

FABRICATION OF Bi-Ti-O THIN FILM PRESSURE SENSOR PREPARED BY ELECTRON BEAM EVAPORATION METHOD

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ABSTRACT

Polycrystalline Bi-Ti-O thin film was prepared by multilayer deposition method using electron beam evaporation. The thin film was obtained by sequentially evaporating Bi_2O_3 / TiO_2 layers on Si / SiO_2 / Ti / Pt substrate followed by annealing for 30 minutes in air at 850°C . A pressure sensor was fabricated by depositing Al film electrode on the top of the annealed multilayer films. The piezoelectric response of the sensor was then measured by pneumatic loading method. It was found that the sensor was sensitive to the applied pressure and showed good repeatability. This study showed the potentiality to obtain Bi-Ti-O thin film pressure sensor by electron beam multilayer deposition.

INTRODUCTION

Ferroelectric thin films pressure sensors are one of the most common micro-sensors devices used in various industrial such as automotive, medical, aerospace or military, process and industrial control [1]. Recently, there is a great demand in industries like automotive, aerospace and aircraft industries for the pressure sensors, which able to work at high temperature ($>500^\circ\text{C}$) without significant changes in sensing properties[2]. One promising ferroelectric material for the growth of high temperature micro-pressure sensor is bismuth titanate based layered structure compositions ($\text{Bi}_4\text{Ti}_3\text{O}_{12}$), due to their high Curie temperature, T_c of 675°C , good piezoelectricity and thermal stability. Their structure can be described as a bidimensional one consisting of $(\text{Bi}_2\text{O}_2)^{2+}$ layers divided by a stacking of perovskite units of composition $(\text{A}_{n-1}\text{B}_n\text{O}_{3n+1})^{2-}$ along the c-axis [3].

The deposition method for obtaining $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ thin films included metal organic chemical vapor deposition (MOCVD) [4], RF magnetron sputtering [5], sol-gel [6] and laser ablation [7]. In this paper, we report the application of Bi-Ti-O thin film as pressure sensor, which the thin film was prepared by electron beam multilayer deposition method.

EXPERIMENTAL

The source materials were Bi_2O_3 and TiO_2 with purity more than 99%. Multilayers structures of Bi_2O_3 and TiO_2 were deposited on substrate Si / SiO_2 / Ti / Pt in sequence. The deposition was made by electron beam at ambient temperature and at base vacuum of 10^{-5} mbar. Layer Bi_2O_3 was deposited first, followed by layer of TiO_2 and the 2-layer sequence was then repeated 3 times for a total of 6 layers. To obtain atomic ratios of 4:3, the thickness of the layers were 600 Å and 900 Å for Bi_2O_3 and TiO_2 . The layer thickness was monitored in situ by a quartz-crystal oscillator. The multilayer-structure of the films were then annealed in air at 850 °C for 30 minutes to form the polycrystalline films. Crystal structures of the annealed films were analyzed by X-ray diffraction (XRD) using Cu K α radiation.

For the piezoelectric measurement, a pressure sensor was fabricated as shown in Fig. 1.

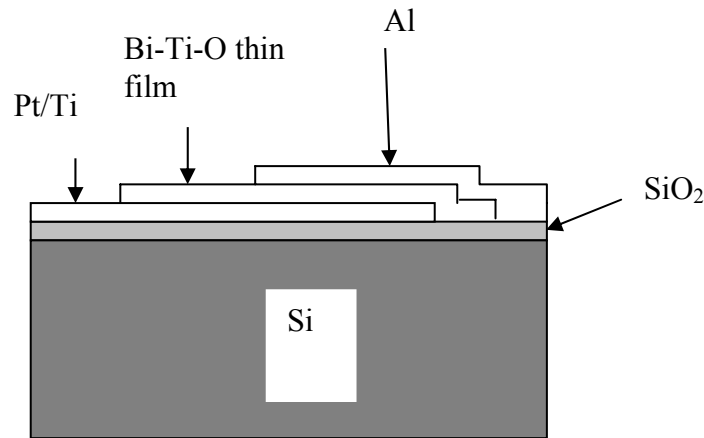


Figure 1: The fabricated Bi-Ti-O thin films pressure sensor.

