

# The Characterization and Fabrication of Pyroelectric Infrared Sensor

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## Abstract

The pyroelectric infrared (PIR) sensor with a calcium-modified lead titanate  $\text{Pb}_{1-x}\text{Ca}_x\text{TiO}_3$  thin film with  $x = 0.3$  [PCT(30)] thin film have been successfully fabricated. A RF planar magnetron sputter was used to deposit PCT(30) thin film. A perovskite thin film can be obtained. From the properties measurement we can obtain the remanent polarization  $Pr = 25.3 \mu\text{C}/\text{cm}^2$  and coercive electric field  $Ec = 52.65 \text{ KV}/\text{cm}$ . The pyroelectric coefficient was measured as a function of temperature which was  $4.13 \times 10^{-4} \text{ C}/\text{m}^2 \text{ K}$  at 300 degree C. For the PIR performance measurement, the voltage response of the single PIR sensor is  $723.5 \text{ VW}^{-1}$  and the specific detectivity is  $8.28 \times 10^6 \text{ cmW}^{-1}$  at 0.3 Hz. In addition, a 2-D  $8 \times 8$  element PIR sensor array is finished with fabricated PIR sensors.

**Key Words:**  $\text{Pb}_{0.7}\text{Ca}_{0.3}\text{TiO}_3$  (PCT(30)), Remanent Polarization, Coercive Electric Field, Pyroelectric Coefficient, Voltage Response, Specific Detectivity

## 1. Introduction

Infrared line and thermal radiation have been known for many years ago. The useful infrared radiation wavelength is about  $0.8 \mu\text{m} - 30 \mu\text{m}$ . Infrared sensor will detect the infrared radiation from the object. Since the infrared radiation is common radiation in many substances, IR sensor is one of the most useful sensors.

Infrared sensor can be classified into two major types that are thermal type and photon type. The photon type sensors often need to be cooled to obtain a better performance. In addition they are wavelength selective. On the other side, there are many advantages about thermal IR sensor such as no cooling equipment is needed, no radiation harmful, low cost, and easily integration.

In this experiment, a thermal type PCT(30) pyroelectric infrared sensor (PIR) is investigated. Furthermore, the fabricated PIR sensor is constructed an  $8 \times 8$  sensor array, too. In addition, for thermal insulation of

the pyroelectric infrared (PIR) sensor and PIR  $8 \times 8$  array sensor, the V-groove etching technique provides thermal isolation and minimizes conductive heat losses between the detector element and the substrate. PIR sensors with V-grooves structure have low thermal mass and low thermal conductivity to the semiconductor substrate. In this experiment 5% TMAH solution at  $85^\circ\text{C}$  etching condition is used to form V-groove structure [1].

## 2. Experimental Procedure

The PIR sensor thin films have been successfully fabricated with the PCT(30). The pyroelectric detector is fabricated on silicon chip. A Microelectromechanical Systems (MEMS) technique is also used to have the V-groove etching technique provides thermal isolation and minimize the conductive heat. The structure diagram is shown in Figure 1. In addition, a RF planar magnetron sputter was used to deposit PCT(30) thin film and the RF-power is  $5.73 \text{ W}/\text{cm}^2$  and the 2-inch target was made by ourselves. Then, the PCT(30) thin film

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was annealed at 650 °C for 15 minutes to obtain better structure quality. In this experiment, a field emission scanning electron microscopy (SEM, Hitachi S4100) which its emission voltage 15KV and its current 10 μA is used to investigate the surface morphology and cross section of the deposited thin film. Furthermore, the X-ray diffraction (XRD) pattern is used to check the deposited thin film structure. The pyroelectric coefficient is defined as  $p(T) = dP_s/dT$  (Coul/m<sup>2</sup>K), where  $P_s$  is the spontaneous polarization quantity. The P-E property of the deposited thin film is also measured [2]. The finished PIR sensors is evaluated quality with voltage response ( $R_v = \text{signal output} / \text{IR input power}$ ), specific detectivity  $D^*$  ( $= 1/NEP$ ;  $NEP$  is the noise equivalent power) measurement [3]. The top view of the 8 × 8 PIR sensor is shown in Figure 2.

