



# Boosting the structural and optical properties of TM-doped V<sub>2</sub>O<sub>5</sub> nanostructures (TM = Cu, Fe, Ni) via $\gamma$ -irradiation for optoelectronics and dosimetry applications

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## ABSTRACT

The technological applications based on vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>) can be developed by doping with transition metals (TM) and irradiation processing. The present study reports the influence of copper (Cu), iron (Fe), and nickel (Ni) doping on the physical properties of V<sub>2</sub>O<sub>5</sub> nanocrystals derived by a modified sol-gel technique. According to FE-SEM investigations, the Cu-, Fe-, and Ni-doped V<sub>2</sub>O<sub>5</sub> powders have a layered structure with different morphologies (nanorods, nanonails, nanobelts, and nanosheets). EDX analyses confirmed the high purity of the samples. Pure and doped films, prepared by casting/spin coating the powder solutions on glass substrates, were exposed to a gamma ( $\gamma$ )-ray source for doses in the range of 10–30 kGy to study their optical and color difference. XRD analyses of the powders and films revealed the formation of orthorhombic  $\alpha$ -V<sub>2</sub>O<sub>5</sub> structures, highly oriented along (001), and having crystallite sizes in the range of 50–80 nm. Doping reduced the sample crystallinity, while the  $\gamma$ -irradiation improved it. FTIR spectra of the films revealed two absorption bands centered at  $\sim$  450 and 760 cm<sup>-1</sup> assigned to the bending and symmetric vibrations of the O–V system and a third wide and intense band at 900 cm<sup>-1</sup> that confirms the lamella's structure of V<sub>2</sub>O<sub>5</sub>. Cu-, Fe-, and Ni-doped films showed transmittances in the ranges of 36–42%, 40–56%, and 20–33%, respectively, in the visible region. Ni-doping reduced the films' band gap from 2.4 to 1.9 eV, which then increased to 2.2 eV at a 30 kGy dose. The color of Cu-, and Ni-doped films converted from red/yellow to green/blue. The influences of doping and  $\gamma$ -irradiation on the texture coefficient, absorption index, and total color difference are reported. The findings reveal that doping and irradiation can be utilized to tailor the physical properties of V<sub>2</sub>O<sub>5</sub> films for optoelectronics and dosimetry applications.

## 1. Introduction

The performance of the transition metal oxides (TMO)-based devices can be improved by thermal treatment, illumination, irradiation, defect engineering, and doping [1]. Among these approaches, doping and irradiation attracted increased attention owing to their direct and reasonable impacts on the material's properties [2–5]. One of the most interesting TMO is V<sub>2</sub>O<sub>5</sub>, which is an *n*-type semiconductor with a 3d<sup>3</sup> 4s<sup>2</sup> structure and valences in the range of V<sup>2+</sup>–V<sup>5+</sup>. It has a high O density and a band gap ( $E_g$ ) of 2.2–2.7 eV [6]. The unique electric, optoelectronic, electrochromic, and thermochromic features of V<sub>2</sub>O<sub>5</sub>, and its reasonable safety performance make it favorable for various industrial and technological applications, including IR detectors, optical and gas sensors, high-speed photoelectric switches, solar cells,

heat-reflecting mirrors, smart windows, electrochemical sensors, supercapacitors, and water splitting [7–10].

The orthorhombic  $\alpha$ -V<sub>2</sub>O<sub>5</sub> is the most thermally stable (saturated) vanadium oxide, and its lamellar structure permits the intermingling of several elements and molecular species amidst its layers through the doping process [11]. Various physicochemical approaches have been utilized for the fabrication of pure and doped V<sub>2</sub>O<sub>5</sub> with different morphologies. Depending on the synthesis route, nature, and concentration of the dopant ions, the incorporated dopants induce imperfections in the host structure and alter the electronic properties of the host due to the induced O vacancies (O<sub>v</sub>), besides the changes in V–O bond length due to the local mismatch between the dopants and the cation charges matrix [8,10]. These O<sub>v</sub> and dopants in interstitial/substitutional locations take on the roles of traps or centers of scattering and are considered the

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