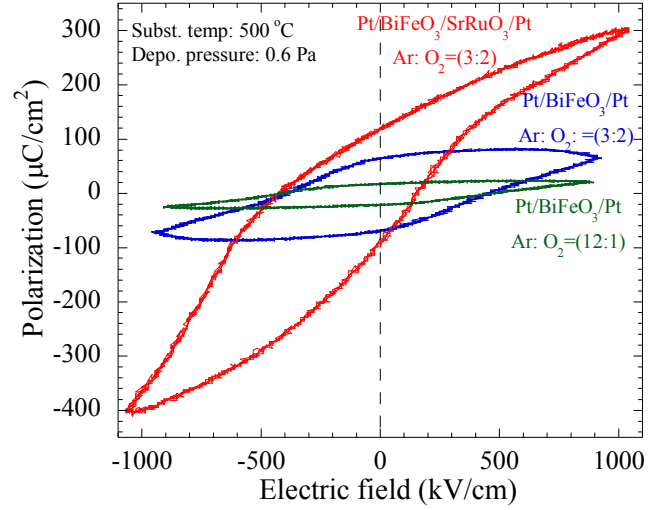


Fig. 4. P-E hysteresis loops of BiFeO₃ thin film capacitors with and without SrRuO₃ buffer layer. BiFeO₃ thin films were deposited at 500°C and 0.6 Pa in Ar and O₂ mixture atmosphere of Ar/O₂=3/2 and 12/1.

B. Compositive Force Detection by Piezoelectric Thin Film and Strain Gauge

To characterize the piezoelectric properties of the BiFeO₃ thin film, a cantilever structure was fabricated by cutting of the substrate to a strip specimen, as shown in Fig. 5. One end of the cantilever structure was fixed on the PCB board, and free end was displaced downward to 2 mm, then it was released and resonant vibration of the cantilever was excited. This experimental set-up is similar to that used by Deschanvres et al. [3]. The strain induced on the cantilever surface was monitored by a commercial strain gauge attached around fixed end of the cantilever. Output voltage of BiFeO₃ capacitor and induced strain monitored by the strain gauge on the cantilever are shown in Fig. 6. The maximum voltage generated from BiFeO₃ capacitor with SrRuO₃ buffer layer on vibrated cantilever is 520 mV, which is around 1.3 times higher than that without buffer layer (410 mV). Transverse piezoelectric constants, $e_{31,f}$, of BiFeO₃ with and without SrRuO₃ buffer layer are estimated by the method shown in Ref. [4] and shown in Fig. 7. It is found that the transverse piezoelectric constant can be enhanced from -5.5 C/m² to -7.5 C/m² by SrRuO₃ buffer layer (cf. $e_{31,f}$ of PZT: -20 C/m² [5]).

In Fig. 6, the tensile strain (positive value) is induced before vibration because the deflection of cantilever is convex upward, then the strain varies sinusoidally with vibration of the cantilever. On the other hand, piezoelectric capacitor do not generates the voltage before vibration, and the sinusoidal output voltage is observed only during vibration of the cantilever. According to this result, it is found that the output from strain gauge depends on both static deflection and dynamic deflection change, on the other hand, the output from piezoelectric capacitor depends only on dynamic change, does not depend on static deflection. Furthermore, to confirm the difference of time response more clearly, the cantilever was

bent slowly. The outputs from strain gauge and piezoelectric capacitor with slow bending of the cantilever are shown in Fig. 9. The strain output varies with bending, however, piezoelectric output is almost zero. Therefore, it is demonstrated that different time response outputs can be obtained from strain gauge and piezoelectric capacitor integrated on a single cantilever.

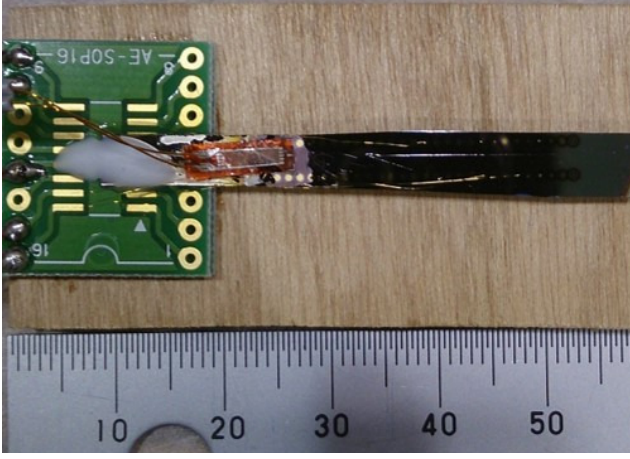


Fig.5 The cantilever structure for characterization of piezoelectric properties of the BiFeO₃ thin film.

