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The new technology for improving heat effect of pyroelectric infrared detector

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Abstract

In this paper, the vacuum layer was formed by He ions injection and heating treatment under SiO_2 layer. Ca modified (Pb,La)TiO_3 (PLCT) films were deposited on Pt coated silicon substrates using metal-organic decomposition (MOD) process. The preferred orientations polycrystalline films were formed. XRD, HRTEM, RBS, had characterized the microstructure. The electric properties were measured by HP4284 and ASR. It was found that the micro-structure had no effect under the cavum layer. The PLCT films exhibit lower dielectric constant and dielectric loss compared with the PLCT films which have not the cavum layer at room temperature. The cavum layer can act as heating barrier and the lower dielectric constant and dielectric loss can improve the quality factor of infrared detector device.

Keywords: Vacuum layer; Pyroelectric property; Infrared detector device

1. Introduction

During the past decades, the pyroelectric detection of infrared (IR) radiation had became well known due to the important advantages offered by the pyroelectric detectors: room temperature operation, flat spectral response from near ultraviolet up to far infrared, good sensitivity, low cast, and simple device structure etc.[1,2] Silicon wafers were chosen as substrates in making ferroelectric thin films for compatible with general integrate circuit (IC) techniques, but it is very difficult to make texture ferroelectric thin film in silicon substrates, and the heat conduct rate of silicon material was very high (145 Wm/k). As a detector, the ferroelectric thin film absorbs heat, which dissipates in the silicon substrates causing remarkable decrease of sensitive degree of heat effect of pyroelectiric response and delicacy degree of detector. Presently, pyroelectric detection was focused on finding material with higher pyroelectric coefficients such as preparing textured ferroelectric thin film and resisting heat loss from detector area for improving pyroelectiric detector's response. Therefore, firstly the research work focused most to make (0 0 1) oriented PT or PLT thin film in MgO single crystal substrates or MgO transition film [4,5], but in Pt/Ti/SiO_2 substrates, it is a difficult problem of making texture ferroelectric thin film. Second, it was designed that all kinds structure in substrates to reduce pyroeletric detector absorbed heat flow from detector film to substrates. It can be used to prevent heat flow to the substrates that have structure of bridge hung in air, structure of air gap, structure of tiny bridge and more hole layer of SiO_2 [1–4]. The previous three methods had great disadvantage: low intensity of engine, more process and complex technique, and low rate of finished product. An isolated heat layer of more holes SiO_2 using sol–gel method have some question of high roughness surface, low repeated quality and stability. In this paper, we report a new technique using SOI technology making a cavum layer as isolated heat layer using ion injecting technique, at the same time making oriented PLCT ferroelectric thin film in the cavum layer substrates by MOD, the cavum layer not only resisted heat flow to substrates but also decreased the dielectric constant, it would improve sensitivity of infrared detector.

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2. Experimental

Si/SiO_2 substrate injected 160 kev 1×10^{17} cm^{-2} He ion at room temperature, then annealed at 700 °C for 0.5 h, after form cavum layer in Si/SiO_2 substrate. The cavum platinized silicon ($Pt/Ti/SiO_2/Si$) substrates were synthesized with 40 nm Ti and 120 nm Pt using UHV electron beam evaporator (Balzers UMS 500P). Before evaporation, the vacuum chamber was initially pumped down 10^{-7} Pa and during evaporation the pressure in the chamber fell to 10^{-6} Pa. The temperature of substrates is room temperature and the growth speed were controlled in 1 Å, first vaporize Ti fountain in controlling electron gun, gained 40 nm Ti film, then vaporize Pt fountain, gained 120 nm Pt film.

$Pb_{0.9}La_{0.1}Ca_{0.1}Ti_{0.975}O_3$ (PLCT) films were fabricated on the $Pt/Ti/SiO_2/Si$ with cavum layer and $Pt/Ti/SiO_2/Si$ substrates. In the MOD process, a precursor solution for PLCT films containing 10 mol% excess lead was synthesized according to the formula $Pb_{1-x-y}La_xCa_yTi_{1-x/4}O_3$ in which 10 mol% La and Ca ($x = y = 0.1$) was adopted to synthesize PLCT precursor solution [6].

The precursor solution was spin-coated on the substrates in a class 100 clean room to form the 'wet' films. The films then were heated to 450 °C in the rapid anneal furnace for 10 min. The coating and heating process repeated for five times and final films were annealed at 600 °C for 1 h in oxygen.