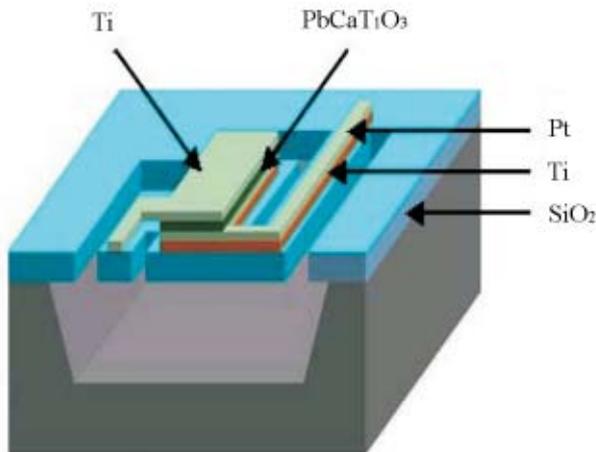


Figure 1. The structure of PIR sensor.

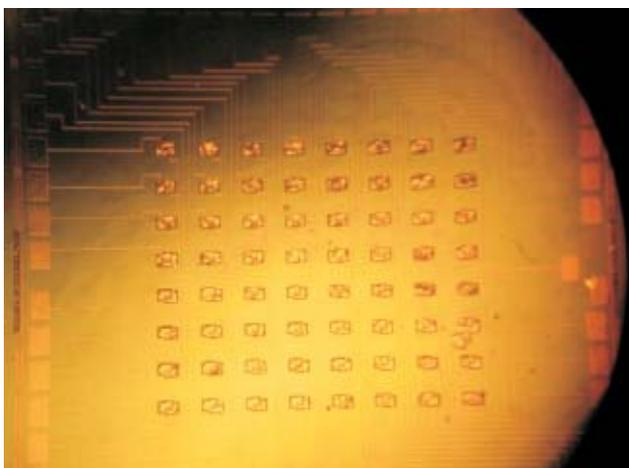


Figure 2. The top view of the PIR array device.

### 3. Experimental Results and Discussion

Figure 3 shows a PCT(30) thin film surface morphology. The result shows a fine-grained crystalline micro-structure of PCT(30) thin film. A cross section of PCT(30) thin film is shown in Figure 4, and it indicates that the grains is columnar.

A XRD pattern of as deposited PCT(30) thin film after 650 °C, 15 minutes annealing is shown in Figure 5 [4]. From Figure 5, (100), (101), (111), (200) and (211) peaks of perovskite structures are observed. From the P-E measurement it can be obtained the remanent polarization  $P_r = 25.3 \mu\text{C}/\text{cm}^2$  ( $P_r = C \times V_y / A$  which  $C$  is external capacitor (0.4 μF),  $V_y$  is measurement voltage,  $A$  is the area of top electrode) and the coercive electric field

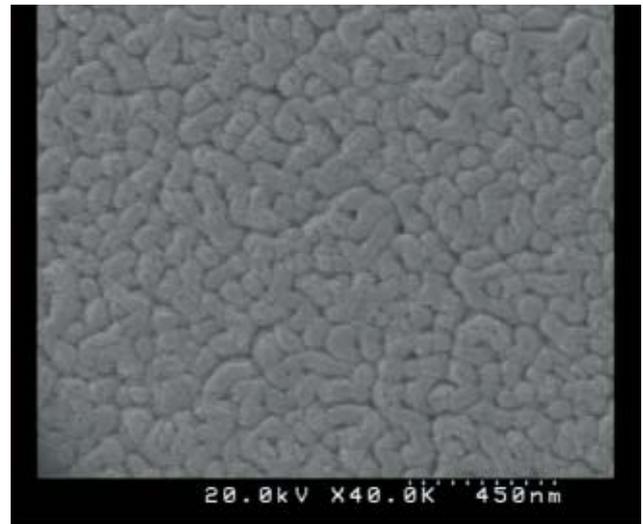


Figure 3. The surface morphology of the PCT(30) thin film.

