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Effect of post-growth annealing on the structural, optical and electrical properties of V_2O_5 nanorods and its fabrication, characterization of V_2O_5/p-Si junction diode

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ABSTRACT

We report the synthesis of V_2O_5 nanorods by utilizing simple wet chemical strategy with ammonia meta vanadate (NH_4VO_3) and polyethylene glycol (PEG) exploited as precursor and surfactant agent, respectively. The effect of post-annealing on structural, optical and electrical properties of V_2O_5 nanorods was characterized by XRD, HRSEM-EDX, TEM, FT-IR, UV (DRS), PL, TG–DTA and DC conductivity studies. The X-ray diffraction analysis revealed that the prepared sample annealed at 150 °C for 5 h which exhibited anorthic phase of V_5O_9 and annealed at 300–600 °C showed the anorthic phase change to orthorhombic phase of V_2O_5 due to the post-annealing effect. The surface morphology results indicated that increasing temperature caused a change from microrods to a nanorods shape in the morphology of V_2O_5. FT-IR spectrum confirmed that the presence of V_2O_5 functional groups and the formation of V–O bond. The optical band gap was found in the range 2.5–2.48 eV and observed to decreases with various annealed temperature. The DC electrical conductivity was studied as a function of temperature which indicated the semiconducting nature. Further, the potential of V_2O_5 nanostructures were grown on the p-Si substrate using the nebulizer spray technique. The junction properties of the V_2O_5/p-Si diode were evaluated by measuring current (I)–voltage (V) and AC characteristics.

1. Introduction

Transition metal oxides, especially vanadium compounds gain immense interest due to their special physical and chemical properties, making them technologically useful for nanoscale device applications. The vanadium atoms exists in different formal oxidation states, vary from VO (V^{2+}), V_2O_3 (V^{3+}), VO_2 (V^{4+}), V_6O_{13} (V^{4+} and V^{5+}) and V_2O_5 (V^{5+}), each of which is stable over a certain composition range [1]. The oxides are well known for their structural transformation, and its electronic phase transitions, metal-to-insulator (MIT) and metal-to-semiconductor (MIS). Among these oxides of vanadium, V_2O_5 with V^{5+} oxidation state and 3d° configurations differs from others in its MIS properties. It is the most stable compound in the V–O system, exhibiting highly anisotropic electrical and optical properties due to its orthorhombic crystal structure and belongs to the P_{mnm} space group. By adopting 'intrinsic' donors, such as vanadium interstitials and oxygen vacancies the unintentional donor hydrogen is reliable n-type conductivity with an energy band gap (E_g) of 2.2 to 2.7 eV [2] and attracts continuing attention owing to its great potential in a wide variety of scientific and technological applications in recent years. They find extensive applications in areas such as high-energy lithium batteries [3], catalysis [4], solar cells [5] and field effect transistors (FETs) [6]. Nowadays, one-dimensional (1D)-V_2O_5 nanostructures such as nanowires, nanobelts and nanorods gain notice considerably due to their unique properties towards electronic and optoelectronic application. Among the 1D-V_2O_5 is perhaps the most studied, owing to its features like inexpensive preparation, high stability and the significantly large energy density. During the past decades, a variety of methods such as reverse-micelles synthesis [7], sol–gel method [8], hydrothermal [9], chemical vapor deposition [10], thermal-decomposition [11], pulsed laser deposition [12] and electro-spinning [13] are commonly used to prepare 1D-V_2O_5 nanostructures. Compared with these methods, the wet chemical synthetic route holds the advantage of easier control of the morphological parameters of nanomaterials and

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does not require any sophisticated equipments.

In this work, we studied the effect of various annealing temperature on structural, optical and electrical properties of 1D-V_2O_5 nanorods by the wet chemical method. We herein a simple and low-temperature nebulizer technique is described to deposit of V_2O_5 nanorods onto p-type Si substrates. Then, the electrical and photoresponse properties of produce V_2O_5/p-Si junction were examined using current (I)–voltage (V) measurements in dark and under illumination condition. Further, the dielectric properties of the dielectric constant, dielectric loss and AC conductivity are also investigated by using V_2O_5/p-Si junction diode at room temperature.

2. Experimental procedure

All the chemicals used in our experiment were of analytical reagent (AR) grade and used without any further purification. The ammonium meta vanadate (NH_4VO_3), hydrogen peroxide (H_2O_2), nitric acid (HNO_3), polyethylene glycol (PEG), purchased from Merck company, was used as the precursor materials for synthesis of V_2O_5 nanoparticles by wet chemical method. The flow chart of the preparation of V_5O_9 and V_2O_5 nanoparticles is shown in Fig. 1. In a typical synthesis procedure, an appropriate amount of ammonium meta vanadate (NH_4VO_3) was dissolved in deionized water and stirred for 10–20 min at room temperature. In the aqueous solution contains a milky white color was precipitated then a given amount of 10 ml 35% H_2O_2 was added, quickly the milky white color changed to light pale yellow shade. Upon an introduction of aliquot concentrated HNO_3 acid was into the system, the color of the reaction mixture changed from pale yellow to dark orange color [14]. Finally, a desired amount of polyethylene glycol (PEG) was added into concoction solution under vigorous stirring for 24 h. After stirring, the dark orange neutral solution yields a pale yellow settlement. In the resulting pale yellow yields

