Pyroelectric Properties of Sol-Gel Derived Lithium Tantalite Thin Films

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Abstract

Lithium tantalite ($LiTaO_3$) thin films ($\sim 0.5\mu$m) have been successfully deposited on $Pt(111)/SiO_2/Si(100)$ substrates by means of sol-gel spin-coating technology. Figures of merit for infrared detector were studied for the $LiTaO_3$ thin films. There exists high figures of merit F_v of 2.1×10^{-10} C·cm/J and F_m of 2.4×10^{-8} C·cm/J because of the relative low dielectric constant (ϵ_r) of 35 and high pyroelectirc coefficient (γ) of 4.0×10^{-8} C/cm^2·K of the films. The pyroelectric infrared detector fabricated by the $LiTaO_3$ thin film exhibits a voltage reponsivity R_v of 4584 V/W at 20 Hz and a high specific detectivity D^* of 4.23×10^7 cm·Hz$^{1/2}$/W at 100 Hz.

Key words: $LiTaO_3$; sol-gel; thin film; voltage responsivity; specific detectivity

In recent years, pyroelectirc detectors have been widely used for inrared (IR) detection applications owing to the advantages of wavelength-independent sensitivity and room temperature operation. There are commonly used materials for pyroelectric applications including triglycene sulphate (TGS), lithium tantalite ($LiTaO_3$), $Ba_{1-x}Sr_xTiO_3$ (BST), PZT and $PbTiO_3$ [1]. In which, $LiTaO_3$ is a suitable material with high figures of merit for pyroelectric detector application. In this study, it is focused on the optical response of the $LiTaO_3$ thin film IR detectors fabricated by a sol-gel method with the 1, 3-prpanediol solvent. The 1, 3-prpanediol can be capable of intermolecular association reactions, and is of low toxicity and air stable. The study of the dynamic response of diol-based sol-gel derived $LiTaO_3$ thin films presented in this work is original and has never been published elsewhere.

The sol-gel process is used to prepare the precursor solutions of $LiTaO_3$ with general chemical formula. Lithium 2,4-pentanedionate, $LiC_5H_7O_2$ and tantalum isopropoxide, $Ta[OCH(CH_3)_2]_5$ were used as precursors and 1,3-propanediol, $HO(CH_3)_2OH$ was used as solvent. The details of the diol-based sol-gel technique and the synthesis process of $LiTaO_3$ film have been reported previously [2]. The films were deposited on $Pt(111)/SiO_2/Si(100)$ substrates by repeated spin-coating at a spin rate of 3000 rpm for 30 s. After each coating step, the films were given a pyrolysis heat treatment at 400 °C for 30 min to remove residual organics. Finally, films with five-layers were fabricated, then heated in air at 700 °C for 1 h.

To measure the optical responses of the $LiTaO_3$ thin film detectors, a light source from a blackbody furnace with a temperature of 1000 K was focused, using a concave lens, and mechanically chopped at frequencies from 5 Hz to 1 kHz. The pyroelectric voltage and current signals were measured using a lock-in amplifier (Model EG&G-7260) and monitored by a digitizing oscilloscope (Model HP-54502A), while the detector was exposed to the incident chopped-IR radiation. These measurements were performed at room temperature, in a shielded room.

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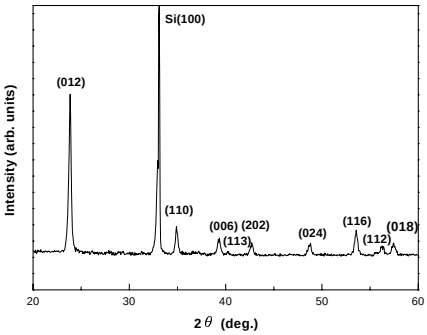

Fig. 1. XRD pattern of $LiTaO_3$ film heated at 700 ^oC for 1 h.

