

# Preparation and Photoelectric Properties of Metal-Semiconductor-Metal TiO<sub>2</sub> Ultraviolet Detectors

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**Abstract:** Anatase TiO<sub>2</sub> 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<sub>2</sub> layer has an obvious effect on the photoelectric properties. When TiO<sub>2</sub> 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<sub>2</sub> films; film thickness; photoelectric 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<sup>[1]</sup>. 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 AlGaIn<sup>[2]</sup>, GaN<sup>[3]</sup>, SiC<sup>[4]</sup> and ZnO<sup>[5]</sup>, 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<sub>2</sub> is one of the most attractive metal oxides have been proposed for a wide range of uses, including solar energy conversion<sup>[6]</sup>, hydrogen storage<sup>[7]</sup>, and environmental pollution remediation<sup>[8]</sup>, due to its wide direct bandgap energy of 3.2 eV at room temperature. Moreover, the preparation methods of TiO<sub>2</sub> thin films are simple, low-cost, and widely

accessible<sup>[9]</sup>. High-quality TiO<sub>2</sub> thin films can be easily obtained by traditional magnetron sputtering techniques<sup>[10]</sup>. Therefore, highly photoelectric characteristics would be possible when the UV detectors based on TiO<sub>2</sub> are realized.

However, there were few articles dealt with the fabrication of TiO<sub>2</sub>-based UV detectors, and none focused on the photoelectric characteristics varying with the thickness of the TiO<sub>2</sub> thin films. In this study, we reported TiO<sub>2</sub> photoconductive UV detector based on a metal-semiconductor-metal (MSM) structure. The dependence of photoelectric characteristics on the thickness of the TiO<sub>2</sub> thin films was also investigated.

## 1 Experiment

TiO<sub>2</sub> thin films were deposited by radio frequency (RF) sputtering equipment which has a base pressure of  $5.0 \times 10^{-4}$  Pa. Quartz substrates with the size of  $10 \times 10$  mm<sup>2</sup> were placed on the sample holder which is parallel to the 99.99%  $\Phi 60$  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

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of O<sub>2</sub> and Ar was kept at 2 Pa during the growth of TiO<sub>2</sub> thin films with the O<sub>2</sub> flow rate of 50 mL/min and Ar flow rate 25 mL/min. TiO<sub>2</sub> 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 °C for 2 h.

Fig.1 shows the schematic full view of TiO<sub>2</sub> UV detector. Ag planar interdigital (IDT) electrodes with thickness of 20 nm were fabricated on the TiO<sub>2</sub> 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<sub>2</sub> 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 photoelectric property

Fig.2 shows *I-V* characteristics of the fabricated TiO<sub>2</sub> MSM detectors with various thicknesses of TiO<sub>2</sub> layer measured under illumination (365 nm). When light impinges onto the MSM UV detector, high-energy photons will be absorbed by the TiO<sub>2</sub> 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<sub>2</sub> UV detector. In Fig.3, it can be seen that the thickness of the TiO<sub>2</sub> 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

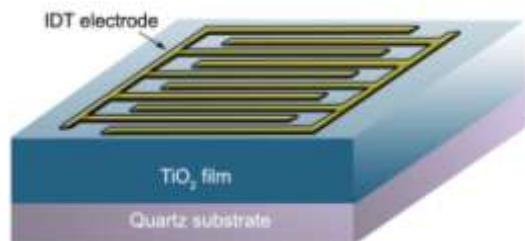


Fig.1 Schematic illustration of MSM-type TiO<sub>2</sub> UV detector

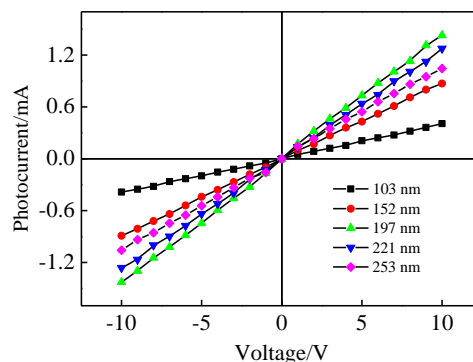


Fig.2 *I-V* characteristics of TiO<sub>2</sub> UV detector with different thickness of TiO<sub>2</sub> layer

