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Opera suspicionată (OS) Suspicious work	Opera autentică (OA) Authentic work

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OA	STAMATE, D.M. On the non-linear I-V characteristics of dc magnetron sputtered TiO2 thin films. *Applied Surface Science*, 205. 2003. 353-357.

Incidenţa minimă a suspiciunii / Minimum incidence of suspicion	
p.218:03 – p.218:27	p.353:03d – p.354:25s
p.219: Fig.1	p.354: Fig.1
p.219: Fig.2	p.354: Fig.2

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On the non-linear *I–V* characteristics of dc magnetron sputtered TiO_2 thin films

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Abstract

In this paper, we have studied the static current–voltage characteristics for TiO_2 thin films deposited by a dc magnetron sputtered method. We have studied the non-linear characteristics for TiO_2 films prepared in sandwich structures (aluminum–TiO_2–aluminum), on microscopic slide glass. We have found that the trap density is lower for films with larger thicknesses. We have calculated the carrier effective mass and the high of the barrier potential at an aluminum–TiO_2 interface and we found that the TiO_2 films are corresponding to an anatase polycrystalline structure of TiO_2 films.

PACS: 73.40Sw; 7350.Fq

Keywords: Thin films; Magnetron; TiO_2; dc electrical properties; Magnetron sputtering; TiO_2 thin films

1. Introduction

Titanium dioxide has been one of the most extensively studied oxides because of its remarkable optical and electronic properties [1,2]. Lately, much attention has been paid to films, which are required for technological applications such as the photo-decomposition of water [3] environmental pollutant [4] and antireflection coatings. Titanium oxide may also be used as a thin film capacitor because of its high dielectric constant. The present work deals with the non-linear current–voltage characteristics of TiO_2 thin films in order to obtain a rapidly describing for the trap density and is motivated by the distinct properties of TiO_2 phases. A better knowledge of these differences should be beneficial to further exploitation of the electrical and optical properties of TiO_2 thin films, particularly in optoelectronics devices.

2. Experimental details

TiO_2 thin films were prepared by a dc magnetron sputtering method in a home built magnetron installation [6]. The vacuum chamber was an 80 l volume stainless steel chamber; a circular magnetron with a 60-mm diameter erosion zone was used as the cathode. The discharge characteristics have been controlled using a variable dc power supply (3 kV and 500 mA). Pure titanium (99.95%) of 130-mm diameter and 3 mm thickness has been used as a sputtering target. Pure argon (4 N) and oxygen were used as the sputtering and reactive gases, respectively. The gases were mixed prior the admission in the sputtering

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chamber at proportion 75% argon and 25% oxygen. The target–substrate distance was 35 mm. The sputtering pressure was maintained at 2×10^{-3} Torr. Prior the deposition the target was well cleaned in order to remove the surface oxide layer. The substrate temperature was held at 300 °C by using a quartz halogen lamp whose power was controlled by varying the input voltage. Titanium oxide films were deposited on vacuum evaporated aluminum bottom electrode made on a well-cleaned microscope glass slide ($75 \times 25 \times 1$). The deposition time was chosen in order to obtain films of several thicknesses and the sputtering power was about 110 W (200 mA × 550 V), that is corresponding to a power density of 1.25 W/cm^2. The top electrode was vacuum evaporated aluminum. The thickness of the films has been determinated by using a multiple beam interferometry method to an accuracy of ±10 nm. The aluminum thickness was about 2 μm. The area of the metal–TiO_2 –metal surface was about 10 mm^2.

The structure of the films was examined by using X-ray diffraction with Cu Kα radiation in a standard X-ray diffractometer. The *I–V* static characteristic was recorded by an X–Y recorder with voltage and current as inputs.

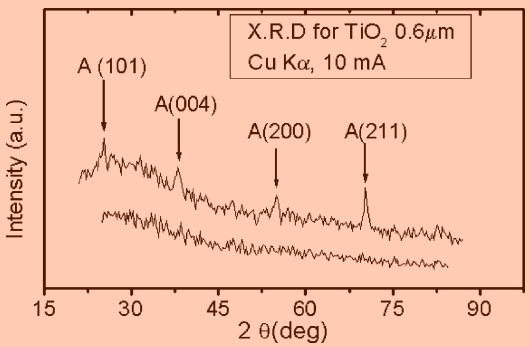

Fig. 1. The X-ray diffraction spectra for TiO_2 as deposited and annealed at 500 °C.

3. Experimental results and discussion

TiO_2 thin films deposited in the dc magnetron sputtering system were amorphous and X-ray diffraction analysis proved that the crystalline diffraction peaks corresponding to the anatase crystalline phase of titanium dioxide appear only for films that are annealed at a temperature greater than 500 °C. The heating and cooling rate were kept symmetrically at a value of about 5 °C/min. In Fig. 1, it is shown the X-ray diffraction for TiO_2 films as deposited and after annealed. The X-ray diffraction peaks are revealed only for annealed films.

