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Original research article

Influence of RF sputtering power on structural and optical properties of Nb_2O_5 thin films

Ateyyah M. Al-Baradi[a,*], M.M. El-Nahass[b], A.M. Hassanien[c], A.A. Atta[a,b], Mohammed S. Alqahtani[d], Abeer O. Aldawsari[a]

[a] Department of Physics, Faculty of Science, Taif University, Taif 888, Saudi Arabia
[b] Department of Physics, Faculty of Education, Ain Shams University, Roxy 11757, Cairo, Egypt
[c] Department of Physics, Faculty of Science and Humanity Studies at Al-Quwayiyah, Shaqra University, Al-Quwayiyah 11971, Saudi Arabia
[d] Department of Physics and Astronomy, King Saud University, Riyadh 11451, Saudi Arabia

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ABSTRACT

In this research, Niobium oxide (Nb_2O_5) films were deposited on glass substrates using RF sputtering technique. The effect of RF sputtering powers (150, 175 and 200 W) on the structural, and optical properties of as-deposited and annealed Nb_2O_5 thin films were examined using X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), UV–vis-NIR double beam spectrophotometer and Photoluminescence (PL) measurements. X-ray diffraction results revealed that the as-deposited and annealed films have polycrystalline structure. The optical parameters such as absorption coefficient, optical band gap energy, refractive index, dielectric constants and oscillators' parameters are estimated. The dispersion parameters are evaluated and analyzed according to a single oscillator model.

1. Introduction

Oxide semiconductor thin films are attractive materials for many important potential applications in modern technology including, Electrochromism, catalysis, batteries, solar cells and other electronic devices such as memristors [1,2]. Niobium oxide (Nb_2O_5) is one of the most attractive potential materials for electronic and optical applications [3–6]. Nb_2O_5 films have recently attracted much attention as a promising alternative material due to their remarkable potential properties such as a high refractive index, a high transparency in the UV–Vis–NIR region, a high permittivity [7,8]. Nb_2O_5 thin film are widely appropriate material for novel applications in several modern microelectronics technologies, such as optical coatings, electrochromic devices, gas sensors, catalysis, photoelectrodes, optical UV filters, high energy density capacitors, electronic gate materials and optoelectronics [7–11].

There are several methods that have been used for depositing Nb_2O_5 thin film such as DC/RF magnetron sputtering, ion beam sputtering (IBS), electron beam evaporation, thermal oxidation, photochemical vapor deposition, plasma enhanced chemical vapor deposition (PECVD), spray pyrolysis, sol-gel techniques, and pulsed laser deposition [12–24]. Furthermore, sputtering technique is known to reproduce thin films of various types of materials such as alloys, compounds, metals and especially the oxides [25,26].

Sputtering technique is best known because of its high deposition rate, uniformity, homogeneous, density, purity, adhesion, good reproducibility, provision for uniform thickness on large-area substrates and the easy access of commercially available sputtering system to deposit the thin films of high transparency and conductivity [27,28].

In the scope of the present work, we have studied the effect of RF sputtering power on structural, surface morphological and

* Corresponding author.
E-mail address: a.albaradi@tu.edu.sa (A.M. Al-Baradi).

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optical properties (refractive index, optical band gap, absorption coefficient, dielectric constants, and dispersion energy parameters) of Nb_2O_5 thin films.

2. Experimental techniques

Nb_2O_5 thin films were deposited on clean and unheated glass substrates using UNIVEX 350 SPUTTERING UNIT with RF POWER MODEL Turbo drive TD20 classic (Leybold) and thickness monitor model INFICON AQM 160. The ceramic Nb_2O_5 target was purchased from Cathey Advanced Materials Limited. The deposition parameters of Nb_2O_5 thin films are listed in Table 1. The as-prepared thin films were annealed at 773 K for 6 h in air under normal atmospheric pressure. Crystalline properties of the films were investigated using Philips X-ray diffractometer model X'Pert with CuKα (1.5406 Å) radiation operated at 40 kV and 25 mA. The patterns were recorded automatically with scanning speed of 2 deg/min. The field emission Scanning Electron Microscope (FESEM) was recorded using SEM Model Quanta 250 FEG (Field Emission Gun) attached with EDX Unit (Energy Dispersive X-ray Analyses), with accelerating voltage up to 30 KV, FEI Company, Netherlands. The film thickness (950, 1327 and 1094 nm) were determined accurately after deposition by using multiple-beam Fizeau fringes in reflection, Tolansky method [29].

Transmittance, T (λ), and reflectance, R (λ), were measured at normal incidence in the wavelength 300–2000 nm by means of a double beam spectrophotometer (JASCO model V-670 UV–vis-NIR) attached with constant angle specular reflection attachment (5°).

The absolute values of T (λ) and R (λ) can be calculated by making a correction to eliminate the absorbance and reflectance of glass substrate and given by the following equations [30]:

$$T = \left(\frac{I_{ft}}{I_g}\right)(1 - R_g) \tag{1}$$

where I_{ft} and I_g are the intensities of light passing through the film-glass system and that passing through the reference glass, respectively and R_g is the reflectance of the glass substrate, and

$$R = \left(\frac{I_{ft}}{I_m}\right)R_m\,(1 + [1 - R_g]^2) - T^2 R_g \tag{2}$$

where I_m is the intensity of light reflected from the reference mirror, I_{fr} is the intensity of light reflected from the sample and R_m is the mirror reflectance.

The optical constants (n, k) are calculated using the same equations described in Refs. [31,32]. The resultant errors for the n and k parameters were less than ± 4% (see Ref. [33]), whereas the errors in determination of the film thickness and the T (or R) parameter were estimated as ± 2% and ± 1%, respectively.

Photoluminescence (PL) measurements were carried out using FluoroMax®-4 & FluoroMax®-4P with Fluor Essence™ 4-Horiba. The continuous light source is a xenon arc lamp (150 W) and the used excitation wavelength, $\lambda_{excitation}$ = 200 nm.

3. Results and discussion

Fig. 1(a&b) shows XRD of as-deposited and annealed Nb_2O_5 thin films at different RF powers. XRD results show that the crystal structure of all films have polycrystalline structure. All films showed a strongly preferred orientation of crystallites in the (201) diffraction peaks at diffraction angle of 2θ = 37.37°. The intensity of the preferred orientation decreases gradually with increasing of RF power. This behavior indicates that both of random orientation and improve in the crystallinity increase with increasing RF

Table 1
Deposition parameters of Nb_2O_5 thin films used in this study.

Material of the Target	Nb_2O_5 (99.9 % purity)		
Substrate	glass		
Substrate temperature (K)	300		
Target substrate distance and angle	10 cm with an angle 65°		
Pure Argon flow rate (sccm)	20 cm^3/min		
substrate rotation	10 rpm		
Target Size	3 in. h diameter × 5 mm thickness		
Base pressure (Torr)	2×10^{-6}		
Sputtering pressure ($P_{chamber}$)	2×10^{-2} mbar		
RF Sputtering Power (Watt)	150	Deposition Time	5 h
		Film Thickness	950 nm
		Deposition Rate	3.17 nm/min
	175	Deposition Time	5.8 h
		Film Thickness	1327 nm
		Deposition Rate	3.81 nm/min
	200	Deposition Time	3.75 h
		Film Thickness	1094 nm
		Deposition Rate	4.86 nm/min