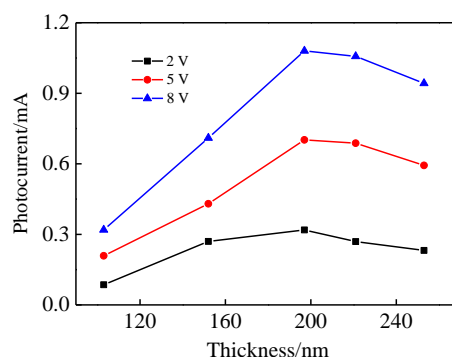


Fig.3 Effect of the film thickness on photocurrent of the TiO<sub>2</sub> UV detector at different bias voltages

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<sub>2</sub> thin films prepared on quartz substrates. The peaks identified comparing with JCPDS file for TiO<sub>2</sub> correspond to anatase TiO<sub>2</sub> (101), (004), (200), (105), and (211) plane reflection; what's more, the thin films exhibit a strong (101) orientation. It must be pointed out that characteristic peaks of anatase TiO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> film. This behavior increases the photocurrent of the detector due

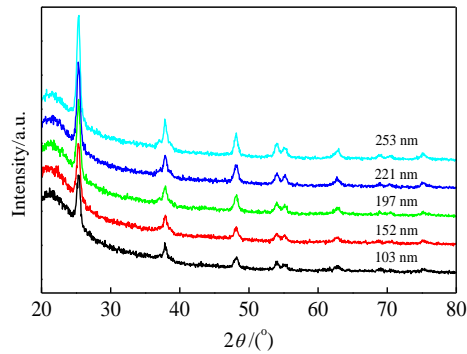


Fig.4 X-ray diffraction patterns of the TiO<sub>2</sub> thin films with different thickness

to the decrease of the carrier loss. However, the influence of the penetration depth of UV light on the TiO<sub>2</sub> 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<sup>[11]</sup>. 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 photoelectric properties of the detector. This decreases the photocurrent with the film thickness further increasing.

## 2.2 Photoelectric property of detector

The UV detector with a TiO<sub>2</sub> layer thickness of 197 nm has the highest photocurrents, and its photoelectric 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<sub>2</sub> UV detector has a significant light sensitivity.

The spectral photoresponse of the TiO<sub>2</sub> 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

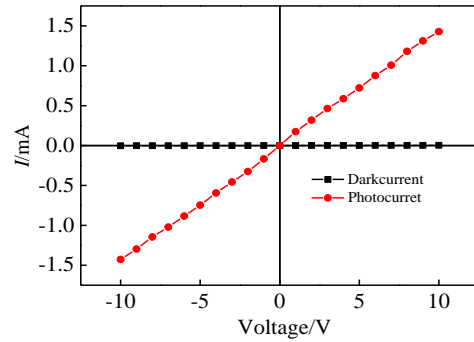


Fig.5 Dark and UV-365 nm illuminated *I-V* curves of the TiO<sub>2</sub> detector

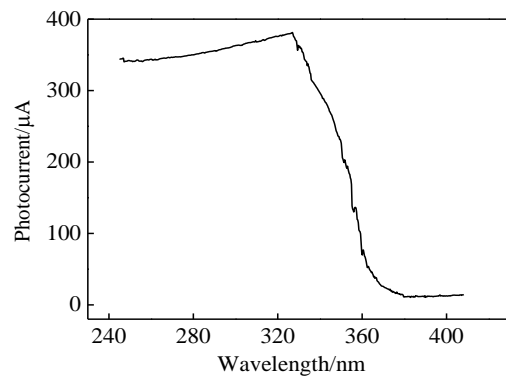


Fig.6 Spectral photoresponse of the TiO<sub>2</sub> UV detector at 5 V bias voltage

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<sup>[12]</sup>. 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<sub>2</sub> thin films for solar-blind UV detector applications.

## 3 Conclusions

1) TiO<sub>2</sub> 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<sub>2</sub> layer has an obvious effect on the photoelectric 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.

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## MSM 结构 TiO<sub>2</sub> 基紫外探测器的制备及光电特性研究

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**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<sub>2</sub>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<sub>2</sub>基紫外探测器。I-V特性测试结果表明, Ag与TiO<sub>2</sub>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<sub>2</sub>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<sub>2</sub>MSM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<sub>2</sub> 薄膜; 薄膜厚度; 光电特性

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