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# Tuning the structural and optical features of $V_2O_5$ nanostructured films by Bi-doping and γ-irradiation for smart window applications

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ABSTRACT

Doping and radiation exposure are two of the most preferred stratagems for enhancing the efficiency of $V_2O_5$ for optoelectronic and smart window applications. This work studies the effect of Bi-doping and γ-ray irradiation on the structural and optical properties and color change of $V_2O_5$ films developed by casting/spin coating processes. Firstly, pure and Bi-doped $V_2O_5$ nano-sized powders with batonnets-like morphology (packs of nano-rods having diameters in the range of 7.28–16.28 nm and 9.32–95.49 nm) were prepared by a facile chemical route. The films were prepared by casting/spin-coating a suspension solution of the powder on glass substrates. X-ray diffraction (XRD) results indicate the formation of a layered $V_2O_5$ of orthorhombic structure, highly oriented in the (001) direction, with a crystallite size in the range of 35.8–51.3 nm, depending on the irradiation dose. The Fourier transform-infrared spectroscopy (ATR/FTIR) exhibited the presence of V–O–V, V═O vibrations, with intensities sensitive to Bi-doping and absorbed dose. Investigating the optical features reveals that the films are semi-transparent. The pure $V_2O_5$ and Bi-doped $V_2O_5$ films have optical direct (indirect) band gaps in the ranges of 2.6–3.0 eV (1.3–1.6 eV) and 2.3–2.9 eV (1.1–1.5 eV), respectively. The optical parameters (*k*-index and the refractive index) can be tuned by Bi-doping and γ-ray doses. The CIE colorimetry was used to evaluate the CIE LAB $L^*$, $a^*$, $b^*$, and the total color change ($\Delta E$) values. The results indicated that $b^*$ and $L^*$ can be used individually as a dosimetry index at doses ≤30 kGy. The results illustrate the feasible controlling of $V_2O_5$ films by Bi-doping and γ-irradiation for optoelectronic devices, dosimetry, and smart windows.

## 1. Introduction

Transition metal oxides exhibit unique physicochemical properties, owing to their outer *d*-electrons, and they are essential materials for various technological and biodevice (medical) applications (Shaban and El Sayed, 2020; Çarpan et al., 2024; Briceno et al., 2024). Among them, vanadium pentoxide ($V_2O_5$) is an *n*-type and direct/indirect gap semiconductor that can be prepared in different morphologies using physical and chemical synthetic approaches. It attracts widespread attention for energy-saving, sensing, spacecraft temperature control, screen applications, and architectural areas (color filters and reflectance mirrors), where it is preferred for thermochromic smart glasses due to its various oxidation states ($V^{+2}$, $V^{+3}$, $V^{+4}$, and $V^{+5}$) and multicolor (Le et al., 2022; Peres et al., 2023; Yang et al., 2024; Chand et al., 2024). The high theoretical specific capacity of $V_2O_5$, and its presenting both cathodic and anodic electrochromic coloration make $V_2O_5$ a preferred material for electrochemical (supercapacitor) applications and as a cathode for rechargeable $Li^+$ batteries (Çarpan et al., 2024; Wang et al., 2024). However, some disadvantages limit the usability and performance of $V_2O_5$ applications, such as the low conductivity ($10^{-3}$–$10^{-2}$ S/cm), low electron mobility (0.03–2.2 $cm^2$/V·s), stability, and the expansion/-contraction of $V_2O_5$ during charge/discharge cycles (Yang et al., 2024; Wang et al., 2024).

The morphology, physical, chemical, and biological properties, and applications of nano-sized $V_2O_5$ depend on the method of preparation and doping with metals or metal oxides. Additionally, irradiating the semiconductors with γ-rays, X-rays, and high-energy particles results in ionization, atomic displacement, vacancies, or dislocations, which create energy levels inside the band gap and trapping or recombination centers for the charge carriers. The material could transform from crystalline to a partial amorphization (due to defect formation) and then recrystallize with increasing the dose due to the associated heating effect. According to Khan et al. (2016), the spin-coated monoclinic $VO_2$ films converted to an amorphous state upon irradiation with 200 MeV

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