Al film was deposited by electron beam evaporation method as top electrode. The piezoelectric response of the sensor was measured using pneumatic loading method, which the test system shown in Fig. 2. The test system can be separated to 3 parts: an air

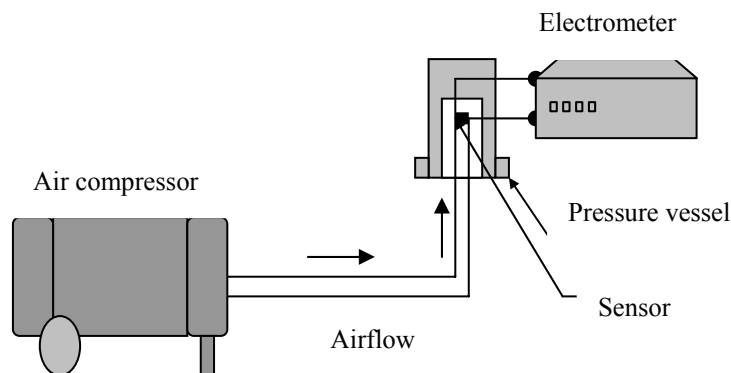


Figure 2: Schematic of piezoelectric property measurements system.

compressor system, a pressure vessel (stainless steel body) and data storage system (electrometer). The pressure was measured from 0 psi to the maximum of 110 psi at room temperature. The air was compressed by the air compressor and imparted at the sensor, which was mounted inside the pressure vessel. The voltage that generated by the sensor was collected by the electrometer. Fig. 3 showed how the sensor was mounted inside the pressure vessel.

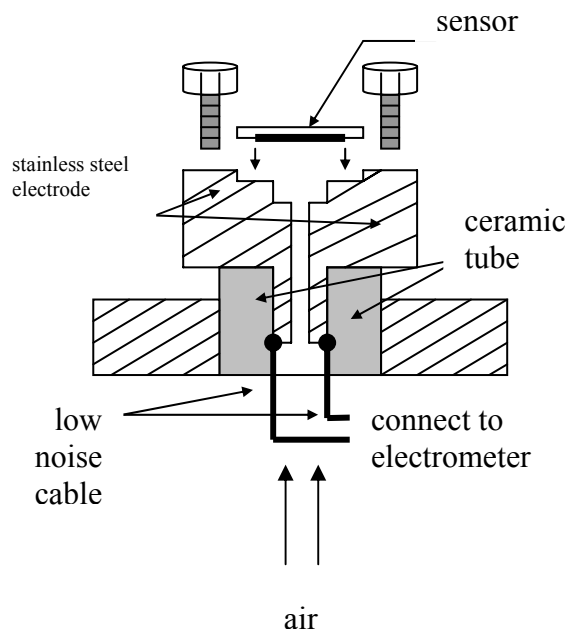


Figure 3. Bi-Ti-O thin film sensor mounted inside the pressure vessel.

RESULTS AND DISCUSSIONS

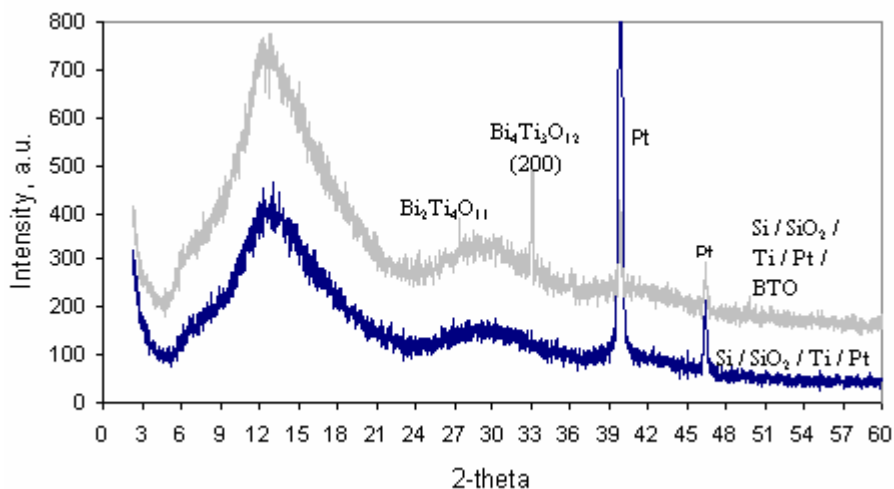


Figure 4: Spectrum XRD of the heat-treated Bi-Ti-O thin film on substrate Si / SiO₂ / Ti / Pt at 850 °C for 30 minutes.

Fig. 4 revealed the XRD spectrum of the annealed Bi-Ti-O thin film. It was found that the film was consisted of $\text{Bi}_2\text{Ti}_4\text{O}_{11}$ and $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ phases, same as our previous studied [8]. The film showed the preferential orientation on direction (200), which indicated the perovskite phase of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$. It was believed that the Bi-deificent phase was caused by the improper control of the thicknesses of the each layer, where the precise control of the elemental thickness is needed to achieve the required stoichiometry. In order to form the polycrystalline $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ with single phase, the thickness ratios between Bi_2O_3 and TiO_2 should be set as variable to achieve the stoichiometry.

