Rare Metal Materials and Engineering
Volume 46, Issue 10, October 2017
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: Rare Metal Materials and Engineering, 2017, 46(10): 2781-2784.

ARTICLE

Preparation and Photoelectric Properties of Metal-Semiconductor-Metal TiO_2 Ultraviolet Detectors

Qi Hongfei, Dai Songyan, Liu Dabo, Wang Jinpeng

Beijing Institute of Aeronautical Materials, Beijing 100095, China

Abstract: Anatase TiO_2 thin films were grown on quartz substrates by RF magnetron sputtering. Metal-semiconductor-metal (MSM) detectors with Ag IDT electrodes were then fabricated. The measurement of the *I-V* characteristics for the detectors shows good ohmic contact. Results indicate that the thickness of TiO_2 layer has an obvious effect on the photoelectronic properties. When TiO_2 film thickness is 197 nm, the photocurrent is nearly 2.5 orders of magnitude higher than the dark current and the photoresponse in ultraviolet region is nearly 2 orders of magnitude higher than in visible light region. The high sensitivity and visible blind properties of the obtained devices indicate their potential application as UV detectors with high efficiency and low cost.

Key words: Ag electrodes; TiO_2 films; film thickness; photoelectronic property

Recently, ultraviolet (UV) detectors play an essential role in a wide range of civil and military applications including ozone layer monitoring, flame detection, air quality monitoring, space communications, and missile plume detection[1]. Particularly, with the development of the electronic warfare technology and stealth technique, UV detectors are increasingly indispensable components in missile warning systems. The most common detectors currently in use are the photomultipliers and the silicon photodetectors, but they are not blind and require costly filters to attenuate unwanted radiation. In the past years, the UV detectors based on wide band-gap semiconductors, such as AlGaN[2], GaN[3], SiC[4] and ZnO[5], have been fabricated and investigated. However, these semiconductor-based UV detectors have a common inevitable drawback in the difficulty to control the crystal quality of semiconductor films despite their evident advantages in the enhancement of responsivity.

TiO_2 is one of the most attractive metal oxides have been proposed for a wide range of uses, including solar energy conversion[6], hydrogen storage[7], and environmental pollution remediation[8], due to its wide direct bandgap energy of 3.2 eV at room temperature. Moreover, the preparation methods of TiO_2 thin films are simple, low-cost, and widely accessible[9]. High-quality TiO_2 thin films can be easily obtained by traditional magnetron sputtering techniques [10]. Therefore, highly photoelectric characteristics would be possible when the UV detectors based on TiO_2 are realized.

However, there were few articles dealt with the fabrication of TiO_2-based UV detectors, and none focused on the photoelectric characteristics varying with the thickness of the TiO_2 thin films. In this study, we reported TiO_2 photoconductive UV detector based on a metal- semiconductor-metal (MSM) structure. The dependence of photoelectric characteristics on the thickness of the TiO_2 thin films was also investigated.

1 Experiment

TiO_2 thin films were deposited by radio frequency (RF) sputtering equipment which has a base pressure of 5.0×10^{-4} Pa. Quartz substrates with the size of 10×10 mm^2 were placed on the sample holder which is parallel to the 99.99% Φ60 mm Ti target. Prior to deposition, the substrates were ultrasonically cleaned with acetone, absolute ethyl alcohol, and de-ionized water, separately. Before the films were deposited, Ti target was presputtered by argon ion for 3 min to weed out the surface oxide. The pressure of the mixture gas

Received date: September 4, 2016
Foundation item: Innovation Foundation of Aviation Industry Corporation of China (JK65150307)
Corresponding author: Qi Hongfei, Ph. D., Senior Engineer, Department of Steel and Rare-Noble Metals, Beijing Institute of Aeronautical Materials, Beijing 100095, P. R. China, Tel: 0086-10-62496842, E-mail: qhfei@sina.com

of O_2 and Ar was kept at 2 Pa during the growth of TiO_2 thin films with the O_2 flow rate of 50 mL/min and Ar flow rate 25 mL/min. TiO_2 thin film with different thicknesses, including 103, 152, 197, 221, and 253 nm, was obtained through varying sputtering time. Subsequently, the samples were annealing at 500 ℃ for 2 h.

