Characteristics of Bismuth trioxide film prepared by rapid thermal oxidation

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This work presents novel results of structural, optical, and electrical properties of Bi$_2$O$_3$ film deposited on glass substrates by rapid thermal oxidation with aid of halogen lamp at 500°C for 45 s in static air condition without post-deposition heat treatment. The structural investigation showed that the grown bismuth trioxide film is polycrystalline and multiphase (α-Bi$_2$O$_3$ and β-Bi$_2$O$_3$). Optical properties revealed that these films having direct optical band gap of 2.55 eV at 300 K with high transparency in the visible and NIR regions. Furthermore, these results are compared with other published results. [DOI: 10.1380/ejssnt.2006.563]

Keywords: Bismuth trioxide; thin film; rapid thermal oxidation

I. INTRODUCTION

Bismuth trioxide (Bi$_2$O$_3$) thin films have attracted the interest of many researches due to the values of some their characteristics parameters e.g., energy gap, refractive index, photoconductivity, transparency and mechanical strength [1–5]. These films are suitable for many applications such as anti-reflecting coating, sensors, fuel cells, optoelectronic devices, as well as a parent substance for some high-T$_C$ superconductors [6–8].

Bi$_2$O$_3$ films were prepared by different methods; spray pyrolysis [9], anodic oxidation [10], flash evaporation [2], thermal oxidation of bismuth film using furnace [11], and pulsed laser deposition [12]. It is shown that the properties of such films were strongly depended on the preparation method. Up to our knowledge, no data have been reported for bismuth trioxide film prepared by rapid thermal oxidation (RTO) technique. In the present paper, the properties of Bi$_2$O$_3$ films prepared by RTO are fully studied and analyzed.

II. EXPERIMENT

High purity of bismuth film was deposited on cleaned glass substrates using thermal resistive technique under pressure of 10$^{-7}$ Torr. Bi$_2$O$_3$ film was obtained with aid of rapid thermal oxidation system with single high power halogen lamp as oxidation source. The experimental setup is presented elsewhere [13]. The oxidation condition used to form Bi$_2$O$_3$ films was 450°C for 35 s with heating and cooling rates of 15°C/s and 25°C/s, respectively. The grown film has dimensions of 2.5 × 2.6 cm and thickness of 500 nm. Ohmic contacts are made on both Bi$_2$O$_3$ films by depositing Ag thick films through certain mask using thermal evaporation system followed by rapid thermal annealing at 300°C for 10 s. The x-ray diffraction (XRD) spectrum of Bi$_2$O$_3$ film grown on glass substrate was investigated by x-ray diffractometer of Cu $K_\alpha$ as a target ($\lambda = 0.15417$ nm).

The D.C dark electrical resistivity of Bi$_2$O$_3$ as function of temperature was measured using a Keithley digital electrometer. Thermoelectric property of the film was used to estimate the carrier concentration and conductivity type of film [9]. Double-beam spectrophotometer (Shimadzu) was used to measure the transmission and absorption spectra of Bi$_2$O$_3$ thin film deposited on glass substrate in spectral range of 400-900 nm.

III. RESULTS AND DISCUSSION

Figure 1 shows X-ray diffraction (XRD) spectrum of Bi$_2$O$_3$ thin film. It is clear that the film is polycrystalline in nature and multiphase. The film exhibits mixture of α-Bi$_2$O$_3$ (monoclinic) and β-Bi$_2$O$_3$ (tetragonal structure). No diffracted peaks concerning Bi and nonstoichiometric phases are noticed in XRD spectrum. The d-values of grown film are very close to ASTM diffraction data of Bi$_2$O$_3$. The maximum intensity peak belong α-Bi$_2$O$_3$ phase is observed corresponding to diffraction angle of 2θ = 27.1° and second peak (2θ = 28.1°) which belongs to β-Bi$_2$O$_3$ phase. These results are in good agreement with published results. This is given an indication that the condition used in this study is optimal.

The published results [5] established that the prepara-

FIG. 1: XRD pattern of grown Bi$_2$O$_3$ film.

1. α-Bi$_2$O$_3$ (121)
2. β-Bi$_2$O$_3$ (221)
3. β-Bi$_2$O$_3$ (123)
4. β-Bi$_2$O$_3$ (402)
5. β-Bi$_2$O$_3$ (624)
6. β-Bi$_2$O$_3$ (442)
FIG. 2: Uniformity and transparency of Bi$_2$O$_3$.

FIG. 3: Transmittance spectrum of Bi$_2$O$_3$.

FIG. 4: Plot of $(\alpha h\nu)^2$ vs. $h\nu$.

FIG. 5: Variation of films resistance with $T^{-1}$.

Characterization method and condition strongly affect the crystalline and granular structure of Bi$_2$O$_3$ films. The film shows good uniformity and transparency as displayed in Fig. 2. On the other hand, the adhesive characteristics of Bi$_2$O$_3$ with glass was very good. Figure 3 displays the transmittance of Bi$_2$O$_3$ films in the spectral range of 400-900 nm. It is obvious that the film gives a good transparency with yellowish color characteristics in the visible and NIR regions ($T_{ave} > 75\%$). The optical energy gap of Bi$_2$O$_3$ at 300 K was obtained from direct optical transitions ($\alpha^2 h\nu$ plot) (Fig. 4) and found to be 2.55 eV. This value is very close to the values of published results [7, 11].

One can notice that this value is very close to the band gap of CdS and CdO, which are promising materials for solar cells and optoelectronic devices. Thermoelectric power (TEP) properties of Bi$_2$O$_3$ film was carried out and show that the Bi$_2$O$_3$ film is $n$-type material. Possible reasons for this are the donors formation by oxygen vacancies and interstitial Bi atoms. The variation of electrical resistance of the film is function of temperature reciprocal is revealed in Fig. 5. This curve confirms the semiconducting behavior of Bi$_2$O$_3$ film. The activation energy of film was 1.25 eV which is in good agreement with that of film prepared by thermal oxidation of bismuth in classical furnace [14]. On the other hand, the activation energy was lower than the optical energy gap of film. The electrical resistivity and electron mobility of Bi$_2$O$_3$ were measured and found to be $8 \times 10^3$ $\Omega$-cm and $3.61 \times 10^{-5}$ cm$^2$V$^{-1}$s$^{-1}$, respectively. These results are close to those of sprayed and thermally oxidized Bi$_2$O$_3$ film results obtained by others [7, 15]. The high resistivity of film might be explained by the presence of the crystallites with lower size.

**IV. CONCLUSION**

The structural, optical, and electrical properties confirms that the rapid thermal oxidation is useful method
to prepared undoped polycrystalline $n$-type Bi$_2$O$_3$ thin film. This novel technique is simple, low cost, and reliable. Multiphase structure with good crystallinity is obtained and the $d$-value was very close to that of bulk material. The transmittance in the visible and near infrared is moderately high and the band gap was found to be around 2.55 eV at room temperature. In the light of obtained results, Bi$_2$O$_3$ film is candidate to be used for optoelectronic devices applications. Efforts to dope it and decreasing of its electrical resistivity by heat treatment are under way.

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