Study on Structural and Optical Properties of Ta_2O_5 Nanocluster

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1 Introduction

Among the metal oxide, Tantalum pentoxide (Ta_2O_5) has been the most popular material in recent years due to its unique properties like electronic application and optical [1–5]. The Ta_2O_5 offers good chemical and thermal stability[6], high refractive index in the broad spectral, optical transmittance [7], and high k dielectric constant [8]. Due to these properties Ta_2O_5 is widely used in optoelectronic applications [9, 10], and memory devices [11, 12]. Deposition methods show an essential role in the physical properties of the Ta_2O_5 nanocluster [9, 13]. Fabrication techniques like electron beam (e-beam) evaporation incorporated with glancing angle deposition (GLAD) [14], atomic layer deposition [15], thermal oxidation [16], ion-assisted deposition[17], chemical vapor deposition, and radio-frequency (RF) magnetron sputtering [18] have been employed to create the Ta_2O_5 nanostructure. Among them, the GLAD technique provides a catalyst-free and user-friendly environment. Moreover, GLAD allows control over morphology and structure during deposition. In addition, there are very few reports on Ta_2O_5 nanostructure using the (GLAD) technique. In this study, we report a Ta_2O_5 nanoclusters' deposition on Fluorine-Doped Tin Oxide (FTO) substrate using the GLAD technique. We used field emission gun-scanning electron microscopy (FEG-SEM), X-ray diffraction (XRD), Energy-Dispersive X-ray spectroscopy (EDS), and UV-visible spectrum analysis to investigate the structural and optical features of a Ta_2O_5 nanocluster placed on an FTO substrate.

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2 Experimental

Ta_2O_5 nanocluster was fabricated on FTO substrates by an e-beam evaporation with the GLAD system (BC 300, HHV India). The proposed structure for the Ta_2O_5 nanocluster was done using Ta_2O_5 granules with a purity of ~ 99.99% as the source material. FTO substrate cleaning was performed for 3 min using isopropyl and deionized water in the ultrasonicator (KJ Group, MTI). An angle of 85° between the substrate holder and the crucible was kept. The vacuum chamber during the deposition was maintained at a pressure of 6×10^{-6} mbar. To track the thickness of the structure, a digital thickness monitor (DTM) was used.

3 Result and Discussion

3.1 Structure Analysis

As shown in Fig. 1, the XRD diffraction peaks show only for the FTO substrate, and there is no distinct peak for the Ta_2O_5 nanocluster, which indicates that the Ta_2O_5 is amorphous [19]. Meenal et al. also reported that amorphous Ta_2O_5 film was formed on an FTO substrate using the spin coating technique, which is used as a transporting layer for solar cell application [20].

FEG-SEM images show the successfully deposited Ta_2O_5 nanocluster over the FTO substrate using a GLAD technique, as shown in Fig. 2a. The deposition nanocluster was obtained with an average diameter of ~ 120 nm. Moreover, nanoclusters are attracting significant attention in a variety of fields due to their unique