We have studied the *I–V* characteristics for different TiO_2 film thicknesses in aluminum– TiO_2–aluminum structures that are shown in Fig. 2. The experimental results shown that the *I–V* characteristics are symmetrically, in Fig. 2 being represented only the positive polarity part. We notice that the *I–V* characteristics are highly non-linear. The *I–V* characteristic analysis was carried up by a method of decomposition within three

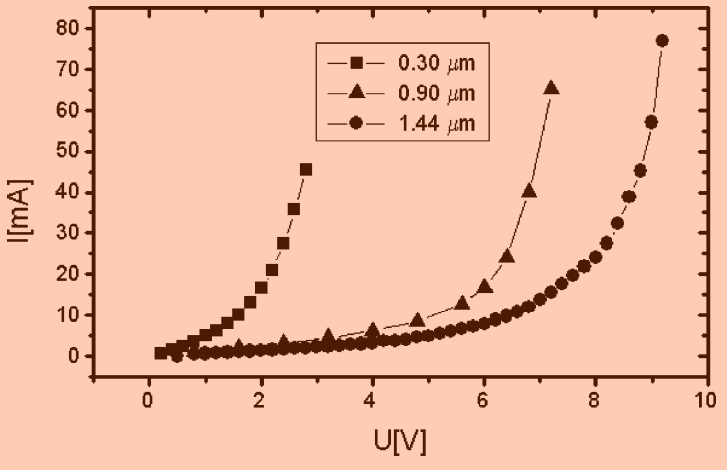

Fig. 2. *I–V* characteristics for different thicknesses TiO_2 thin films.

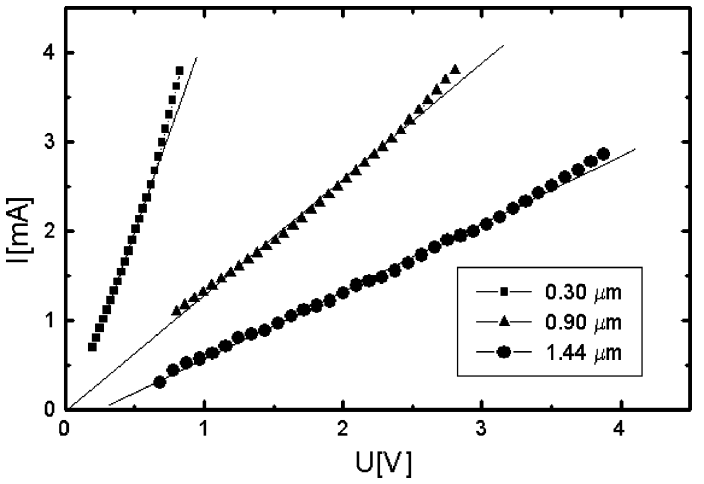

Fig. 3. Linear dependence region of electric current vs. voltage for TiO_2 thin films.

regions. Each of these regions is corresponding to a specific carrier conduction mechanism.

In Fig. 3, it is shown the linear region of the current–voltage dependencies. The linear domain boundaries present a slightly thicknesses dependence. The ohmic or linear region of current–voltage is involved only for electric fields lower than 20–30 kV/cm. Over these values of the electric fields the non-linear dependencies for current versus voltage occurs.

In Fig. 4, the features of the second domain for current–voltage characteristics are shown where it is revealed a dependence by the square voltage for dc electrical current ($I = f(U^2)$).

From Fig. 4, it is revealed that the experimental results fit very well a dependence that is corresponding to a space charge limited current conduction mechanism [5]:

$$j = \frac{9}{8}\frac{\mu\varepsilon_r\varepsilon_0}{d^3}\frac{N_c}{N_t}\left[\exp\left(-\frac{E_t}{kT}\right)\right]U^2 \quad (1)$$

where d is the distance between electrodes, μ the carrier mobility, ε_r the relative dielectric constant, ε_0

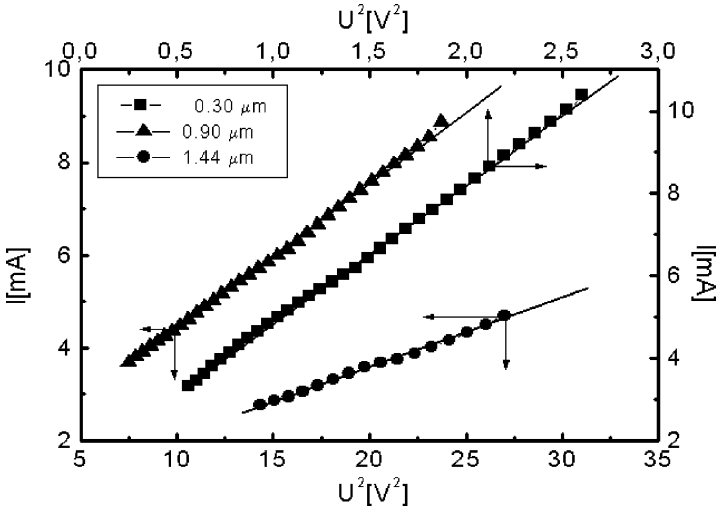

Fig. 4. I–V^2 characteristics for different TiO_2 thicknesses.

