International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 08 Issue 08 August 2025
DOI: 10.47191/ijcsrr/V8-i8-05, Impact Factor: 8.048
IJCSRR @ 2025
www.ijcsrr.org

Optical Transmission Spectra of $Pb_{0.80}Sr_{0.20}TiO_3/Pb_{0.90}Sr_{0.10}TiO_3$ Compositional Graded Ferroelectric Thin Films

Waris Tanvir
Teaching Assistant, Physics Department, Paktia University, Afghanistan

ABSTRACT: This study looks at the optical transmission properties of ferroelectric thin films made from two different compositions of lead strontium titanate: $Pb_{0.80}Sr_{0.20}TiO_3$ and $Pb_{0.90}Sr_{0.10}TiO_3$. The films were created using a method called metallo-organic decomposition (MOD) combined with spin coating on quartz substrates. The researchers analyzed the optical properties by recording transmission spectra from 300 to 1500 nm. They found that the films were highly transparent in the longer wavelength range and that their optical characteristics varied significantly with grain size. By deriving the refractive index, extinction coefficient, and absorption coefficient from the spectra, the team demonstrated that these films have promising applications in electro-optic devices, photodetectors, and photonic sensors. Overall, this work showcases the progress made in creating and studying lead strontium titanate thin films, highlighting their versatile optical features.

KEYWORDS: Experimental, Ferroelectric materials, thin films, PST.

INTRODUCTION

Ferroelectric materials are essential components in a wide range of applications. In thin film form, ferroelectrics have now been used for several years in rf devices and in nonvolatile memories. Ferroelectric materials are interesting for electromechanical and optoelectronic applications. Components based on ferroelectric films are also being developed for various sensor and actuator applications and for tunable microwave circuits [1,2].

The development of ferroelectric thin films started at the late 1960 and early 1970s when progress in integrated Si devices and thin film processing techniques triggered interest in the use of ferroelectric thin films for fabrication of nonvolatile memories. Difficulties with ferroelectric materials processing and integration frustrated the attempts to make practical memory devices until the 1980s. The advances in processing of complex ferroelectric oxides at the mid-1980s resulted in a revival of interest in ferroelectric memories, and in 1987, ferroelectric memory integrated with silicon complementary metal-oxide semiconductor (CMOS) was demonstrated [3].

The (Pb,Sr) TiO_3 (i.e.PST) materials are solid solutions of the $PbTiO_3$- $SrTiO_3$ system which possesses the perovskite structure [4]. The Curie temperature of PST decreases linearly from 490 to -230°C with increasing Sr content. By choosing appropriate Pb/Sr ratios, electronic devices requiring different properties such as tunable capacitors, FeRAM, and piezoelectric filters can be fabricated in one system of materials. Recently, the Sr-rich PST thin film has attracted much attention in its large electric-field-dependent dielectric constant for microwave device applications [5].

PST thin films

A thin film can be defined as a quasi-two-dimensional material created by condensing, atomic/molecular/ionic species of matter. PST thin film refers to the thin layer of $(Pb_{1-x}Sr_x)TiO_3$ deposited on a suitable substrate. Here x is mole fraction of strontium. PST thin films have been extensively studied in relation to their applications for making electronic devices. To study the microstructure and optical properties of $(Pb_{1-x}Sr_x)TiO_3$, it is better to prepare its thin film on quartz substrate. The controlled synthesis of lead strontium titanate as thin film is a fundamental step in many applications. In addition to its applied interest, thin films play an important role in the development and study of lead strontium titanate (PST) with new and unique properties. Examples include multiferroic materials, and super lattices that allow the study of quantum confinement by creating two-dimensional electron states.

Optical properties

In Nano optics many promising optical properties of nanostructure are being studied. Ferroelectric PST (Pb, Sr, TiO3) thin films has the potential for wide applications due to their excellent dielectric, piezoelectric and ferroelectric properties. Recently it has been observed that PST thin film also offers interesting optical parameters when the grains are in Nano size. The Nano optic films are usable in wavelength filters, optical low pass filters, electrically controllable optical attenuators, polarization filters. These Nano-optic films also minimize the amount of material required for achieving desired optical functions.