The crystallographic structure was investigated by X-ray diffraction (XRD, D/MAX 2400), and the microstructure by JEOL 4000EX HRTEM. The composition of the films was characterized by RBS. The measurement of the dielectric properties was performed using a HP4192A. The spreading resistance profile of the films was revealed using automatic spreading resistance (ASR). The pyroelectric coefficient was measured by a dynamic technique [7].

3. Results and discussion

Fig. 1 shows that the preferred orientation of the films at the above mentioned conditions is (1 0 0), on the $Pt/Ti/SiO_2/Si$ with cavum layer and $Pt/Ti/SiO_2/Si$ substrates. The intensities of the (1 0 0) peaks are almost equal on the different substrates. But (1 1 0) small peaks can be seen on the $Pt/Ti/SiO_2/Si$ with cavum layer.

Fig. 2 shows the microstructure of the PLCT layer characterized on the $Pt/Ti/SiO_2/Si$ with cavum layer by bright-field cross-section TEM. All sharp and continuous of the PLCT/Pt films is observed. Thickness of the PLCT thin film is about 330 nm and that of Pt/Ti bottom electrode layer is about 100 and 20 nm, respectively. Selected area diffraction pattern of the PLCT thin film indicated that the film almost (1 0 0) textured growth. About 500 nm cavum layer shown as Figs. 2 and 3. From Fig. 3, 20–30 nm holes can be clearly seen that the rate of the holes were about 50%.

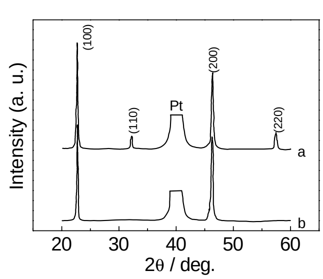

Fig. 1. XRD of PLCT films grown on (a) cavum layer and (b) no cavum layer.

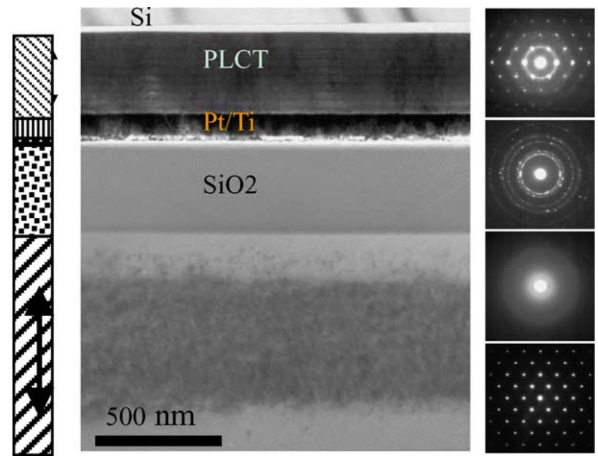

Fig. 2. Cross-sectional TEM images of $PLCT/Pt/Ti/SiO_2/Si$ with cavum layer which was formed by He ions injection and heating treatment.

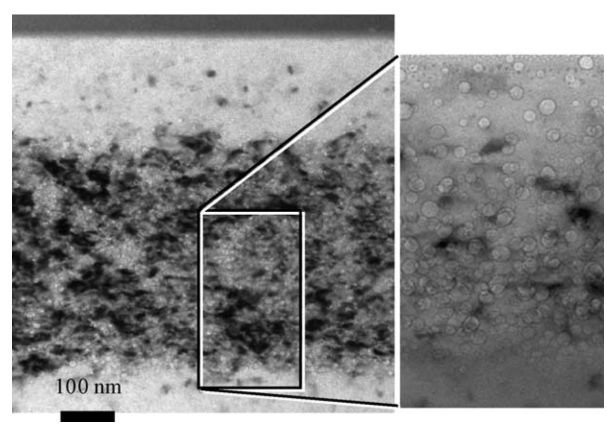

Fig. 3. Cross-section of cavum layer which was formed by lots of nano-holes.

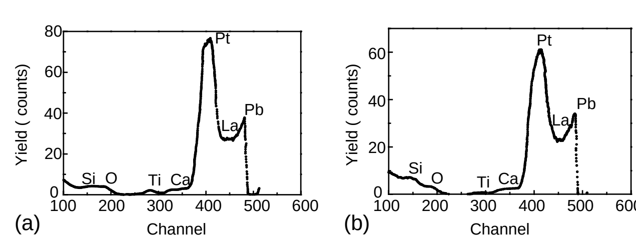

Fig. 4. RBS results of PLCT thin films: (a) with cavum layer and (b) without cavum layer.