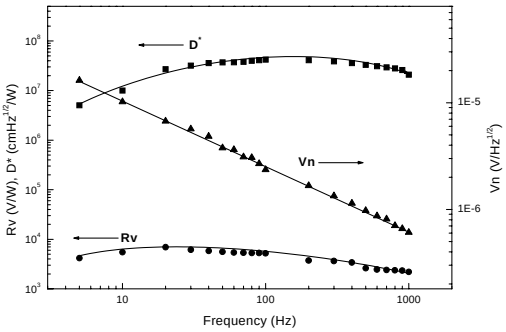

Fig. 2. The modulation frequency dependence of R_v, D^* and voltage noise V_n for $LiTaO_3$ thin film IR detector.

Figure 1 shows the XRD pattern of $LiTaO_3$ thin film heated at 700 ^oC for 1 h. It is obvious that the polycrystalline lithium tantalite can be obtained. The ratio of the standard XRD intensities of $LiTaO_3$ powder, I(hkl), from the JCPDS file is: $I(012) : I(110) : I(006) : I(202) : I(116) : I(018) = 100 : 25 : 4 : 16 : 20 : 6$. In this study, we can find that the diffraction intensities of these planes are quite similar to those of the standard powder sample.

The pyroelectric coefficient γ of the $LiTaO_3$ thin film heated at 700 ^oC for 1 h can be measured by ramping the temperature of the material at a rate of 3 ^oC/min. The maximum value of γ, the pyroelectric coefficient, was calculated to be about 4.0×10^{-8} C/cm^2·K at 62 ^oC. The average figures of merit, $F_v = \gamma/C_V \cdot \epsilon_r$ for the voltage responsivity, R_v, and $F_m = \gamma/C_V(\epsilon_r \cdot \tan\delta)^{1/2}$ for the specific detectivity, D^*, of the $LiTaO_3$ thin films were estimated to be 2.1×10^{-10} C·cm/J and 2.4×10^{-8} C·cm/J, respectively [2]. These values are much larger than those of PZT [$F_v = 0.5\times10^{-10}$ C·cm/J and $F_m = 1.6\times10^{-8}$ C·cm/J] [3].

The optical response of $LiTaO_3$ thin film IR detector is expressed in terms of voltage responsivity (R_v) given by [4]:

$$R_v = \frac{\eta\gamma AR\omega}{\sqrt{1+\omega^2\tau_t^2}\sqrt{1+\omega^2\tau_e^2}}, \quad (1)$$

where ω is the angular modulation frequency, τ_t the thermal time constant (= H/G, where H and G are the thermal capacity and the thermal conductance, respectively.), and τ_e (= RC) is the electrical time constant. The specific detectivity ($D^* = R_v(\triangle f \cdot A)^{1/2} V_n$) gives the area-normalized signal to noise ratio in the frequency bandwidth $\triangle f$ for the detector. Figure 2 shows the modulation frequency dependence of R_v, D^* and voltage noise V_n for $LiTaO_3$ thin film IR detector.

The R_v value decreases at high frequencies because R_v is inversely proportional to the frequency at a modulation frequency $> \tau_t^{-1}$. The present results are consistent with the above phenomenon described by equation (1). The detector has a maximum voltage responsivity R_v of 4584 V/W at 20 Hz. Figure 2 also shows that V_n varied nearly proportionately to $f^{-1/2}$, possibly because Johnson noise dominated in pyroelectric detectors [5]. D^* was proportional to $f^{-1/2}$ for $f > 100$ Hz, because R_v varied proportionately to f^{-1} and V_n varied with $f^{-1/2}$. In contrast, D^* decreased as f decreased for $f < 50$ Hz. This phenomenon probably occurred because R_v was almost saturated, and V_n increased nearly proportionately to $f^{-1/2}$. A maximum D^* of 4.23×10^7 cm·Hz$^{1/2}$/W at 100 Hz has been obtained.

In summary, the high quality pyroelectric $LiTaO_3$ thin films have been fabricated on $Pt(111)/SiO_2/Si(100)$ substrates by a diol-based sol-gel technology, and the optical response of the $LiTaO_3$ thin film detector were also investigated. The corresponding results of dynamic response show that the obtained $LiTaO_3$ thin film exhibited excellent pyroelectric properties and, thus, was suitable for application as highly sensitive pyroelectric IR devices.

Acknowledgements

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