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Low reflectance sputtered vanadium oxide thin films on silicon

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HIGHLIGHTS

- V_2O_5 (major phase) thin films of thickness ~21 nm to ~211 nm developed on Si.
- Low (~1–2%) interference minima in reflectance spectra recorded at UV–VIS region.
- Almost constant and linear reflectance behavior observed at NIR region.
- Refractive index of V_2O_5 on Si estimated as 2.9–3.27.
- Extinction coefficient decreases as increase in thickness of the film.

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ABSTRACT

Vanadium oxide thin films on silicon (Si) substrate are grown by pulsed radio frequency (RF) magnetron sputtering technique at RF power in the range of 100–700 W at room temperature. Deposited thin films are characterized by field emission scanning electron microscopy (FESEM), X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) techniques to investigate microstructural, phase, electronic structure and oxide state characteristics. The reflectance and transmittance spectra of the films and the Si substrate are recorded at the solar region (200–2300 nm) of the spectral window. Substantial reduction in reflectance and increase in transmittance is observed for the films grown beyond 200 W. Further, optical constants viz. absorption coefficient, refractive index and extinction coefficient of the deposited vanadium oxide films are evaluated.

1. Introduction

The fascinating characteristic of vanadium oxide films leads researchers to concentrate in continual way for its futuristic applications, viz. optical applications e.g., optical switching and optical shutter, in both electrochromic and thermochromic devices [1,2], electronic device applications e.g., cathode material for lithium ion batteries, un-cooled IR imaging [2,3], supercapacitors [4], Mott transition field effect transistors [5], energy related device applications [6], space applications e.g., IR detectors [7] and variable emittance coating [8,9]. Further, V^{2+}, V^{3+}, V^{4+}, V^{5+}, etc. oxide states of vanadium (except V_7O_{13}), shows smart transition behavior as a function of temperature or voltage. However, smart or reversible phase transition of V_2O_5 is still debatable issue [10] though the reversible phase transitions of V_2O_5 thin films/layers are experimentally observed by three groups [9,11,12] including the present authors [9].

Further, Si is considered most important substrate material for state of art and futuristic electronic, functional and energy harvesting device applications [13]. Recently, Debari and Ezzaouia [14] have reported the novel antireflection property of V_2O_5 coating on Si substrate while the total reflectivity of the V_2O_5 /Si reduces to about ~9% as compared to the bare Si substrate in the 300–500 nm wavelength region. Thus the V_2O_5 coating assists to increase the efficiency of solar cell. Additionally they [15] showed the enhancement of surface passivation property by the application of V_2O_5 on Si. However, the scarcities of the reports are found in particular with the optical properties of V_2O_5/Si system [14–16] though the systematic and in-depth studies on optical properties of V_2O_5 are available on transparent glass and quartz substrates [9,12,13,16].

The Si based antireflection technologies consists of self surface texturing e.g., nanotexturing, porous surface, etc. [17–20], coating of oxides and nitrides viz., SiO_2, TiO_2, Al_2O_3, Si_3N_4, etc. on Si as

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single layer (SLAR) [21], double layer (DLAR) [21,22] and multilayer (MLAR) [23–25] antireflection and combinations of texturing along with suitable ceramic coatings [26,27]. Porous Si based antireflection technology shows nearly zero reflectance, however it suffers from high surface recombination effect [18,19]. To overcome this issue, an additional passivating layer is devised [18,19]. Further, SLAR coatings exhibits low reflectance property at only for selected optical spectrum due to the interference effect where as DLAR coatings possesses linear antireflection property almost for entire visible spectrum [22]. In order to obtain very low reflectance in entire solar spectrum; researchers propose stacking of several antireflection layers. However, this technology offers enhance in manufacturing cost and complication too. Further, the selection criteria of suitable antireflective coating materials are stringent as it requires both desired optical properties as well as surface passivation behavior [21]. Thus, many of the aforesaid Si based antireflection techniques for the energy harvesting applications are not utilized effectively.

Therefore, in the present work, the development of low reflectance and passivating ceramic coating i.e., vanadium oxide on Si substrate is attempted toward futuristic high efficiency Si based solar cell application. We have studied in-depth optical properties such as solar reflectance and transmittance behaviors as well as optical constants viz. absorption coefficient, refractive index and extinction coefficient of vanadium oxide films grown on Si substrate sputtered at RF power of 100–700 W.