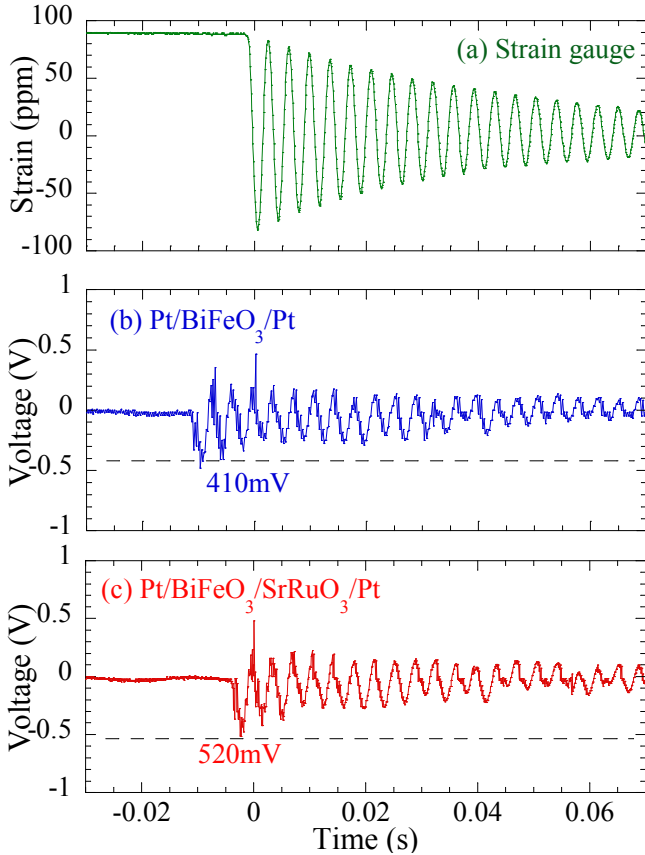


Fig. 6. Output voltages of piezoelectric capacitors and strain gauge with vibration of the cantilever.

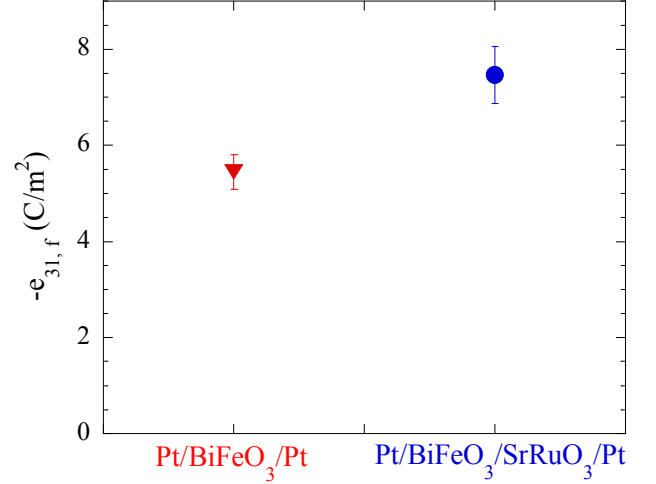


Fig. 7. Transverse piezoelectric constants of BiFeO₃ thin film with and without SrRuO₃ buffer layer.

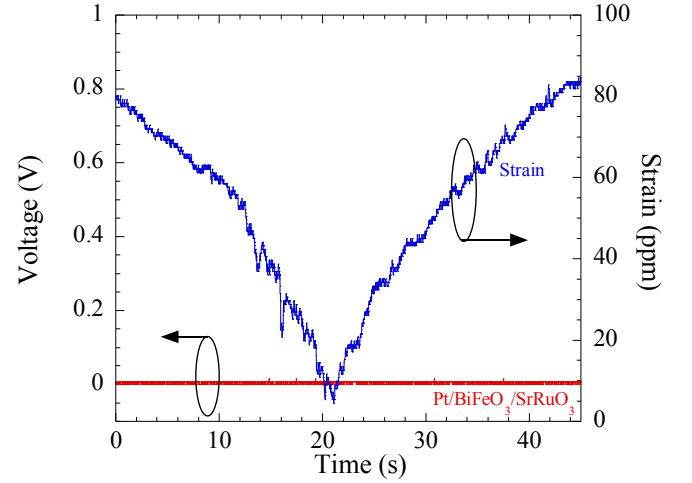


Fig. 8. Output voltages of a piezoelectric capacitor and a strain gauge on the cantilever bent slowly.

IV. CONCLUSIONS

BiFeO₃ lead-free piezoelectric thin films were deposited and characterized for the tactile sensor. Using the SrRuO₃ buffer layer, crystalline structure, insulation property, and ferroelectric property of BiFeO₃ thin films were improved. Furthermore, the output voltage generated by piezoelectric effect of BiFeO₃ thin film can be successfully obtained. It is found that piezoelectricity of BiFeO₃ thin film is enhanced by SrRuO₃ buffer layer. In addition, by integration of piezoelectric film and strain gauge, it is demonstrated that the output with different time response can be obtained from a single cantilever structure. This result allows the miniature tactile sensor which has multiple detection parts with different time response like human tactile sense.

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