Fig.1 shows the schematic full view of TiO_2 UV detector. Ag planar interdigital (IDT) electrodes with thickness of 20 nm were fabricated on the TiO_2 layers by optical photolithography. There are 16 fingers in the IDT structure, 8 up and 8 down. The Ag fingers are 20 μm in wide and 8 mm in long, with a 20 μm in gap.

The crystal quality of TiO_2 thin film was characterized by X-ray diffractometer (PW3040, Philips) where Cu Kα source was used. Photocurrent and darkcurrent of the fabricated detectors were then measured by an HP4145B semiconductor parameter analyzer at room temperature. UV spectral response was also measured under photo-irradiation from the (IDT) electrodes using a light source (Oriel Optical System) which employed a 250 W xenon arc lamp and a monochromator covering the range of 280~400 nm.

2 Results and Discussion

2.1 Effect of thin film thickness on photoelectronic property

Fig.2 shows *I-V* characteristics of the fabricated TiO_2 MSM detectors with various thicknesses of TiO_2 layer measured under illumination (365 nm). When light impinges onto the MSM UV detector, high-energy photons will be absorbed by the TiO_2 film layer. With a certain bias voltage, photon-generated carriers drift toward the contact electrodes and a photocurrent is observed. It shows a basically linear *I-V* dependence indicating a good ohmic behavior of the obtained MSM structure.

Fig.3 shows effect of the film thickness on photocurrent of TiO_2 UV detector. In Fig.3, it can be seen that the thickness of the TiO_2 layer significantly influences the photocurrent of the detector. This change trend is well observed in Fig.3. With the increase of film thickness, the photocurrent increases quickly and then decreases gradually. The

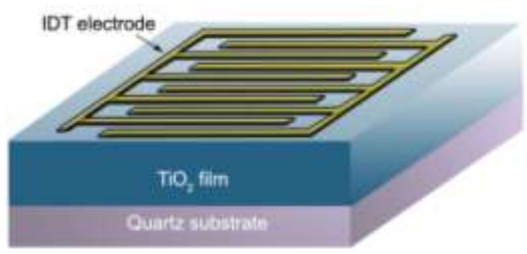

Fig.1 Schematic illustration of MSM-type TiO_2 UV detector

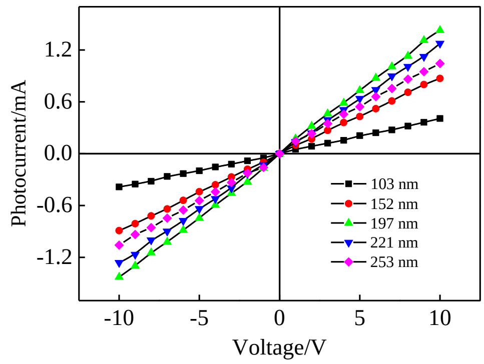

Fig.2 *I-V* characteristics of TiO_2 UV detector with different thickness of TiO_2 layer

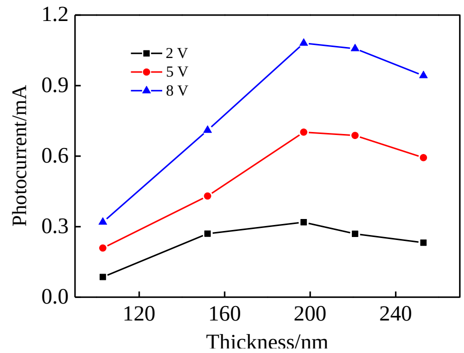

Fig.3 Effect of the film thickness on photocurrent of the TiO_2 UV detector at different bias voltages

sample with a film thickness of 197 nm reveals the highest photocurrent. In addition, similar results can be obtained at different bias voltage including 2, 5, and 8 V, which shows the generality of the results.

