DOI 10.5162/SMSI2021/B9.4

Metal/semiconductor hetero-interface engineering for photocurrent controlling in plasmonic photodetectors

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Summary:

The heterointerface engineering at metal/semiconductor (MS) hetero-interfaces in $Au/Ga_2O_3/TiO_2$ plasmonic photosensors enabled the modulation of charge transfer and photoconductance of detectors for adaptive perception of visible optical lights. The photoconductance at heterointerface between plasmonic Au antenna and main TiO_2 semiconductor was modulated by deposition of ultra-thin Ga_2O_3 film at the Au/TiO_2 hetero-interface. The fast and improved photoresponsivity were achieved by the surface functionalization of Au plasmonic antenna with N_2 doped Ga_2O_3 ultra-thin film.

Keywords: Meta/semiconductor heterointerface, Plasmonic Sensors, Atomic layer deposition

Introduction

The photodetectors have been developing for few decades as the artificial extension of the human eye receptors. Smart photodetecting gadgets with capability of the coverage of optical signals in the entre visible light spectrum with the self-adapting characteristics are highly required in various fields of visible light optical sensing. The state-of-the-art self-adaptive photodetectors can mimic the human eye's receptors functionalities.

The modulation of charge transfer at the metal/semiconductor hetero-interfaces is one of the key parameters for development of performance of the optical photosensors based on all-oxide optoelectronic semiconductors. Specifically, the charge transfer at hetero-interface between Au antenna and semiconductor body in plasmonic photodetectors should be controlled to decrease the undesired dark current and also control the charge transfer at Au/Semiconductor hetero-interfaces [1]. An $Au/WO_3/TiO_2$ plasmonic photodetector was recently developed where the dark current of device was tangibly decreased by the employment of ultra-thin WO_3 film at Au/TiO_2 hetero-interfaces [1]. The present research has proposed the employment of *high-k* ultrathin Ga_2O_3 film as interlayer between plasmonic Au antenna and TiO_2 semiconductor film to control the charge transfer at Au/TiO_2 hetero-interfaces (Fig. 1). The incorporation of nitrogen atoms in ultra-thin Ga_2O_3 film via rapid thermal annealing in N_2 atmosphere enabled the modulation of charge transfer at the $Au/Ga_2O_3/TiO_2$ hetero-interfaces in plasmonic photodetector.

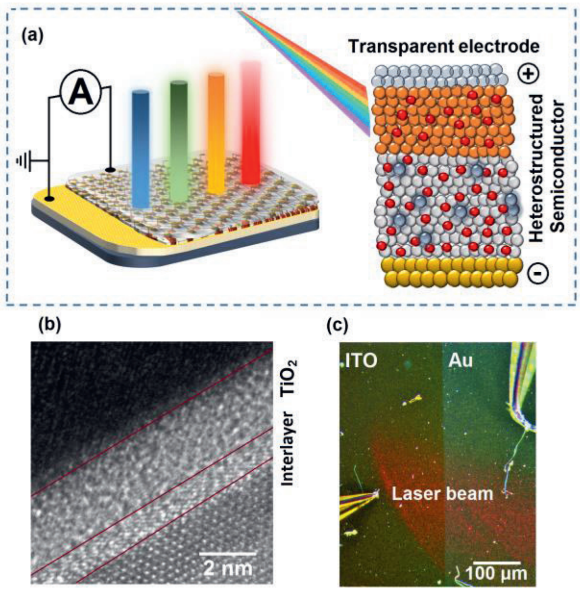

Fig. 1. (a) The graphical scheme depicts the heterostructured $Au/Ga_2O_3/TiO$ photosensor with its (b) cross sectional TEM struture. (c) The actual top view optical photograph of photosensor with transparent ITO and Au plasmonic electrodes.

Results

Atomic layer deposition was used to deposit 4.0 nm thick Ga_2O_3 film on the Au plasmonic substrate accompanied by the following deposition

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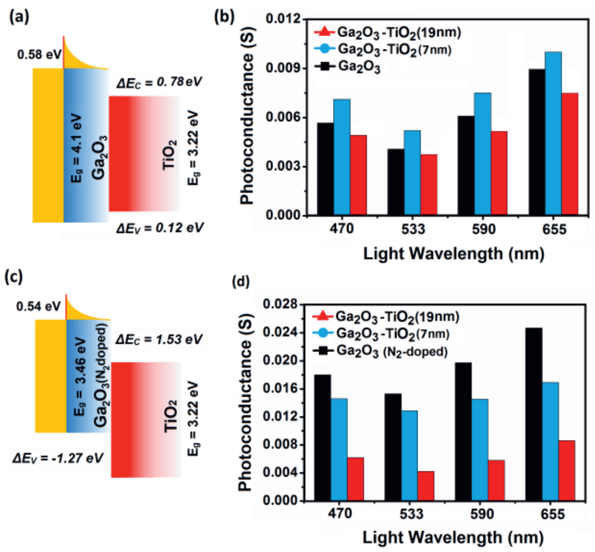

Fig. 2 (a) & (c) respectively show the energy band alignment of heterostructured Ga_2O_3/TiO_2 and Ga_2O_3 $(N_2)/TiO_2$ films. (b) & (d) respectively demonstrate the photoconductance of Ga_2O_3/TiO_2 and Ga_2O_3 $(N_2)/TiO_2$ plasmonic photodetectors.