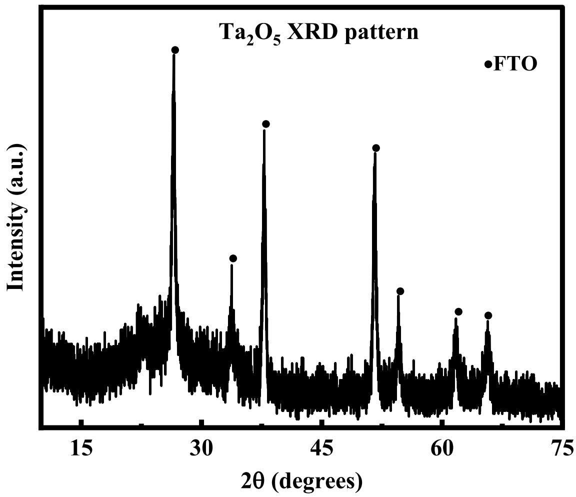

Fig. 1 XRD peaks showing FTO crystalline and amorphous Ta_2O_5

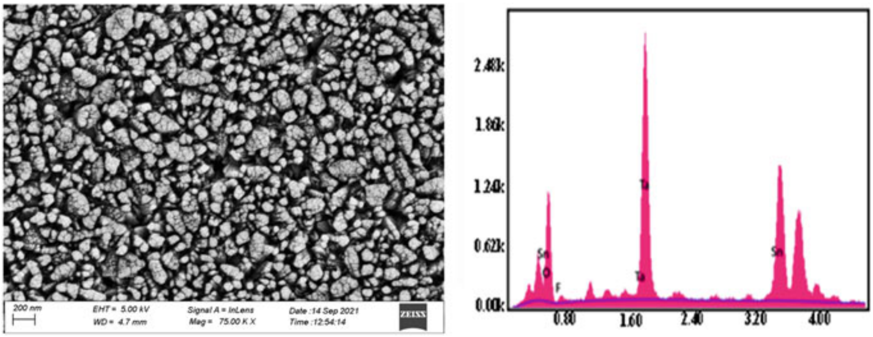

Fig. 2 **a** FE-SEM image of the Ta_2O_5 nanocluster and **b** EDS spectrum for the Ta_2O_5 nanocluster

properties, including their small size, high surface area-to-volume ratio, and optical properties [21].

EDS is a common analytical tool used to determine the elemental composition of a sample. As shown in Fig. 2b, the results of an EDS analysis on the Ta_2O_5 nanocluster showed that it is made up of only Ta, Sn, F, and O, with no other elements detected. This indicates that the sample is pure and free from impurities, which is important for understanding its properties and behavior.

3.2 Optical Analysis

The optical absorption spectrum was examined by UV-visible absorption measurement, giving a strong absorption in the UV region, as shown in Fig. 4a. Tauc plot was plotted from the obtained absorption using the relation [22], in which the bandgap was found to be 3.9 eV for the FTO substrate and 3.8 eV for the Ta_2O_5 nanocluster, as shown in Fig. 4b. These values are close to the reported optical bandgap [23, 24] (Table 1).

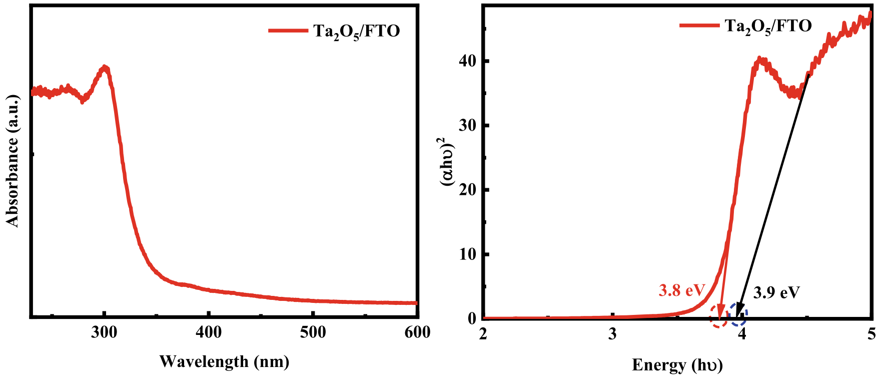

Fig. 4 **a** UV-vis absorption **b** direct band gap $(\alpha h\upsilon)^2$ versus energy (hυ)

Table 1 Comparison table with the existing structure

Material	Technique	Catalyst used
In_2O_3/TiO_2 [25]	Hydrothermal	Yes
Ta_2O_5 [26]	Hydrothermal	Yes
ZnO [27]	Pulsed laser deposition	No
This work Ta_2O_5	GLAD	No

4 Conclusion

Ta_2O_5 nanocluster was successfully deposited on an FTO substrate with the help of the GLAD, which is incorporated with the e-beam evaporator chamber. The FEG-SEM confirmed the successful growth of the nanocluster, and the amorphous nature of the Ta_2O_5 nanocluster was revealed by XRD analysis. EDS study manifests the presence of the elements Ta, Sn, F, and O without impurities during the deposition. Lastly, the absorption was found in the UV region with the obtained band gap of 3.9 eV for the FTO and 3.8 eV for the Ta_2O_5 nanocluster. From the obtained parameters, it can be concluded that the deposited Ta_2O_5 nanocluster can be helpful in developing UV light photodetector and other optoelectronics devices.

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