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Pulse laser deposition of epitaxial TiO_2 thin films for high-performance ultraviolet photodetectors

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ABSTRACT

The authors report on high quality TiO_2 epilayers grown on lattice-matched $LaAlO_3$ substrates by pulsed laser deposition. A prototype of metal–semiconductor–metal ultraviolet (UV) photodetector based on TiO_2 was fabricated by employing Au as the Schottky contact metal. The UV–visible transmittance spectrum of the TiO_2 epilayer and the spectral response of the photodetector reveal that the deposited anatase TiO_2 thin film exhibits excellent visible-blind UV characteristics with an optical bandgap of 3.25 eV. In addition, the fabricated photodetector exhibits a high UV-to-visible rejection ratio ($R_{270\,nm}/R_{400\,nm}$) of 10^5 while displaying a low dark current of 0.25 pA under 5 V bias and a high responsivity of 0.21 A/W, suggesting a potential application in UV photodetection.

1. Introduction

Titanium oxide (TiO_2), an intrinsically n-type wide indirect bandgap (3.2 and 3.0 eV for anatase and rutile phase respectively) metal–oxide semiconductor, has been regarded as a very promising material for ultraviolet (UV) photodetectors (PDs) due to its chemical stability, high refractive index and low cost [1–4]. Since the high quality TiO_2 films is essential for high-performance UV photodetectors, many techniques have been employed to prepare these high-quality TiO_2 films, including pulsed laser deposition (PLD) [5–7], magnetron sputtering [8–10], atomic layer deposition [11,12] and sol–gel method [13,14]. Our group recently demonstrated the growth of polycrystalline TiO_2 films by magnetron sputtering and sol–gel method for UV photodetectors [15,16]. As compared to other epitaxial wide bandgap semiconductors, such as SiC, GaN and ZnO, etc. [17–21], the dark currents of the polycrystalline TiO_2-based photodetectors in previous reports are still high due to the presence of defects such as oxygen vacancies in the polycrystalline TiO_2 films. The problem of oxygen vacancies is known to be characteristics of TiO_2 systems and to substantially affect the performances of TiO_2 based-device [22–25].

Therefore, current and future technologies require new materials systems encompassing excellent properties of TiO_2. Chambers suggested that when the additional degrees of freedom afforded by heteroepitaxial film growth are introduced, the range of properties exhibited by metal oxides increases all the more [26]. Of all the oxide substrates investigated, $LaAlO_3$ is one high-quality TiO_2 thin films owing in part to its extremely small lattice mismatch with TiO_2 along the interface [27].

PLD is a widely used and versatile technique that provide high quality epitaxial oxide films with much less defects by controlling the relevant growth parameters such as laser power, pulse frequency, substrate temperature, deposition rate and material composition, etc. [28]. To the best of our knowledge, the UV photodetectors based on pulse-laser-deposited epitaxial TiO_2 thin films have not been reported so far.

In this paper, we reported on epitaxial growth of anatase TiO_2 thin films on $LaAlO_3$ substrate at 500 °C using PLD for UV detection applications. A prototype of metal–semiconductor–metal (MSM) UV photodetector based on pulse-laser-deposited TiO_2 film is demonstrated and it exhibits a high UV-to-visible rejection ratio while displaying a low dark current and high responsivity. These results suggest anatase epitaxial TiO_2 film has a potential application in visible-blind photodetection area.

