THE FABRICATION AND CHARACTERIZATION OF TiO_2 UV DETECTOR

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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. It was found that the thickness of TiO_2 layer had 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.

1 Introduction

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 a few 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 report 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 is also investigated.

2 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% (4N) Φ60mm Ti target. Prior to deposition, the substrates were ultrasonically cleaned with acetone, absolute ethyl alcohol, and de-ionized water, respectively. 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 of O_2 and Ar is kept at 2 Pa during the growth of TiO_2 thin films with the O_2 flow rate of 50 sccm and Ar flow rate 25 sccm. TiO_2 thin film with different thicknesses, including 103 nm, 152nm, 197 nm, 221 nm, and 253 nm, was obtained through varying sputtering time. Subsequently, the samples were annealing at 500℃ for 2h.

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 wide and 8 mm long, with a 20 μm gap.

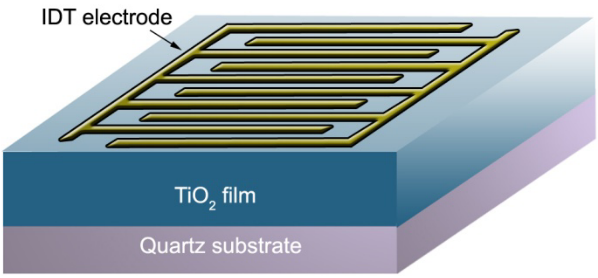

Fig. 1 Schematic illustration of MSM-type TiO_2 UV detector

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 250W xenon arc lamp and a monochromator covering the range of 280-400 nm.

3 Results and Discussion

3.1 Effect of Thin Film Thickness on Photoelectronic Property

Fig. 2 shows the I-V characteristics of the fabricated TiO_2 MSM detectors with various thickness 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 will drift toward the contact electrodes and a photocurrent will be observed. It shows a basically linear I-V dependence indicating a good ohmic behavior of the obtained MSM structure.

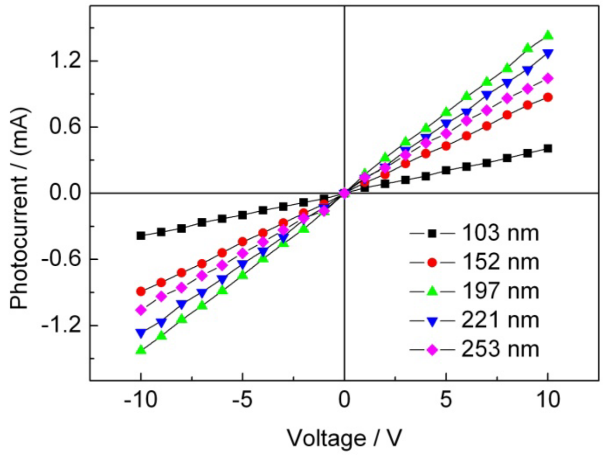

Fig. 2 I-V characteristics of TiO_2 UV detector with different thickness of TiO_2 layer

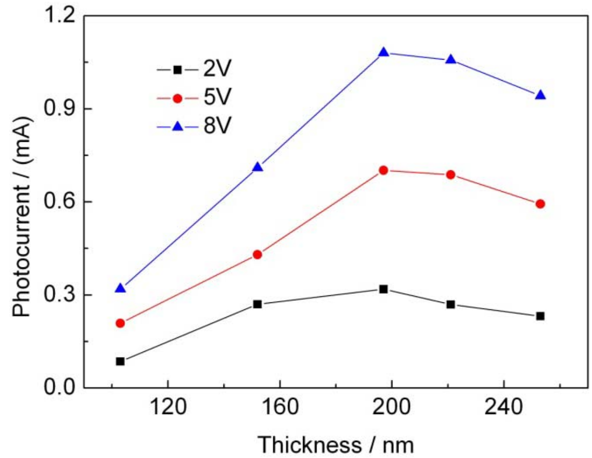

Fig. 3 Effect of film thickness on photocurrent of TiO_2 UV detector

In Fig. 2, 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 increase quickly then decrease gradually. The sample with a film thickness of 197 nm reveals highest photocurrent. In addition, similar results can be obtained under different bias voltage including of 2V, 5V, and 8V, which shows the generality of the results.

Fig. 4 shows X- ray diffract ion pattern 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 exhibited 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.