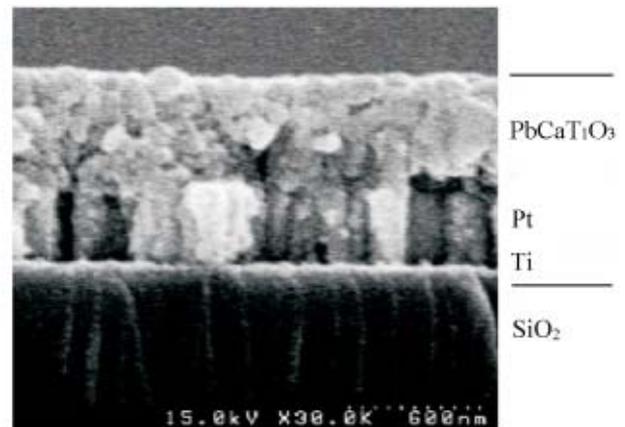


Figure 4. The cross section of PCT(30)/Pt/Ti/SiO<sub>2</sub>.

$E_c = 52.65$  kv/cm ( $E_c = V_x / D$  where,  $V_x$  is measurement voltage,  $d$  is the thickness of PCT(30)), the pyroelectric coefficient is  $4.13 \times 10^{-4}$  C/m<sup>2</sup>K at 300 °C shown in Figure 6 [5].

Figure 7 shows voltage response of PCT(30) thin film sensor which these thin films were annealed at 550 °C, 600 °C, 650 °C, 700 °C, respectively, for 15 minutes as a function of the modulation frequency of the incident radiation. An opaque chopper is used to block the radiation from the blackbody. It can be found the maximum voltage responses of the integrated PIR image sensor are 414.65 (VW<sup>-1</sup>), 598.7 (VW<sup>-1</sup>), 723.5 (VW<sup>-1</sup>) and 668.98

(VW<sup>-1</sup>), respectively, when chopper modulation frequency is 0.3 Hz. From above, PCT(30) thin film annealed at 650 °C has better quality.

Figure 8 shows the specific detectivity of PCT(30) thin film sensors, which were annealed at 550 °C, 600 °C, 650 °C, 700 °C, respectively, for 15 minutes. The maximum specific detectivity ( $D^*$ ) of these sensor is  $3.75 \times 10^6$  cmHz<sup>1/2</sup>W<sup>-1</sup>,  $6.03 \times 10^6$  cmHz<sup>1/2</sup>W<sup>-1</sup>,  $8.28 \times 10^6$  cmHz<sup>1/2</sup>W<sup>-1</sup> and  $7.33 \times 10^6$  cmHz<sup>1/2</sup>W<sup>-1</sup> for a modulation frequency of 0.3 Hz. These results show that PCT(30) thin film with being annealed at 650 °C for PIR sensor has a better performance [6,7].

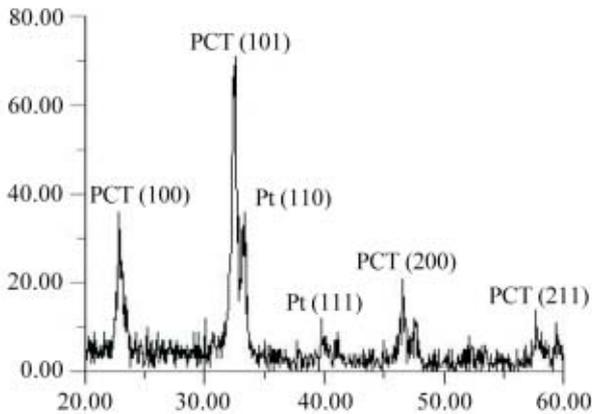


Figure 5. The XRD pattern of PCT(30) thin film on Pt/Ti/Si substrate.

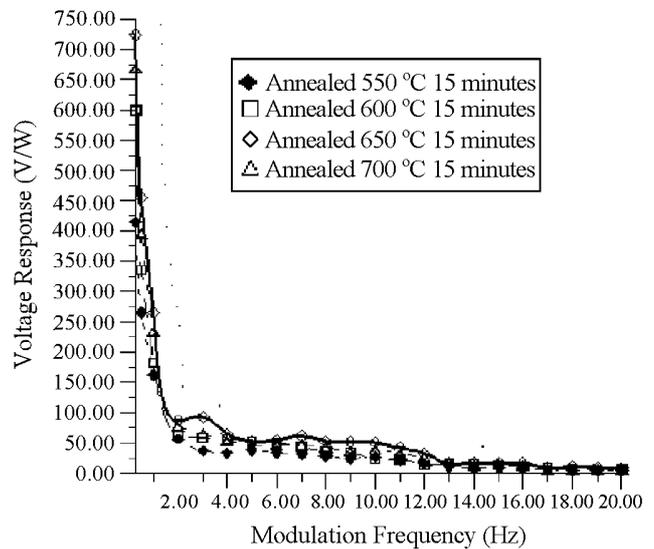


Figure 7. Voltage response of PIR sensor.