Of TiO_2 films. It enabled the fabrication of Au/Ga_2O_3/TiO_2 and Au/Ga_2O_3 $(N_2)/TiO_2$ plasmonic sensors (Fig. 1 a, b, c).

The hetero-interface engineering at metal/semiconductor interface was accompanied by the alteration of Schottky barrier height (SBH) at Au/Ga_2O_3/TiO_2 hetero-structures. The SBH at MS interface can alter the charge transfer mechanism at the plasmonic hetero-interfaces. Results showed that the nitrogen doping was accompanied by a small decrease of SBH (Fig. 2a, c). Considering the mechanisms of charge injection and charge tunneling through the Schottky barrier, the Ga_2O_3 (N_2) film with lower Schottky barrier height is more favorable option for transfer of plasmonic photogenerated charge carriers from Au antenna to main TiO_2 film. The hetero-interface engineering with nitrogen doped Ga_2O_3 film considerably altered the energy band alignment at Ga_2O_3/TiO_2 hetero-interfaces (Fig. 2 a, c). The energy band alignment at Ga_2O_3/TiO_2 heterostructure is type I, while the Ga_2O_3 $(N_2)/TiO_2$ hetero-interface is type II. To investigate the photoconductance of fabricated plasmonic heterostructured photo-receptors, several light sources (blue 470 nm, green 530 nm, yellow 590 nm and deep red with tunable intensities were employed. Results confirmed that the photoconductance of Au/ Ga_2O_3 $(N_2)/TiO_2$ plasmonic photodetectors was considerably increased (Fig. 2b, d). It was found that Plasmonic photodetectors showed the highest photoconductance at higher wavelength of visible light, including λ=590 and λ=655 nm.

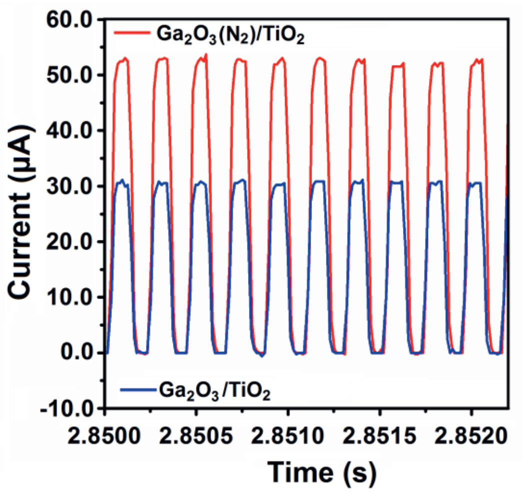

Fig. 3. The ultra-fast response of Ga_2O_3/TiO_2 and Ga_2O_3 $(N_2)/TiO_2$ photodetectors to visible light (λ=650 nm) pulses.

The fabricated plasmonic photodetectors already presented ultra-fast response to the visible light laser pulses (Fig. 3). A λ=655 nm pulsed laser light was employed to excite the visible light generated photoelectrons in Au antenna accompanied by the following transfer of them into TiO_2 film through Ga_2O_3 or Ga_2O_3 (N_2) inter layer barrier. The optoelectronic measurements confirmed higher photoresponse of Au/Ga_2O_3 $(N_2)/TiO_2$ visible light sensors compared with that of Au/Ga_2O_3/TiO_2 photodetectors.

Conclusions

The control of charge transfer at metal/semiconductor hetero-interface enabled the photoresponsivity of plasmonic Au/Ga_2O_3/TiO_2 photodetectors. The Ga_2O_3 interlayer has altered the charge transfer mechanism at Au/ TiO_2 hetero-interfaces, where the photoconductance of metal/semiconductor was altered by employment of Ga_2O_3 and Ga_2O_3 (N_2) interlayer films. The hetero-interface engineering enabled the alteration of Shockey barrier height at metal/semiconductor interface and already reshaped the energy band alignment at Ga_2O_3/TiO_2 semiconductors. The photoelectrical measurement confirmed considerable improvement of photoconductance and photocurrent of plasmonic photodetectors.

References:

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