Composing modification of $SrTiO_3$ (ST) into A-site of perovskite $Pb\,TiO_3$ (PT) thin film reduces its grain size as well as morphology. PST thin films present high transparency in the visible and infrared wavelength region, resulting higher value of refractive index. It has been reported in the literature that optical parameter of different materials like chalcogenide semiconducting glasses system etc. [7]. It has some limitations of higher frequency applications. Recently optical thin film has been developed which is crystalline and its grains are in Nano-size such type of Nano-optic film shows better transmittance, large refractive index, appropriate energy band gap and results in improvement of absorption coefficient, optical dielectric constant and conductively in short visible wavelength. In the view of these improvements in optical parameters, we have fabricated PST films which are usable in electro-optic switches, photodetectors, photonic crystals and photonic sensors for digital camera.

Experimental

Sample preparation

To prepare compositionally graded thin films of lead strontium titanate (PST), we had two forms of solution of $(Pb_{1-x}Sr_x)\,TiO_3$, which were different in composition between lead and strontium. One was $PST\ (x = 0.10)$ and the second was $PST\ (x = 0.20)$. Here x is mole fraction of strontium. Solution based thin film deposition technique was used to deposit thin films. PST thin films were deposited by metallo-organic decomposition (MOD) processed spin coating technique on quartz substrates under an ambient atmospheric condition.

Sample

$PST\ (x = 0.10)$ solution was dropped on a quartz substrate and spin coated for 30 s at 4500 rpm. The sample was dried in furnace at $350°C$ for 5min. After that, $PST\ (x = 0.20)$ solution was dropped above the $PST\ (0.10)$ layer of that substrate and coated. It was dried in furnace at $350°C$ for 5min. The resultant sample containing two layers of PST was then annealed at temperature $650°C$ for 2h in air. The process is more simple, economic and fast for preparing reproducible films in a large scale.

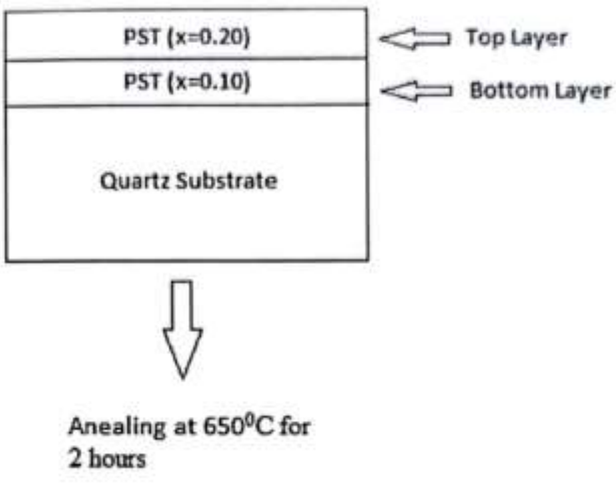

Fig.1 Preparation of sample

Optical properties

Optical properties were measured on films deposited on quartz substrate. Transmission spectra were recorded with a Perkin Elmer UV-0637 spectrometer and from this refractive index and optical band gap were calculated.

Figure 12 shows the optical transmission spectra in the wavelength range 300-1500nm of $Pb_{0.80}Sr_{0.20}TiO_3/Pb_{0.90}Sr_{0.10}TiO_3$ thin films deposited on quartz substrate (sample) annealed at temperature $650°C$.

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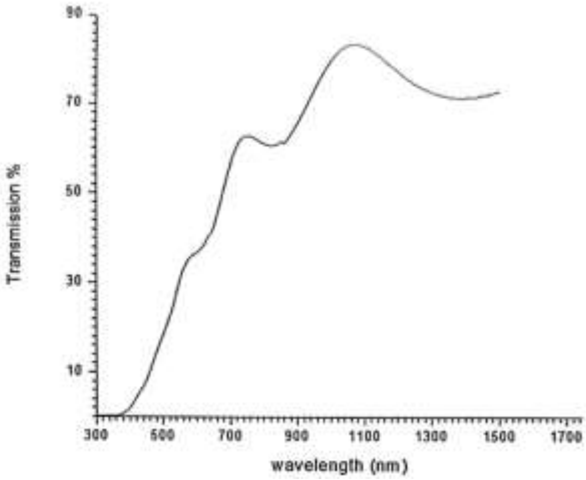