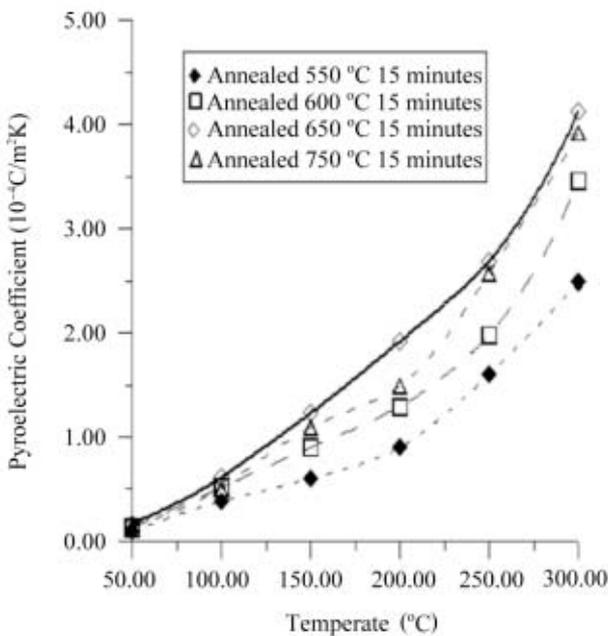


Figure 6. Pyroelectric coefficient of PIR sensor.

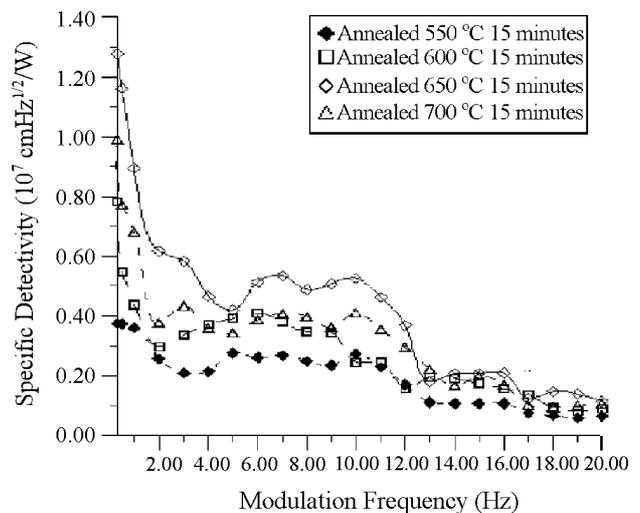


Figure 8.  $D^*$  with PIR sensor.

#### 4. Conclusion

In this experiment, integrated pyroelectric infrared sensors have been successfully fabricated. The deposited PCT(30) thin film is a perovskite structure. The 500 nm thick PCT(30) thin film which was annealed at 650 °C for 15 minutes can obtain the better performance. From the experimental result, the FWHM of the PCT(30) thin film (100) peak is 0.145, the pyroelectric coefficient of the obtained PCT(30) thin film is  $4.13 \times 10^{-4} \text{ C/m}^2\text{K}$  at 300 °C. The P-E measurement results of PCT(30) thin film show that remanent polarization is  $25.3 \mu\text{C/cm}^2$  and the coercive electric field is 52.65 KV/cm. In addition, the PIR properties are also measured. The voltage response of the single PIR sensor is  $723.5 \text{ VW}^{-1}$  and the specific detectivity is  $8.28 \times 10^6 \text{ cmW}^{-1}$  at 0.3 Hz. the PCT(30) thin film with thickness of 500 nm at the annealed condition of 650 °C and 15 minutes which condition can obtain the better performance of sensor.

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