Figure 5 showed the piezoelectric response of the Bi-Ti-O thin film pressure sensor. It was found that the sensor sensitive to the applied pressure and the response was recovered back when the pressure was removed from the chamber. The response was measured for three cycles and the sensor presented good repeatability. Fig. 6 showed the linearity of the Bi-Ti-O pressure sensor. The result revealed that the sensor also presented good linearity, where the voltage sensitivity is 0.06 mV/psi.

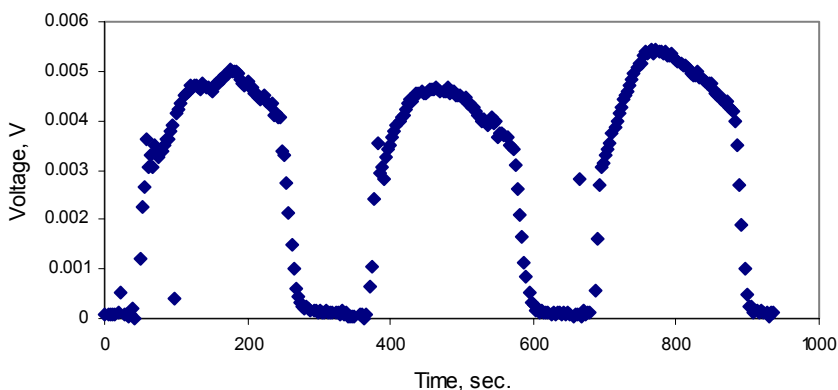


Figure 5: The piezoelectric response of the Bi-Ti-O thin film sensor measured at room temperature at maximum pressure of 110 psi.

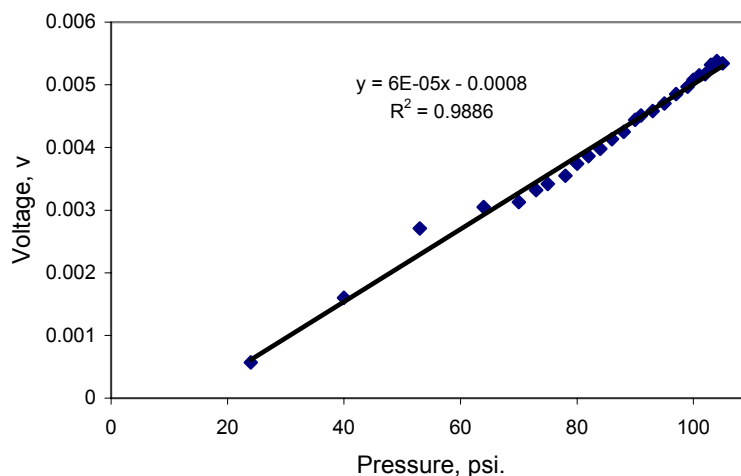


Figure 6. The linearity of the Bi-Ti-O thin film pressure sensor.

The piezoelectric measurement system was designed using the concept of direct piezoelectric effect. When pressure is applied to piezoelectric materials, they create a strain or deformation in the materials. The strain will generate electrical potential difference in the materials. The origin of the generated voltage is the non-symmetry arrangement of positive and negative charged of atoms in their crystal structure [9].

Figure 7 showed the crystal structure of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ [10], where the pseudo-perovskite block is the origin of the piezoelectric effect. The perovskite structure has the general formula of ABO_3 , where O is oxygen, A and B represent cations with larger and smaller ionic radius, respectively. In the case of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$, A denotes Bi^{3+} and B denotes Ti^{4+} . The perovskite structure of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ is essentially a three-dimensional network of TiO_6 octahedron as shown in figure 8. To simplify the description, the piezoelectric effect is illustrated by the two dimensional sketches in figure 9, where the polar crystal of the single domain of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ is shown. The figure 9a illustrated the unit cell in the situation without an external applied stress. It was clearly showed that there is a permanent electrical dipole in the unit cell of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ due to the asymmetrical arrangement of Ti^{4+} and O^{2-} . When stress is now applied in the X_3 direction, the unit cell will be distorted and forcing the ions Ti^{4+} and O^{2-} move farther away each other from the cell center. This displacement will generate an enhancement of electrical potential, which the magnitude proportional to the applied stress. This property has made the $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ be used as a piezoelectric pressure sensor.

