Metal–semiconductor–metal photodetector on as-deposited TiO_2 thin films on sapphire substrate

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TiO_2 thin films are prepared on c-plane sapphire substrates by the RF magnetron sputtering method. The performance of the Pt contact metal–semiconductor–metal (MSM) photodetector fabricated on as-deposited films is studied. The dark current density and the responsivity obtained were 1.57×10^{-9} A/cm^2 at 5 V bias and 1.73 A/W at 50 V bias, respectively. Breakdown is not observed up to 50 V bias. Rise and fall times for the photocurrent were 7 and 3 s, respectively. Our results show that high quality MSM photodetectors can be fabricated without high temperature and complicated fabrication steps. © *2013 American Vacuum Society*. [http://dx.doi.org/10.1116/1.4794526]

I. INTRODUCTION

GaN, SiC, and ZnO are materials for ultraviolet (UV) photodetection that have been studied for years.[1–4] However, it is known that the epitaxial growth optimization[5] and the cost of the epitaxial material are considerably high for civil applications where UV detection is needed, such as solar UV monitoring and flame detection.[6] Although TiO_2 is a widely studied material for its photocatalytic property, it has recently been shown that the performance of photodiodes is suitable for UV photodetection.[7,8] The most common methods to prepare TiO_2 films are SOLGEL (Ref. 9) and RF magnetron sputtering,[10] but both methods require either postannealing[5,6,11] or O_2 plasma treatment[12] before device processing. In this work, the performance of MSM type photodetector fabricated on as-deposited RF magnetron sputtered film is presented.

II. EXPERIMENT

TiO_2 films are grown by RF magnetron sputtering from the TiO_2 target. Sputtering is performed under 7 sccm Ar flow, 2.2×10^{-3} mbar chamber pressure and 250 W RF power conditions on c-plane sapphire substrate with a deposition rate of 1 Å/s, without sample heating or cooling. Film thickness is measured as 170 nm with a stylus profilometer.

Interdigitated contacts are photolithographically defined and Pt/Au (150/1500 Å) metals are deposited by an e-beam evaporator. The finger width and spacing were 2 and 4 μm, respectively. Mesa etching of the photodetector is performed with inductively coupled plasma (ICP) RIE system at 0.4 Pa chamber pressure, 100 W ICP, and 80 W RF power under 60 sccm CHF_3 gas flow. Then, Ti/Au (200/2000 Å) interconnect metallization is performed for probing pads. The active area of the device was 0.0028 cm^2.

III. RESULTS AND DISCUSSION

Current–voltage (IV) and time response measurements are performed with Agilent B1500A semiconductor parameter analyzer. For the photoresponse measurement, a monochromator with an Xe light source is used. The optical power of the monochromator output was calibrated with an UV enhanced Si photodetector. The transmission and reflection measurements are performed with an Xe light source and an UV-visible spectrometer. Absorption is calculated using these two measurement results. An electronically controlled mechanical chopper is used for chopping the light for time response measurements.

X-ray diffraction (XRD) and atomic force microscopy (AFM) investigations are performed on the TiO_2 films. Figure 1 shows the XRD pattern obtained from the as-deposited TiO_2 sample. The peak at 41.6° is (006) peak of sapphire substrate. Both (004) anatase and (101) rutile phase peaks are observed for this sample. The broad peaks seen in the figure show that crystalline grain sizes are small. Grain sizes for each peak, calculated from Scherrer equations,[13] are around 10 nm for both peaks. In the inset of Fig. 1, AFM image is shown. The RMS roughness measured for this sample is 0.58 nm, which also shows uniform coating.