Fig.4 shows X-ray diffraction (XRD) patterns of TiO_2 thin films prepared on quartz substrates. The peaks identified comparing with JCPDS file for TiO_2 correspond to anatase TiO_2 (101), (004), (200), (105), and (211) plane refection; what's more, the thin films exhibit a strong (101) orientation. It must be pointed out that characteristic peaks of anatase TiO_2 are gradually strengthened with the increase of film thickness, which indicates that both the grain size and the degree of crystallinity increase with the increase of the film thickness.

In fact, when the TiO_2 thin films are illuminated by a photon with energy greater than the band gap energy of the films, an electro-hole pair is created. Such pairs can play as photocurrent, and be used in a circle and generate an electrical current. The increase of the grain size and the degree of crystallinity may promote the migration of the photo-generated holes toward the surface of TiO_2 film. This behavior increases the photocurrent of the detector due

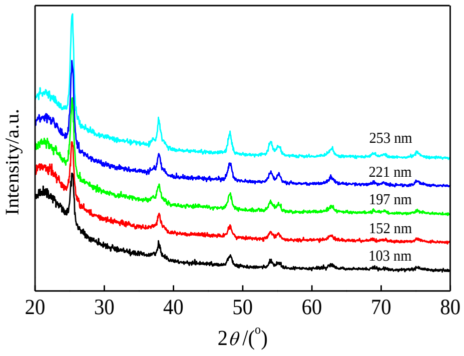

Fig. 4 X-ray diffraction patterns of the TiO_2 thin films with different thickness

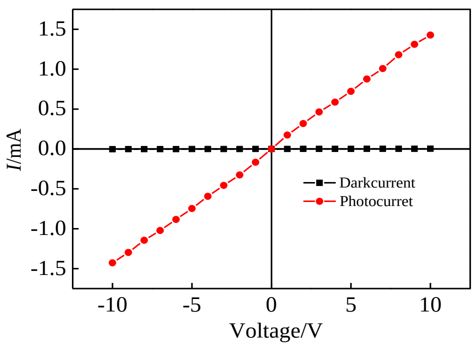

Fig. 5 Dark and UV-365 nm illuminated *I-V* curves of the TiO_2 detector

to the decrease of the carrier loss. However, the influence of the penetration depth of UV light on the TiO_2 film also should be taken into account. The threshold value corresponds to the depth where the absorption of UV light in the films becomes so strong that no obvious number of electron-hole pairs can be produced. In this case, the diffusion length of photon-generated carriers increases with increasing the film thickness and the possibility of charge carriers to reach the surface of the film before recombination is too small[11]. Therefore, it is thought that the thickness value around 197 nm corresponds to the penetration depth.

When the film thickness is less than 197 nm, both the degree of crystallinity and the number of electron-hole pairs increase with the increase of the film thickness, which contribute to the enhancement of the photocurrent. However, when the film thickness is beyond 197 nm, the recombination of charge carrier may be major influencing factors on the photoelectronic properties of the detector. This decreases the photocurrent with the film thickness further increasing.

2.2 Photoelectronic property of detector

The UV detector with a TiO_2 layer thickness of 197 nm has the highest photocurrents, and its photoelectronic properties have been measured detailedly. The dark and 365 nm UV light illuminated *I-V* characteristics of the detector are shown in Fig.5. Linear *I-V* curves show that this is a photoconductive UV detector. The dark current at 5 V bias voltage is 1.45 μA. The photocurrent upon 365 nm UV light illumination is 0.72 mA at 5 V bias voltage, which nearly 2.5 orders of magnitude higher than the dark current. This result indicates that the obtained TiO_2 UV detector has a significant light sensitivity.