Fig.2 Optical transmission spectra for Sample

The transmittance of the film decreases to zero near 400nm and shows good transparency more than 70% in longer wavelength region. The high transmittance indicates low surface roughness and homogeneous thin films. The value of refractive index (n), film thickness (t), extinction co-efficient (k) and absorption co-efficient (α) are the optical properties of any materials. Using Swanepoel method [10] the values of refractive index of the films can be calculated from the transmission spectra. In the transparent region when the absorption co-efficient $\alpha \approx 0$, the refractive index (n) is given by

$$n = [N + (N^2 - S^2)^{1/2}]^{1/2} \quad (1)$$

$$N = \frac{2S}{T_m} - \frac{(S^2+1)}{2} \quad (2)$$

T_m is the transmission minimum and S being the refractive index of the substrate used (for quartz $S = 1.46$). Where in the weak region $a \neq 0$, the transmittance decreases due to the influence of absorption instead of equation (2) we have

$$N = 2S\frac{T_M - T_m}{T_M T_m} + \frac{(S^2+1)}{2} \quad (3)$$

Where, T_M is the transmission maximum corresponding to minimum T_m. The film thickness t was determined by using the relationship

$$t = \frac{\lambda_1 \lambda_2}{(\lambda_1 n_2 - \lambda_2 n_1)} \quad (4)$$

Where, n_1 and n_2 are the refractive indices of two consecutive maxima or minima at wavelengths λ_1 and λ_2, respectively. Alternatively, the film thickness was directly measured by Talystep stylus instrument (Embios Technology) model XP2. The difference between the measured and optically determined values is less than 10%. The extinction coefficient (k) can be obtained from the relation

$$k = \frac{\alpha\lambda}{4\,\pi} \quad (5)$$

Where, α is the absorption coefficient and is given by

$$\alpha = \left(\frac{1}{d}\right)\ln\left(\frac{1}{x}\right) \quad (6)$$

Where, x is the absorbance and d is thickness of compositional graded PST thin films. In weak and medium absorption regions, x is given by

$$x = \frac{E_M - [E_M^2 - (n^2-1)^3(n^2-S^4)]^{1/2}}{(n-1)^3(n-s^2)} \quad (7)$$

Where,

$$E_M = \frac{8n^2S}{T_M} + (n^2-1)(n^2-S^2 \quad (8)$$

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The experimental data of the real part of the complex refractive index of the sample nanocrystalline thin films deposited on quartz substrates is shown in figure 3. The variation of extinction coefficient with varying spectral wavelength is shown in figure 4.
Fig.3 Variation of refractive index of sample with wavelength

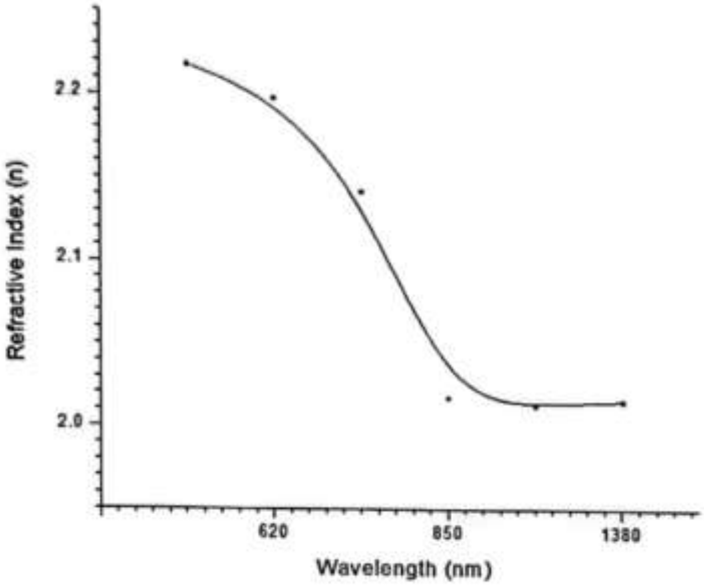

Fig. 4 Variation of extinction coefficient with spectral wavelength

CONCLUSION

In summary, the thin films of $Pb_{0.80}Sr_{0.20}TiO_3$ and $Pb_{0.90}Sr_{0.10}TiO_3$ show promising optical characteristics, such as high transparency and suitable refractive indices. The use of the MOD spin coating technique has proven effective in creating consistent and reproducible films, which is essential for various technological applications. These findings suggest that these thin films could play a significant role in the development of advanced electro-optic devices and sensors. Looking ahead, it will be important to optimize the processing methods and investigate how to integrate these films into functional devices to fully harness their potential in optoelectronics.

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Cite this Article: Tanvir, W. (2025). Optical Transmission Spectra of $Pb_{0.80}$ $Sr_{0.20}$ TiO_3/$Pb_{0.90}$ $Sr_{0.10}$ TiO_3 Compositional Graded Ferroelectric Thin Films. International Journal of Current Science Research and Review, 8(8), pp. 3987-3990. DOI: https://doi.org/10.47191/ijcsrr/V8-i8-05

 *Corresponding Author: Waris Tanvir