Dark and photocurrent measurements are performed for the MSM type photodiode. It can be seen from Fig. 2 that a breakdown is not observed up to 50 V, which corresponds to a 166 kV/cm electric field, indicating a good quality film. The dark current at 50 V is 59 pA and only 4.4 pA at 5 V

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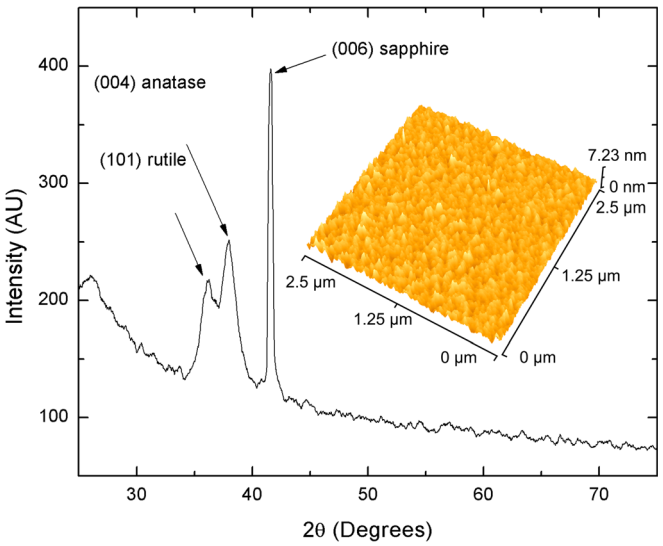

FIG. 1. (Color online) XRD pattern of the TiO_2 film. Inset shows the AFM image of this sample.

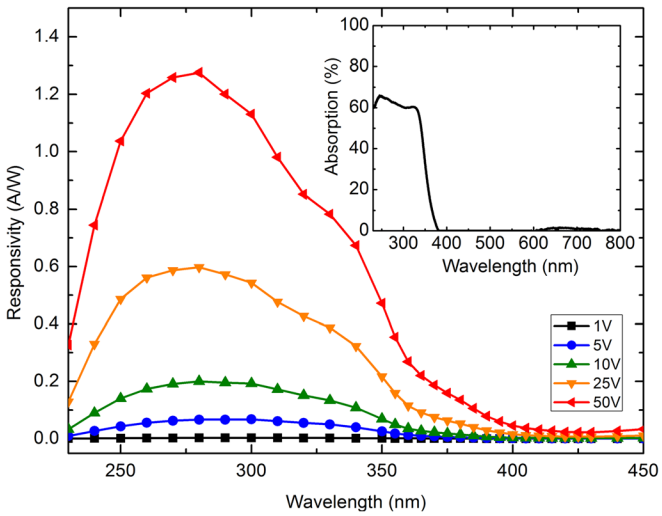

FIG. 3. (Color online) Spectral photoresponse of MSM type photodiode. Inset shows the spectral absorption of the TiO_2 film.

bias, which corresponds to 1.57 nA/cm^2 dark current density. This dark current density is in the range of the recently published[6,12] dark current densities of 3.84 and 0.91 nA/cm^2. The responsivity at a bias of 50 V at 300 nm wavelength is 1.73 A/W. This low photoresponse, compared to published result,[14] is related to the traps that recombine some portion of the photogenerated electrons. Since the spacing between the contacts of our devices is only 4 μm the responsivity of the devices can be increased by increasing the spaces between the contacts, which increases the neutral region between the contacts.[15]

Figure 3 shows the spectral photoresponse of the device. Peak responsivity is observed at 275 nm wavelength. The responsivity decreases below this wavelength, which is in good agreement with the absorption measurement. As the applied bias voltage increases, the photoresponse of the photodetector also increases. Since the device type is a photoconductor, the gain obtained from the device will have a photoconductive portion. In addition, the exponential behavior of the dark current can be explained by avalanche effect due to high electric field between the contacts.[16] So it seems that an avalanche contribution to the total gain is also present. The measured surface reflection from the bare sample in the absorption region is around 40% and as it can be seen in the inset of Fig. 3 the rest of the incident light is absorbed. The total light entering to the device because of the thick finger metallization is 66% of the incident light due to filling ratio. Therefore, only ~40% of the incident light reaches the TiO_2 thin film. By using the total light entering to the film and the photocurrent, the internal quantum efficiency of the photodetector is calculated as 1800% at 300 nm wavelength. At a 50 V bias, the UV-visible contrast (275/425 nm) is measured as 55.