2. Materials and methods

Vanadium oxide thin films were deposited on Si substrate utilizing pulsed RF magnetron sputtering system (SD20, Scientific Vacuum Systems, UK) at room temperature. V_2O_5 target with 99.999% purity; dimension of 200 mm diameter and thickness of 3 mm (Vin Karola Instruments, USA) was used in the present development. A copper backup plate of the same dimension was firmly boned with the V_2O_5 target. The target and the substrate were kept at 140 mm constant distance. During the film deposition the duration of deposition time was kept constant as 1 h. while the RF power was varied from 100 W to 700 W with an increment of 100 W. The pulse cycle was set at 100 Hz and the duty cycle was 57%. The deposition chamber was evacuated to a pressure of 5×10^{-6} mbar prior to deposition procedure and the working pressure was set at 1.5×10^{-2} mbar by supplying ultra high pure argon gas (~99.9998%, Praxair, India).

Table 1
Thickness and corresponding RF power of V_2O_5 films grown on Si substrate.

RF Power (W)	Film thickness (nm)
100	21 ± 5
200	36 ± 7
300	90 ± 5
400	133 ± 3
500	156 ± 11
600	202 ± 10
700	211 ± 15

Thicknesses of the deposited film was measured using a nanoprofilometer (Nanomap 500 LS 3D, USA). The surface morphology and elemental composition of the vanadium oxide films were characterized by FESEM (Supra VP40 Carl Zeiss, Germany) and energy dispersive X-ray (EDX: X-Max, USA), respectively. XRD (X'pert Pro, Philips, The Netherlands) technique is used to analyze phases of the deposited film with Cu $K_{\alpha1}$ radiation, at glancing incident angle of 2° and with a very slow step size of 0.03°. SPECS spectrometer using non-monochromatic Al Kα radiation (1486.6 eV) X-ray source used to perform XPS of deposited films on Si substrate, spectrum recorded with run at 150 W (12 kV, 12.5 mA). Pass energy of 70 eV with step increment of 0.5 eV used to obtain the survey spectra and pass energy 25 eV and step increment of 0.05 eV used for individual spectra. CasaXPS program employed to curve fit V2p–O1s core level spectra and its components with Gaussian–Lorentzian peaks subsequent to Shirley background subtraction.

The reflectance and transmittance spectra of the deposited vanadium oxide films on Si and bare Si substrate were recorded by the UV–VIS–NIR spectrophotometer (Cary 5000, Agilent Technologies, USA) in the range of 200 to 2300 nm of spectral window. Further, the absorption coefficient (α) of the vanadium oxide films on Si was calculated from the transmittance data obtained from UV–VIS–NIR spectrophotometer from the following relation (1). [9]

$$\alpha = \frac{In(T)}{t} \tag{1}$$

where T is the transmittance and t is known as thickness of the film.

Refractive index (n) of the deposited film was determined by using usual method from the reflectance spectra [28,29]. The conventional relation (2) was employed to evaluate extinction coefficient [30]

$$k = \alpha\lambda/4\pi \tag{2}$$

where k is the extinction coefficient and λ is the wavelength.

3. Results and discussion

The thicknesses of the films are summarized in Table 1. As expected, the thickness increases with increase in the sputtering power. At constant deposition duration (i.e., 1 h.); the increase in RF power directs to increase sputtering yield which ultimately results increase in film thickness.

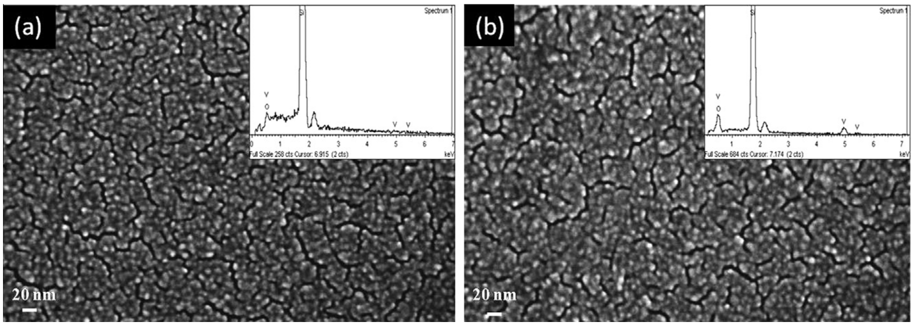

Fig. 1. Typical FESEM images of deposited vanadium oxide film on Si substrate grown at (a) 100 W and (b) 400 W (the corresponding EDX spectra are in the insets).