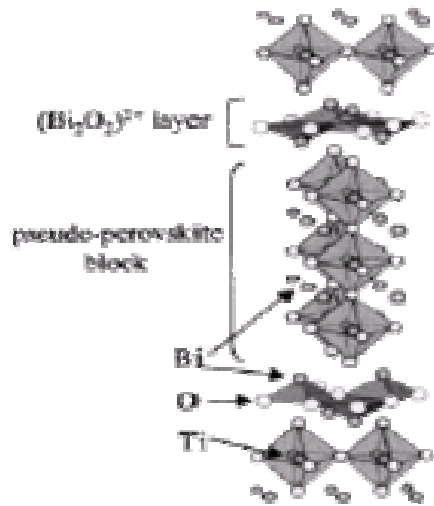


Figure 7: The crystal structure of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$.

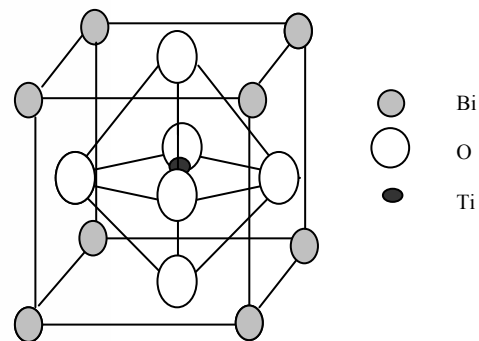


Figure 8: The BiTiO_3 perovskite-type unit cell.

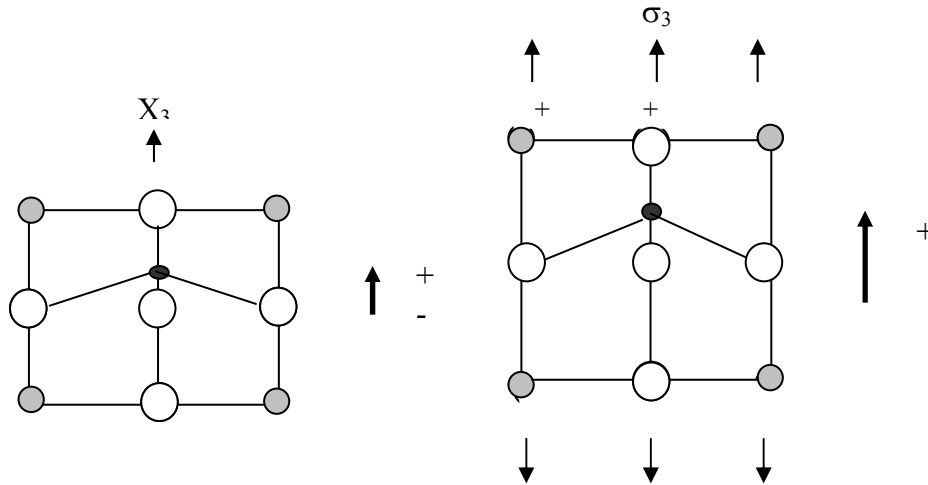


Figure 9: Illustrations of piezoelectric effect in two dimensional single domain $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ crystal:(a) Situation without external applied stress; (b) Displacement of the ion Ti^{4+} and O^{2-} under stress σ_3 .

CONCLUSION

The study shows the potentiality to obtain Bi-Ti-O thin films pressure sensors by electron beam multilayer deposition method. The sensor shows good repeatability and linearity, where the sensitivity is 0.06 mV / psi.

ACKNOWLEDGEMENT

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REFERENCES

- [1] D. Tandeske 1984, *Pressure sensors: selection and application*, 73-75, 271-277.
- [2] A. Megriche, L. Lebrun and M. Troccaz 1999, *Sensors and Actuators A*. **78**, 88-91.
- [3] Y. Xu 1991, *Ferroelectric materials and their application*, 121-143.
- [4] R. Muhammet, T. Nakamura, M. Shimizu and T. Shiosaki 1994, *Japanese Journal of Applied Physics*. **33**, Part 1, No. 9B, 5215-5218.
- [5] M. Yamaguchi and T. Nagatomo 1999, *Thin Solid Films*. **348**, 294-298.
- [6] K.K. Jong, K. S. Tae, S. K. Sang and K. Jinheung 2002, *Materials Letters*. **57**, 964-968.
- [7] W. Wu, K. Fumoto, Y. Oishi, M. Okuyama and Y. Hamakawa 1995, *Japanese Journal of Applied Physics*. **34**, Part 1, No. 9B, 5141-5145.
- [8] C.W. Chong, M. Yahaya and M.M. Salleh 2003, *Proceedings of IEEE National Symposium on Microelectronics, Perlis, Malaysia*. 48-51.

- [9] T.L. Jordan and Z. Ounaies 2001, *ICASE, NASA Langley Research Center, Hampton, Virginia.*
- [10] M. Takahashi, Y. Noguchi and M. Miyayama 2002, *Jpn. J. Appl. Phys.* **41**, Part 1, No 11B, 7053-7056.