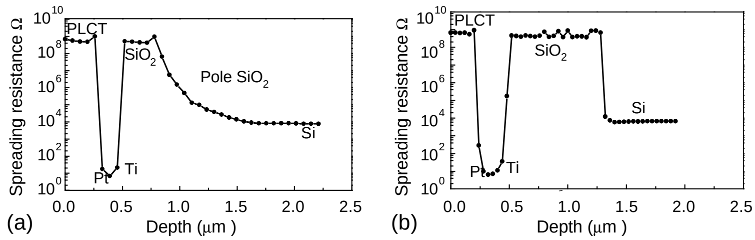

Fig. 5. ASR results of PLCT thin films: (a) with cavum layer and (b) without cavum layer.

Fig. 4 shows the RBS spectra for PLCT films with different substrate. All peaks are almost same, but the peak associated with La of PLCT film with vacuum layer become wider compare with normal substrate from Fig. 4b. This indicate that the cavum layer will influence the atom pervasion to the underlay at some degree, but will not affect the constitute of the PLCT thin film a lot.

Fig. 5 show the spreading resistance of PLCT films with different substrates. The multi-layer structure is clearly revealed in agreement with the result of HRTEM (Figs. 2 and 3). It can been see that cavum layer will not influence the resistance of Pt/Ti and PLCT thin film, but will influence the resistance of the SiO_2 layer a lot. The cavum layer makes the resistance of the SiO_2 layer gradually reduce along the cross section. Fig. 5b shows the resistance of PLCT, SiO_2 layer with high resistance and Pt/Ti, Si layer with low resistance. Sharp change of resistance take place at the interfaces of the multi-layer films.

The dielectric constant and loss tangent of PLCT films with different substrates are shown in Fig. 6. The dielectric constant decreases as the frequency increases. The dielectric loss tangent decreases a lot first, and then increase with frequency and it can be explained by the L–C resonance [8]. The dielectric constant and tangent loss of the cavum layer sample is lower than that of the normal sample, at 1 kHz dielectric constant are about 245 and 342, respectively. The dielectric loss tangent are about 1.6 and 2.1, respectively. The pyroelectric coefficient of the PLCT thin films are 2.1×10^8 and $2.4 \times 10^8\,\mathrm{C\,cm^{-2}\,K^{-1}}$, respectively. The PLCT film on cavum layer substrate have a almost same pyroelectric coefficient. The voltage responsivity, defined as $F_v = \gamma/(C_v\varepsilon_r)$, where C_v is heat capacity per unit volume, γ is pyroelectric coefficient, and ε_r is dielectric constant. Detective degree, defined as $F_m = \gamma/[C_v(\varepsilon_r \tan\delta)^{1/2}]$, where $\tan\delta$ is dielectric loss constant. This formula indicate that high pyroelectric coefficient, low dielectric constant, dielectric loss tangent and volume specific heat are required for pyroelectric devices. The cavum layer is useful to decrease volume specific heat because it can effectively resist heat flow from device to Si substrate. Meanwhile, lower dielectric constant and dielectric loss tangent can improve voltage responsivity and detective degree.

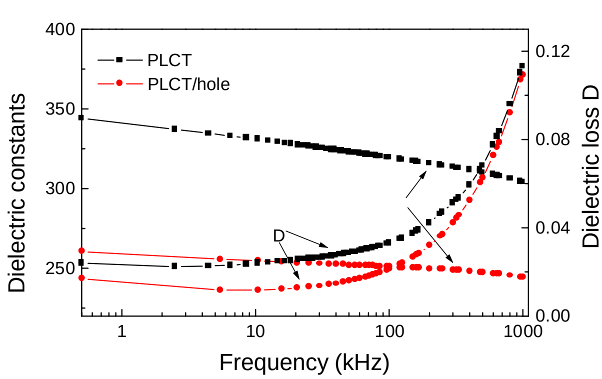

Fig. 6. The dielectric constant and loss tangent of PLCT film: (a) with cavum layer and (b) without cavum layer.

4. Conclusion

In conclusion, the 500 nm cavum layer serves as an absolute heat layer formed in the way of combining He-hydronium injection and heating treatment shown as HRTEM. The cavum layer are consist with 20–30 nm holes which have about 50% rate of the holes. The cavum layer have a lot influence to micro-structure and composition, but it can not influence much the PLCT film. The vacuum layer's influence to the atom pervasion to the underlay is approved by RBS. The spreading resistance of PLCT and Pt/Ti films is almost same with different substrates, but the spreading resistance of SiO_2 is very different by existing of cavum layer. The films properties of dielectric and pyroelectric indicates: the existing of the cavum layer can efficiently prevent the heat flow from PLCT film to substrate, lower dielectric constant and dielectric loss tangent can efficiently improve the voltage responsivity and detective degree.

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