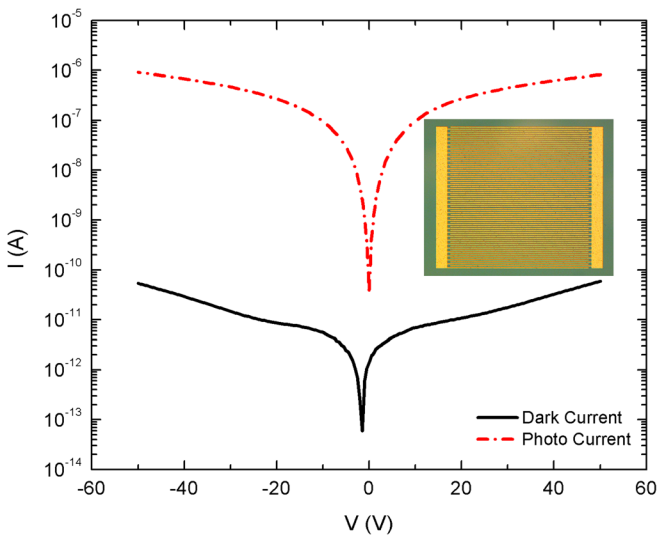

FIG. 2. (Color online) Dark and photocurrents of MSM type photodetector. Inset shows optical photograph of fabricated device.

The time response measurement of the device, which is shown in Fig. 4, is performed at a 300 nm wavelength illumination and 50 V bias. The device shows a relatively slow time response where the 10–90% rise time is 7 s and the 90–10% fall time is 3 s. This slow response is related to the defect traps in the TiO_2 film. Since the TiO_2 film is not processed after deposition, the trap density is high, which leads to a slow time response for the devices. This is also consistent with small grain sizes, which is seen in the XRD measurement, where the trap density is proportional to the total grain surface area.

IV. SUMMARY AND CONCLUSIONS

In conclusion, TiO_2 thin films are prepared by RF magnetron sputtering and the properties of Pt/Au contact MSM type devices fabricated on as-deposited films are studied. The fabricated MSM photodetector exhibits very low dark current density 1.57 nA/cm^2 at 5 V. The responsivity of the devices is measured as 1.73 A/W at 50 V bias and 300 nm

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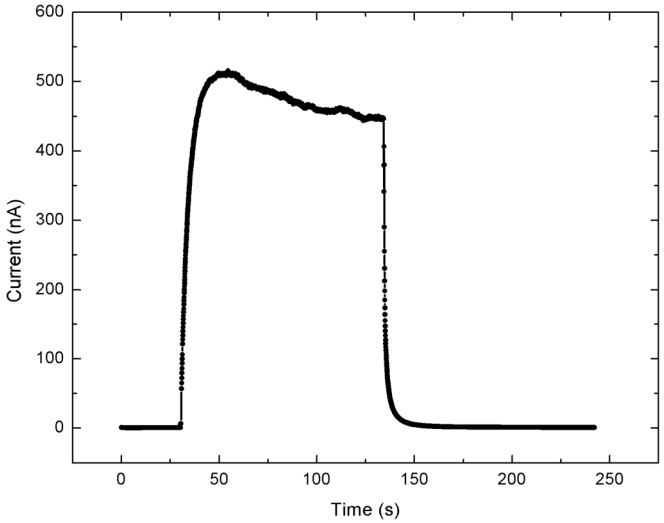

FIG. 4. Time response of the photodetector.

illumination. The time response of the photodetector is measured and the rise and fall times of 7 and 3 s are obtained, respectively. The dark current, photoresponse, and time response characteristics of device fabricated with as-deposited TiO_2 films are found to be comparable with the annealed and plasma treated films reported in previously reported studies. These results show that the optimized growth conditions yield very high quality TiO_2 thin films on sapphire that does not require postannealing and O_2 plasma treatments.

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