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Ultraviolet radiation detection by barium titanate thin films grown by Sol-gel hydrothermal method

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Abstract

Ferroelectric Barium titanate, $BaTiO_3$ (BTO) thin film has been prepared successfully by sol-gel hydrothermal method (SG-HT) which combines the basic sol-gel process with hydrothermal treatment. High resolution X-ray diffraction (HR-XRD) study reveals single phase polycrystalline tetragonal structure of the prepared BTO thin film. Optical properties were studied using UV-Visible spectroscopy and band gap was found to be 3.51 eV. The I–V characteristics revealed a low dark current (I_{off}) of 6.07×10^{-9} A for the prepared BTO thin film which increases to 4.06×10^{-6} A (I_{on}) by almost three orders of magnitude when illuminated with UV radiation ($\lambda = 365$ nm , Intensity = 24 $\mu W/cm^2$). The photoconductive gain ($K = I_{on}/I_{off}$), was found to be 6.7×10^2. It can be clearly seen that the prepared BTO film can be utilized as an efficient Ultraviolet photodetector.

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Keywords: Ferroelectric; Photodetector; Thin film; Hydrothermal; Sol-gel

1. Introduction

In the last few decades, there has been an increasing demand for UV radiation sensors due to its harmful effects [1]. The preparation of UV radiation detectors is important because of their potential applications in the various fields of science and technology, including space science, aircraft science, defense and other industries [2]. Barium titanate, $BaTiO_3$ (BTO) is a well known ferroelectric material with high dielectric constant and ferroelectric properties being used in a number of applications like gas sensing, capacitors, memory devices etc [3-4]. There are a

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number of physical and chemical methods for preparing BTO thin films, including pulsed laser deposition (PLD), sputtering, thermal evaporation, vacuum deposition, chemical vapor deposition, co-precipitation, sol–gel, chemical bath deposition etc. On the contrary, sol-gel- hydrothermal (SG-HT) technique is a promising chemical method for low cost, low temperature fabrication of BTO thin films with large surface area. So, in the present work, BTO thin film has been prepared by the low-temperature sol-gel hydrothermal method and its UV photodetection characteristics have been studied.

2. Experimental Details

The SG-HT technique consists of two steps: 1) preparation of BTO gel films by a conventional sol-gel process and 2) hydrothermal treatment of the gel films to prepare BTO thin films. The starting materials were barium acetate and titanium(IV)isopropoxide. Glacial acetic acid, 2-methoxyethanol, and ethylene glycol were used as the solvent and polymerizing agents. Barium acetate was first dissolved into heated glacial acetic acid followed by addition of titanium isopropoxide under constant stirring. The mixture was then added with ethylene glycol to form a final solution. After that, the final solution was diluted with equivolume amounts of glacial acetic acid and 2-methoxyethanol. The concentration of solution was about 0.2 M. After this, thin-film deposition was carried out on Pt Inter Digital Electrodes (IDEs) patterned Si substrates by spin coating. Fabrication details of IDEs are presented elsewhere [5]. The gel films were pyrolysed at 400°C for 5 min to evaporate the solvents. The desirable thickness was obtained through multiple coatings. Afterwards, the conventional sol-gel derived BTO gel films of 150 nm thickness were fixed in the middle of a Teflon vessel. A suitable concentration of $Ba(OH)_2$ and $(C_4H_9O)_4Ti$ aqueous solutions was added to the vessel, then the vessel was kept into a sealed autoclave at 150 °C for 12 hrs to perform the hydrothermal treatment. After hydrothermal treatment, the samples were rinsed several times with de-ionized water, absolute ethanol, and glacial acetic acid to clean the surface of the films and then dried at 90 °C for 2 hrs.

3. Results and Discussion

Fig. 1 shows the High resolution X-ray diffraction (XRD) pattern of the BTO thin film with all the planes corresponding to tetragonal structure without the formation of any other secondary phase indicating polycrystalline nature of the deposited film.

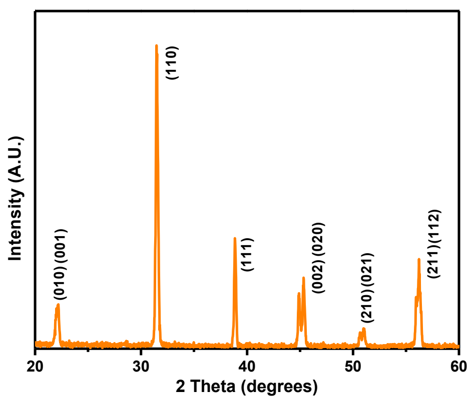

Fig. 1. XRD spectra of BTO thin film prepared by sol-gel hydrothermal method

The optical properties of the prepared BTO thin film were studied by UV-Visible spectrophotometer as shown in Fig. 2(a) having high transparency of ~ 80 % in the visible region. The band gap as calculated from the Tauc plot of $(\alpha h\nu)^2$ versus photon energy ($h\nu$) where α is the absorption coefficient [Fig. 2(b)] was found to be about 3.51eV.