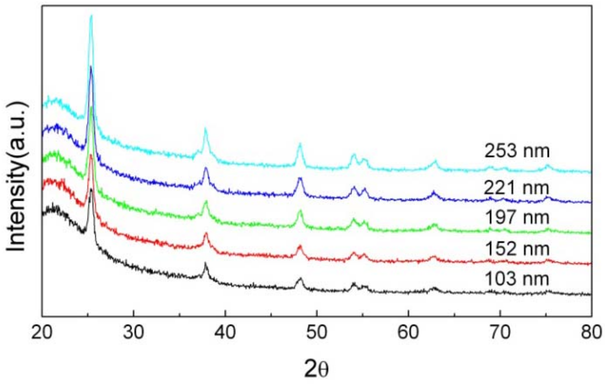

Fig. 4 X- ray diffraction pattern of TiO_2 thin films with different thickness

Under the UV illumination, electron-hole pairs are created, and 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 leads to the increase of the photocurrent of the detector due 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 charge carriers′ chance to reach the surface of the film before recombination occurs is too low [11]. Therefore, it is thought that the thickness value around 197 nm corresponds to the penetration depth.

When the film thickness 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 beyond 197 nm, the recombination of charge carrier may be major influencing factors on the photoelectronic properties of the detector. This leads to the decrease of the photocurrent with the film thickness further increasing.

3.2 Photoelectronic Property of Detector

The UV detector with a TiO_2 layer thickness is 197 nm has the highest photocurrents, and its photoelectronic properties has 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 5V bias is 1.45 μA. The photocurrent upon 365 nm UV light illumination is 0.72 mA at 5V bias, which is nearly 2.5 orders of magnitude higher than the dark current. This result indicates that the obtained TiO_2 UV detector has the characteristic of high sensitivity.

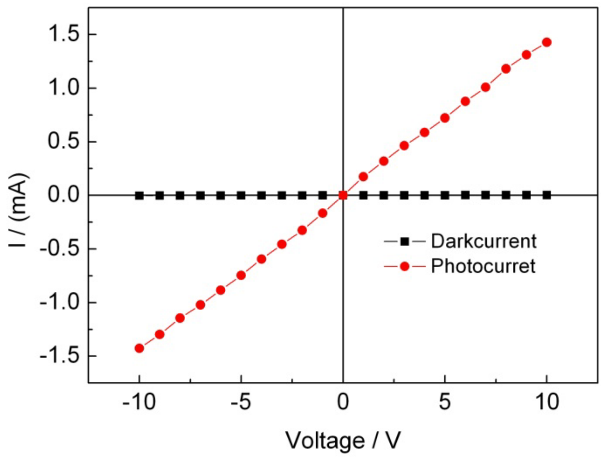

Fig. 5 Dark and UV-365 nm illuminated I-V curves of TiO_2 detector

The spectral photoresponse of the TiO_2 UV detector under 5V bias voltage is shown in Fig. 6. The maximum UV photoresponse is found in wavelengths ranging from 240 to 330 nm, with a cut-off wavelength at 360 nm. It is observed that some absorption started at around 380 nm and continued to grow up to 410 nm. It is thought that the carriers from the deep-level traps within the band-gap, which 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.

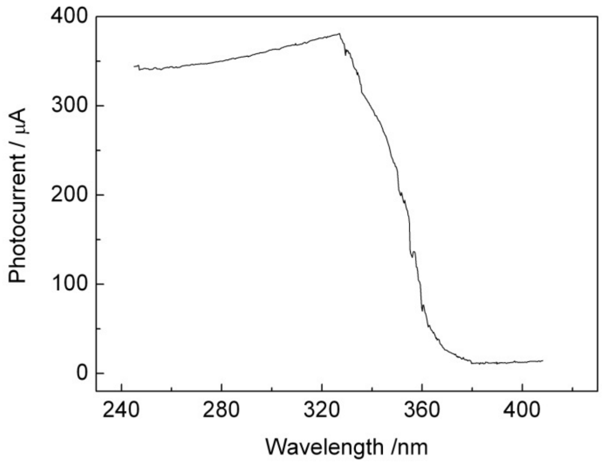

Fig. 6 Spectral response of TiO_2 UV detector

4 Conclusion

In summary, TiO_2 thin films were grown on quartz substrates by RF magnetron sputtering. MSM detectors with Ag IDT electrodes were then fabricated. 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 5V applied bias, 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. It is obviously that the obtained TiO_2 UV detector with high sensitivity and visible blind properties is promising for the civil and military applications.

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