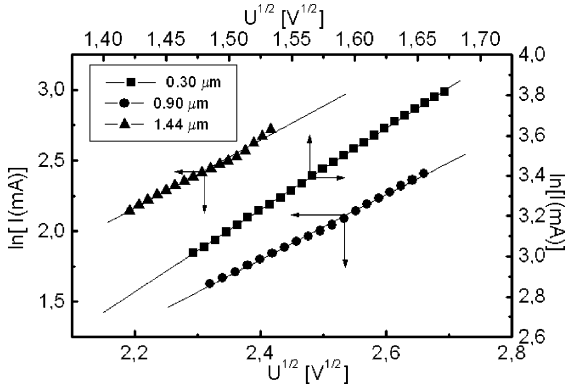

Fig. 5. Logarithmic characteristic $\ln I = f(U^{1/2})$ of TiO_2 thin films.

the vacuum permitivity, N_c the effective state density in the conduction band, N_t the trap density located in the forbidden band at the level E_t, and k is the Boltzmann's constant.

From Fig. 4, we notice that the films with smaller thickness reveal a larger value for slope that suggests that there is a variation with the thickness for the trap density in films. We notice that the trap density is lower for films with larger thicknesses. This behavior may be explained by a better crystallinity for films with larger thicknesses.

In Fig. 5, it is shown the third domain for the current–voltage characteristics for TiO_2 thin films prepared by a dc magnetron sputtering method. There is revealed that for some particular's values of the electric fields the carrier conduction mechanism is changed from one that is corresponding to a space charge limited current conduction mechanism to a trapping conduction mechanism. This type of carrier conduction mechanism is very well described by the Schottky theory [5], and is characterized by the Richardson–Schottky law:

$$J = AT^2 \left[\exp\left(-\frac{\Phi_0}{kT}\right)\right] \exp\left[\frac{1}{kT}\left(\frac{e^3 U}{4\pi\varepsilon_r\varepsilon_0 d}\right)^{1/2}\right] \quad (2)$$

where Φ_0 is the extraction work function at the metal–semiconductor interface, and A is the Richardson–Dushmann expression [5]:

$$A = \frac{4\pi m_e e k^2}{h^3} \quad (3)$$

Table 1
The TiO_2 carrier effective mass and the high of potential barrier

	Thickness of TiO_2 thin films		
	0.30 μm	0.90 μm	1.44 μm
E_k (kV/cm)	53.8	52.6	36.6
m_e	$1.26m_0$	$1.22m_0$	$0.71m_0$
Φ_0 (eV)	1.5909	1.5948	1.5958

From I–V characteristic's, we have evaluated the carrier effective mass upon a method proposed by Vodenicharov [5]. According to Vodenicharov, the carrier effective mass may be calculated from the current–voltage characteristics domain that is corresponding to a transition in carrier conduction mechanism using Eq. (4):

$$m_e = \left[\frac{h(e\varepsilon_r\varepsilon_0)^{1/4}}{1.76\pi^2 kT}\right]^2 E_k^{3/2} \quad (4)$$

where h is the Planck constant, e the elementary charge, ε_r the dielectric constant at low frequency calculated elsewhere [6], k the Boltzmann constant, T the absolute temperature, and E_k is the electric field intensity that is corresponding to the transition in conduction mechanism point. From extrapolation of the data from Fig. 5 ($\ln I = f(U^{1/2})$) for $U = 0$ V, we have obtained the value of the potential barrier high. In Table 1, the calculated values for the carrier effective mass and barrier potential high for TiO_2 thin films prepared by a dc magnetron deposition method are shown.

The values that have been calculated for carrier effective mass and the high of the potential are consistent to those reported in literature [7,8].

As for as the carrier effective mass the values obtained in this paper are very closed with the data reported by Tang et al. [9], and are corresponding to anatase polycrystalline structure of TiO_2 films.

4. Conclusion

We have analyzed the non-linear I–V characteristics of dc magnetron deposited TiO_2 thin films. We found that there are some transitions that occur in carrier conduction mechanism from a linear or ohmic regime to a trapping and Schottky conduction mechanism. We have found that the trap density is lower for films with

larger thicknesses. We have calculated the carrier effective mass and the high of the barrier potential at an aluminum–TiO_2 interface and we found that the TiO_2 films are corresponding to anatase polycrystalline structure of TiO_2 films.

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