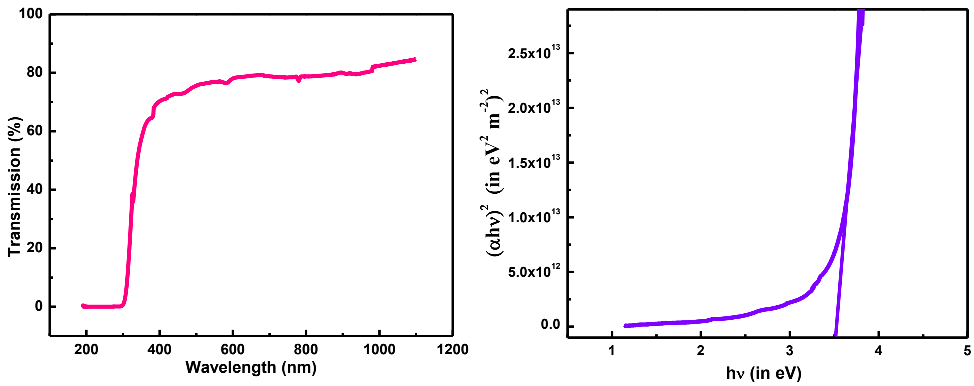

Fig. 2(a): UV- Visible spectra of BTO thin film deposited on quartz substrate; (b): Tauc plot of BTO thin film to calculate its band gap

UV photoresponse characteristics of the BTO thin film were investigated towards UV radiation of $\lambda = 365$ nm and intensity = 24 $\mu W/cm^2$ at a bias voltage of 5 V. Fig. 3 shows the I–V characteristics of BTO thin film under dark and illumination conditions. The dark current (I_{off}) was found to be 6.07×10^{-9} A which increases by almost three orders of magnitude (4.06×10^{-6} A) when illuminated with UV light (I_{on}). The photoconductive gain ($K = I_{on}/I_{off}$), measured under the presence and absence of UV illumination was found to be 6.7×10^2.

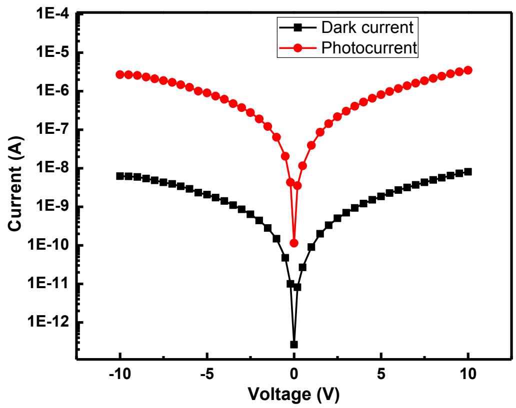

Fig. 3: I–V characteristics of BTO thin film under dark and illumination conditions

Fig. 4 represents the time-dependent photoresponse transient of the BTO thin film in the presence and absence of UV light. When the UV light is off, BTO UV- photodetector has a low value of dark current I_{off} (nA) which increases with time upon UV irradiation and then saturates to a high photocurrent Ion (μA). Afterwards when UV radiation is turned off (recovery), current decreases to attain its initial low value (I_{off}).

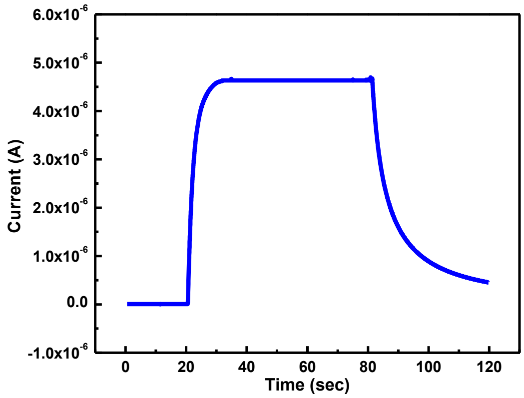

Fig. 4: Time dependent photoresponse transient of BTO thin film

4. Conclusion

Ferroelectric Barium titanate, $BaTiO_3$ (BTO) thin film has been prepared successfully by sol-gel hydrothermal method (SG-HT). A low dark current (I_{off}) of 6.07×10^{-9} A was obtained which increases by almost three orders of magnitude when illuminated with UV radiation. The photoconductive gain ($K = I_{on}/I_{off}$), was found to be 6.7×10^2. The obtained UV photoresponse characteristics of the prepared BTO film are encouraging to use it as an efficient Ultraviolet photodetector.

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