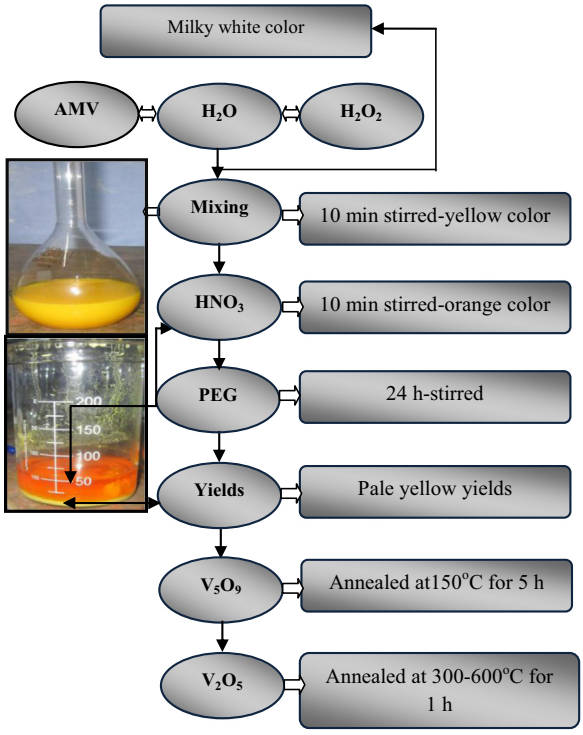

Fig. 1. Flow chart describing the wet-chemical method used for the synthesis of V_5O_9 and V_2O_5 nanoparticles. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

was filtered, washed with deionized water and absolute ethanol, and dried at 150 °C for 5 h to get as-prepared sample of V_5O_9. Then dried product was transferred to a silicon crucible for purpose of sintering and placed in muffle furnace at different temperatures, say 300, 500 and 600 °C for 1 h till yellow colored V_2O_5 nanoparticles were obtained.

3. Characterization techniques

The synthesized powder samples are characterized for their structure using a Bruker AXS D8 advance X-ray diffraction. SEM images are obtained using FEI Quanta FEG 200 (1.2 nm gold particle separation on a carbon substrate) at an accelerating voltage of 30 kV attached with energy dispersive spectrometer (EDX). HRTEM along with their SAED pattern images are observed using TECHNAI T20 operated at 200 kV for fine surface morphological studies. Thermo gravimetric (TG–DTA) analysis is performed with a UL-VAC-7000 thermal analyzer from R_T to 1000 °C with heating rate of 10 °C/min in air. The Fourier transform infrared (FT-IR) spectrometer (Thermo Nicolet 60-SXB Spectrometer) is used to record the spectra range from 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1}. The diffuse reflectance spectral studies are also done using UV–vis–NIR spectrophotometer between 200 and 1300 nm (Varian; Model Cary 5000). The photoluminescence spectrum is examined by the instrument model of Horiba Jobin Yuon Fluorolog with the range of 185–900 nm. DC electrical conductivity studies (in pellet form) are made to using a Keithley 6517 B. The photoresponse characteristics of the diode are measured under a halogen lamp with a solar stimulator (100 mW/cm^{-2}) using a Keithley 6517 B. Dielectric measurements are carried out in the frequency range 42 Hz to 5 MHz using LCR HI-Tester (HIOKI 3532-50).

4. Results and discussion

4.1. Structural analysis

Fig. 2(a)–(d) shows the X-ray diffraction patterns of V_5O_9 and V_2O_5 samples with annealed at different temperatures. In Fig. 2(a), the characteristic peaks at 2θ values of 11.430°, 14.38°, 17.22°, and 28.97° can be associated with (010), (100), (002) and (200) planes, respectively. The strong and dominant (200) orientation for the sample indicates that the synthesized particles had a (200) growth

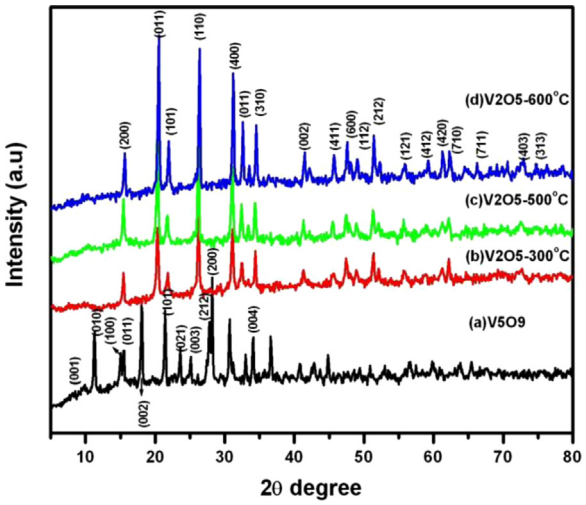

Fig. 2. XRD patterns of (a) V_5O_9 sample annealed at 150 °C and (b–d) V_2O_5 samples annealed at various temperatures.