

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/Ga₂O₃/TiO₂ 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 TiO₂ semiconductor was modulated by deposition of ultra-thin Ga₂O₃ film at the Au/TiO₂ hetero-interface. The fast and improved photoresponsivity were achieved by the surface functionalization of Au plasmonic antenna with N₂ doped Ga₂O₃ 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 entire 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/WO₃/TiO₂ plasmonic photodetector was recently developed where the dark current of device was tangibly decreased by the employment of ultra-thin WO₃ film at Au/TiO₂ hetero-interfaces [1]. The present research has proposed the employment of *high-k* ultrathin Ga₂O₃ film as interlayer between plasmonic Au antenna and TiO₂ semiconductor film to control the charge transfer at Au/TiO₂ hetero-interfaces (Fig. 1). The incorporation of nitrogen atoms in ultra-thin Ga₂O₃ film via rapid thermal annealing in N₂ atmosphere enabled the modulation of

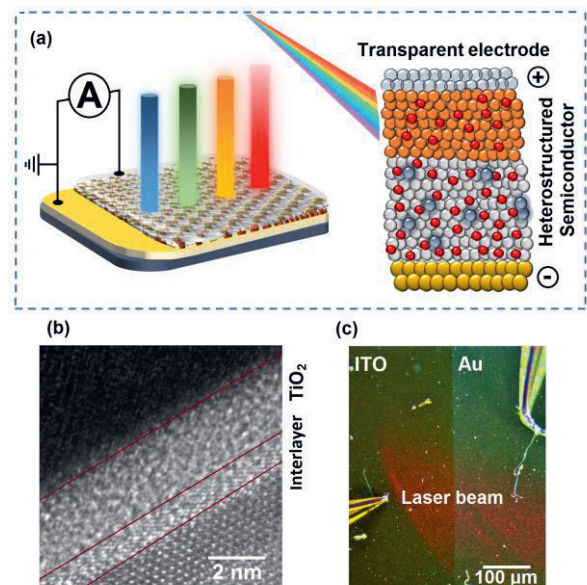


Fig. 1. (a) The graphical scheme depicts the heterostructured Au/Ga₂O₃/TiO₂ photosensor with its (b) cross sectional TEM structure. (c) The actual top view optical photograph of photosensor with transparent ITO and Au plasmonic electrodes.

charge transfer at the Au/Ga₂O₃/TiO₂ hetero-interfaces in plasmonic photodetector.

Results

Atomic layer deposition was used to deposit 4.0 nm thick Ga₂O₃ film on the Au plasmonic substrate accompanied by the following deposition

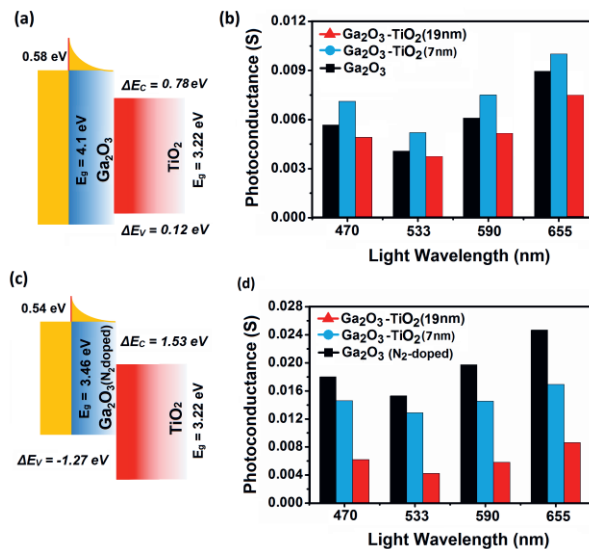


Fig. 2 (a) & (c) respectively show the energy band alignment of heterostructured Ga₂O₃/TiO₂ and Ga₂O₃(N₂)/TiO₂ films. (b) & (d) respectively demonstrate the photoconductance of Ga₂O₃/TiO₂ and Ga₂O₃(N₂)/TiO₂ plasmonic photodetectors.

Of TiO₂ films. It enabled the fabrication of Au/Ga₂O₃/TiO₂ and Au/Ga₂O₃(N₂)/TiO₂ 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/Ga₂O₃/TiO₂ 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 Ga₂O₃(N₂) film with lower Schottky barrier height is more favorable option for transfer of plasmonic photo-generated charge carriers from Au antenna to main TiO₂ film. The hetero-interface engineering with nitrogen doped Ga₂O₃ film considerably altered the energy band alignment at Ga₂O₃/TiO₂ hetero-interfaces (Fig. 2 a, c). The energy band alignment at Ga₂O₃/TiO₂ hetero-structure is type I, while the Ga₂O₃(N₂)/TiO₂ 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/Ga₂O₃(N₂)/TiO₂ 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.

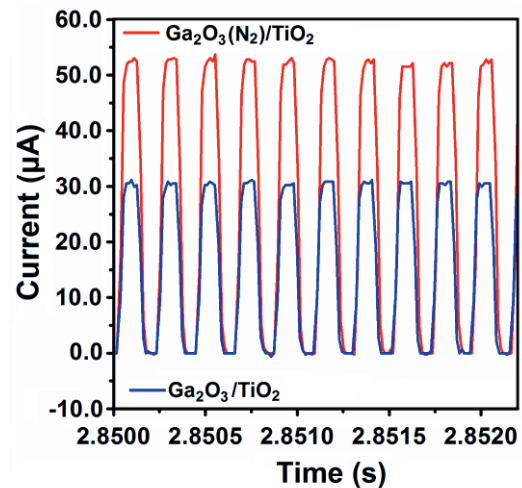


Fig. 3. The ultra-fast response of Ga₂O₃/TiO₂ and Ga₂O₃(N₂)/TiO₂ photodetectors to visible light (λ=650 nm) pulses.

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 TiO₂ film through Ga₂O₃ or Ga₂O₃(N₂) inter layer barrier. The optoelectronic measurements confirmed higher photoresponse of Au/Ga₂O₃(N₂)/TiO₂ visible light sensors compared with that of Au/Ga₂O₃/TiO₂ photodetectors.

Conclusions

The control of charge transfer at metal/semiconductor hetero-interface enabled the photoresponsivity of plasmonic Au/Ga₂O₃/TiO₂ photodetectors. The Ga₂O₃ interlayer has altered the charge transfer mechanism at Au/TiO₂ hetero-interfaces, where the photoconductance of metal/semiconductor was altered by employment of Ga₂O₃ and Ga₂O₃(N₂) inter-layer films. The hetero-interface engineering enabled the alteration of Schottky barrier height at metal/semiconductor interface and already reshaped the energy band alignment at Ga₂O₃/TiO₂ semiconductors. The photoelectrical measurement confirmed considerable improvement of photoconductance and photocurrent of plasmonic photodetectors.

References:

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