The spectral photoresponse of the TiO_2 UV detector under 5 V bias voltage is shown in Fig. 6. The maximum UV photoresponse is found in a wavelength range from 240 nm to 330 nm, with a cut-off wavelength at 360 nm. It is observed that some absorption start at around 380 nm and

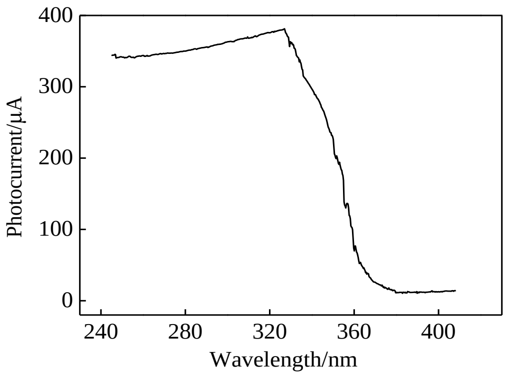

Fig. 6 Spectral photoresponse of the TiO_2 UV detector at 5 V bias voltage

continue to grow up to 410 nm. It is thought the carriers from the deep-level traps within the band-gap, were excited by the incident light having energy less than the band-gap[12]. In addition, the photoresponse in ultraviolet region is nearly 2 orders of magnitude higher than in visible light region, which reveals high UV light sensitivity of TiO_2 thin films for solar-blind UV detector applications.

3 Conclusions

1) TiO_2 thin films are grown on quartz substrates by RF magnetron sputtering. UV light sensitivity MSM detectors with Ag IDT electrodes are then obtained.

2) *I-V* characteristic of the detectors is linear under dark or 365 nm UV light illumination. The thickness of TiO_2 layer has an obvious effect on the photoelectronic properties of the obtained detector. For a given 5 V applied bias voltage, the photocurrent is nearly 2.5 orders of magnitude higher than the dark current and the photoresponse in ultraviolet region is nearly 2 orders of magnitude higher than in visible light region.

References

1 Kar J P, Das S N, Choi J H *et al*. *Journal of Crystal Growth*[J], 2009, 311: 3305

2 Lee I H. *Physica Status Solidi A*[J], 2002, 192: R4

3 Kang Y, Xu Y, Zhao D *et al*. *Solid-State Electronics*[J], 2005, 49: 1135

4 Borchi E, Macii R, Bruzzi M *et al*. *Nuclear Instruments and Methods in Physics Research Section A*[J], 2011, 658: 121

5 Kim J, Yun J H, Jee S W *et al*. *Materials Letters*[J], 2011, 65: 786

6 Bougheloum C, Messalhi A. *Physics Procedia*[J], 2009, 2: 1055

7 Nazeeruddin M K, Grätzel M. *Comprehensive Coordination Chemistry II*[J], 2003, 9: 719

8 Zhang L, Li L, Mou Z *et al*. *Procedia Engineering*[J], 2012, 27: 552

9 Mahajan L H, Mhaske S T. *Materials Letters*[J], 2012, 68: 183

10 Meng F, Song X, Sun Z. *Vacuum*[J], 2009, 83: 1147

11 Tada H, Tanaka M. *Langmuir*[J], 1997, 13: 360

12 Basak D, Amin G, Mallik B *et al*. *Journal of Crystal Growth*[J], 2003, 256: 73

MSM 结构 TiO_2 基紫外探测器的制备及光电特性研究

祁洪飞，戴松嵒，刘大博，王锦鹏

(北京航空材料研究院，北京 100095)

摘　要：采用RF磁控溅射技术在石英衬底上生长了厚度可调的锐钛矿相TiO_2薄膜，继而采用光刻技术在薄膜上生长了Ag叉指电极，获得了MSM结构TiO_2基紫外探测器。*I-V*特性测试结果表明, Ag与TiO_2之间表现出优良的欧姆接触特性，所制备探测器为欧姆接触。此外，TiO_2薄膜厚度对探测器的光电性能影响显著，当薄膜厚度达到197 nm时，光电性能达到最高。此时，光电流高出暗电流近2.5个数量级，紫外光区的响应度高出可见光区近2个数量级。所制备Ag/TiO_2MSM紫外探测器表现出明显的光敏性和可见盲特性。

关键词：Ag 电极；TiO_2 薄膜；薄膜厚度；光电特性

作者简介：祁洪飞，男，1978 年生，博士，高级工程师，北京航空材料研究院钢与稀贵金属研究所，北京 100095，电话：010-62496842，E-mail: qhfei@sina.com