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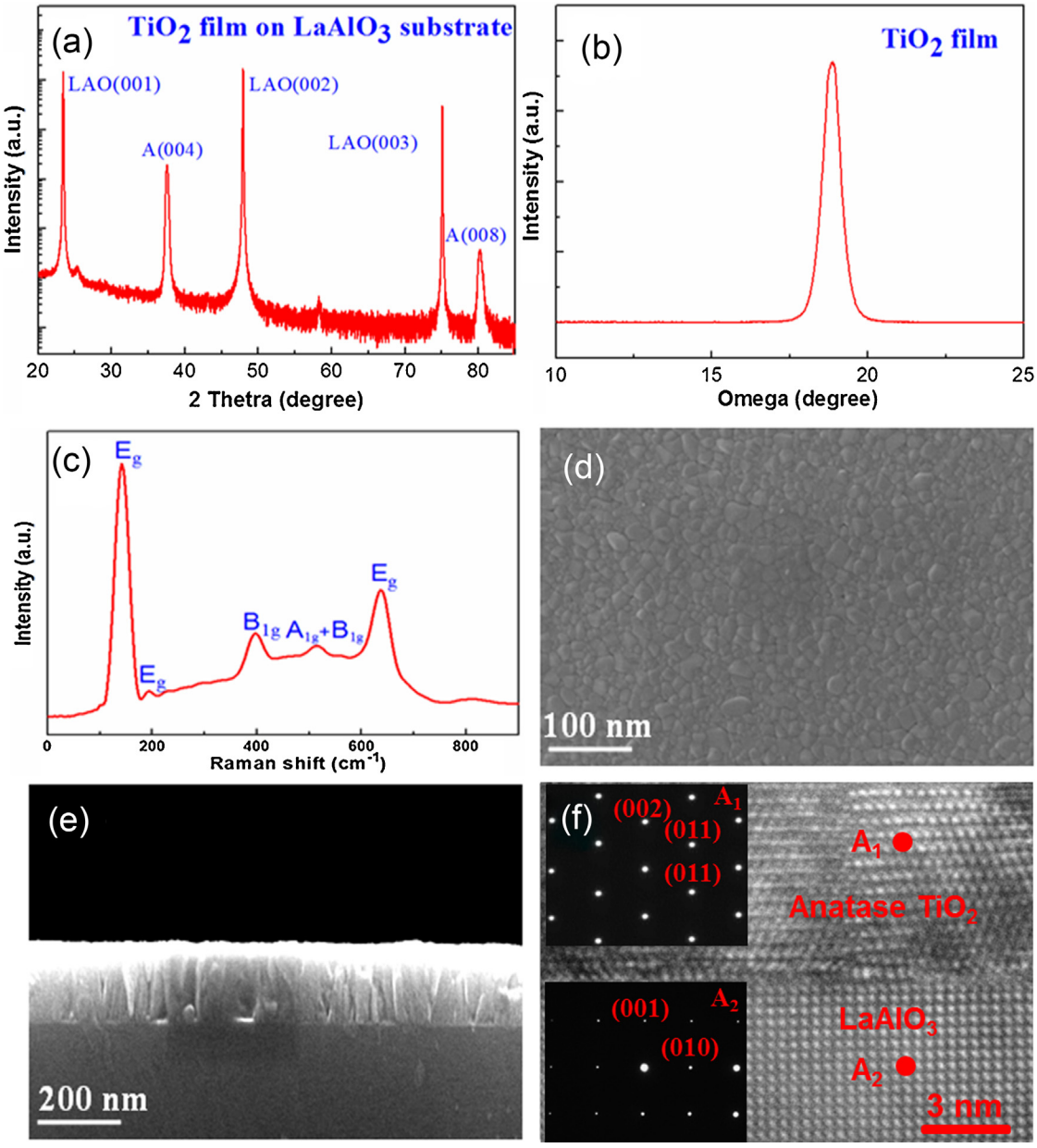

Fig. 1. (a) Two theta XRD pattern, (b) omega XRD pattern, (c) Raman spectrum, (d) SEM images of surface, (e) cross-sectional morphologies, and (f) HRTEM and SAED (inset) collected from the indexing spots of the TiO_2 thin film (Spot A_1) and $LaAlO_3$ substrate (Spot A_2).

2. Experimental details

2.1. Growth method

TiO_2 films were deposited on $LaAlO_3$ substrates by PLD method. A KrF (248 nm) excimer laser was used as ablating source and a ceramic target of TiO_2 was used. The pulse energy used is 300 mJ with a repetition rate of 20 Hz and growth duration of 90 min. Before being loaded into the growth chamber, the $LaAlO_3$ substrates were cleaned sequentially in acetone, ethanol and deionized water. The TiO_2 films (230 nm in thickness) were grown at an oxygen pressure of 16 mTorr and at temperature of 500 °C.

2.2. Device fabrication

Interdigitated MSM (Au/TiO_2/Au) structures with 3 μm finger spacing were designed. The schematic diagram of the TiO_2 MSM detector is shown in the inset of Fig. 3. The devices were fabricated by using standard photolithography to pattern the photoresist for subsequent metallization and using lift-off to define the metal Schottky contacts on the TiO_2 films. The optically active area is 200 μm × 300 μm. The fingers are kept at 3 μm wide and 300 μm long. To increase the Schottky barrier height and reduce the dark current, a high work function metal Au electrode of 250 nm thickness was deposited on TiO_2 film by direct current magnetron sputtering technique.

2.3. Characterization techniques

The structural properties of the TiO_2 films were analyzed with a Rigaku Ultima IV powder X-ray diffractometer (XRD) which uses a Cu-Kα radiation (λ = 0.15406 nm). The surface morphology of the TiO_2 films was examined by using a field emission scanning electron microscopy (SEM) LEO 1530. The optical transmission of the