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Visible Light Blinded IR Detector by a Si-based MIS Device with Multi-dielectric Layers

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Abstract

We demonstrate the fabrication of a Si based metal insulator semiconductor (MIS) photo-detector with multi-dielectric-layers of SiO_2/TiO_2 and its characteristics of photo-responsivity. Spectral responsivity as high as 0.3 A/W had been achieved at wavelength beyond 850 nm with high spectral discrimination against visible light. In addition, current-voltage (I-V) and optical reflectivity measurements of the multi-dielectric MIS device were applied to explore photo-excited carrier transportation mechanism of the device.

1. Introduction

Visible light blinded IR photo-detectors are attractive to biological signal identification and environment sensing applications. Thought, Si-based devices exhibit advantages inherent to silicon technology, are the most popular devices used in photo detection [1]. However, the spectral responsivity of Si based photo-detectors covered almost all visible light due to the band gap property of intrinsic Si. Therefore special designed optical components are needed to filter the background visible light signal against object of infrared source. The metal-semiconductor (MS) device structure had been demonstrated with the advantage of high response times, low cost of process, and high breakdown voltages operation from far IR to UV photo-detection [2-5]. We demonstrate here a Si-based IR photo-detector by using multi-layers of TiO_2/SiO_2 dielectric in a MIS device to achieve IR photo-detection with high discrimination against visible light.

2. Device Fabrication

Fig. 1-(a) and 1-(b) show the top view and side view of the fabricated multi-layers MIS photo-detector. An electrode pattern of a 200 nm Al/Si film was deposited on a chemically cleaned p-type Si(100) substrate by electron beam evaporation, then followed by annealing at 600 ℃ for 5 minutes in N_2 atmosphere to form good ohmic contact. Structure of multi-dielectric layers was designed by numerical calculation based on multiple films interference to achieve optimized optical filtering off the spectrum of visible light. Dielectric layers with step index of TiO_2 (n=2.13) and SiO_2 (n=1.46) were consecutively deposited on Si substrate. Alpha-Step surface profiler (TENCOR KLA 500) was used to measure the total thickness of the deposited multi-dielectric film. Deposited multi-dielectric layers were then annealed at 800℃ for 39 seconds in N_2 atmosphere for improving the dielectric property. Then, a 300 nm thick aluminum film was deposited by e-beam evaporation on top of the multi-dielectric layer for electric contact.

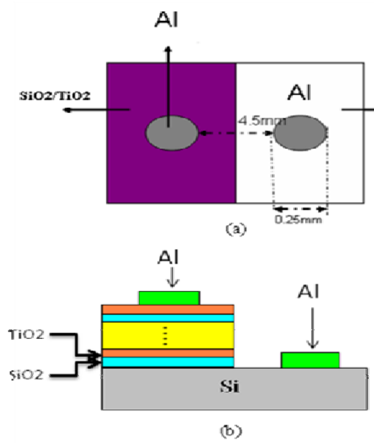

Fig.1. Dimensions and structure of the fabricated multi-dielectric layer MIS device on top view (a), at side view (b).

3. Results and Discussions

Fig. 2 shows the reflection spectrums by the transmission/reflection spectral analysis system (SHIMADZU UV-2101PC) of two multi-dielectric layers, a 12 layers of repeated TiO_2/SiO_2 dielectric structure with each layer thickness of 10 nm, and another one is an 8 layers of same dielectric structure but with each layer thickness of 15 nm. Both dielectric layers show strong reflection at spectral range around 500 nm to 650 nm which are approximately fitted to the numerical calculation result.

Fig. 3 shows the current-voltage (I-V) characteristics of the MIS device with 8 TiO_2/SiO_2 dielectric layers by a semiconductor parameter analyzer (HP 4145). It shows a typical I-V characteristic of the MIS device without illumination, but photo-current can be generated at negative bias under illumination by a high pressure Xe light source.

Fig. 4 shows the comparison of the spectral responsivity between a standard Si based PIN photo-detector (ET-2020) and a fabricated MIS devices both illuminated by a calibrated monochromatic light from a 150 W Xe arc lamp. It shows that the photo-responsivity of the fabricated MIS device is smaller than the Si PIN detector. However, the photo-responsivity of the MIS device can obtain high spectral discrimination from 300 nm to 700 nm which correspond to visible light spectrum, and the responsivity can reach beyond 1300 nm at level as high as 0.3 A/W by applying -10 V bias.

It had been reported that the impurity states in the mid gap of dielectric layer play an important role to carrier transportation in the MIS device [6]. Fig 5 shows the mechanism of the photo-current generation in this multi-dielectric MIS device. With charges accumulation biasing, impurity state in the dielectric layer can be excited by incident photon and provides carriers tunneling channels for accumulated holes at the interface. Since the excitation energy of impurity states can be smaller than the Si band gap, it reasonably explains the generation of photo-current beyond far IR irradiation due to these mid impurity states.

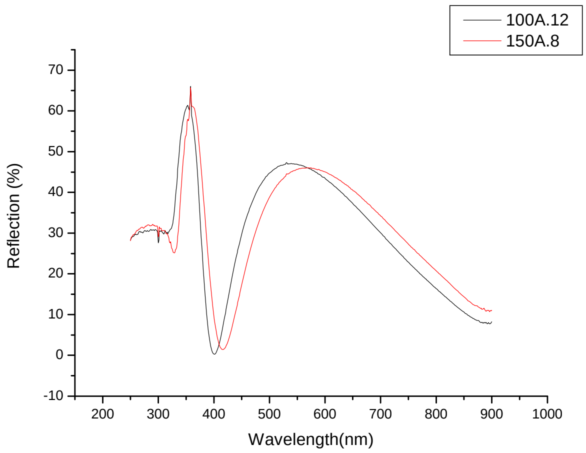

Fig.2.Optical reflectivity measurement of the SiO_2/TiO_2 multi-dielectric films on Si substrate; black line refers to the film of 12 repeated TiO_2/SiO_2 dielectric layers with each layer thickness of 10 nm, and the red line refers to the film of 8 repeated TiO_2/SiO_2 dielectric layers with each layer thickness of 15 nm.

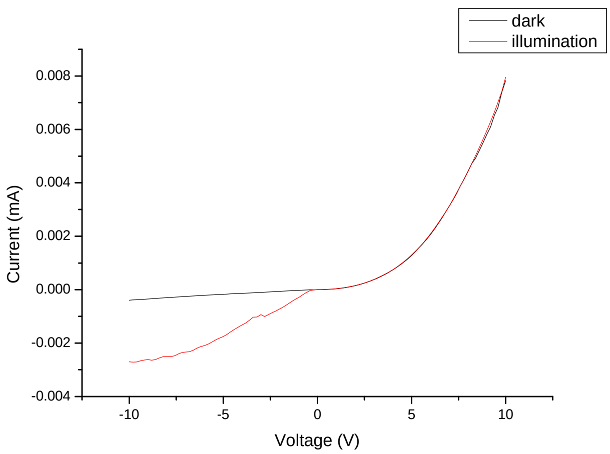

Fig.3. I-V characteristics of the fabricated MIS device with 8 TiO_2/SiO_2 layers with (read) and without (black) illumination.

4. Conclusions

We demonstrate the fabrication of a MIS device of multi-dielectric layers for IR detection with good discrimination against visible light spectrum. The multi-layers dielectric layer is effective to manipulate the incident spectrum with high discrimination to visible light and to provide carriers transport channels by IR irradiation. More investigation of the photo current generation mechanism by different dielectric materials to enhance the IR sensitivity will be conducted and reported.

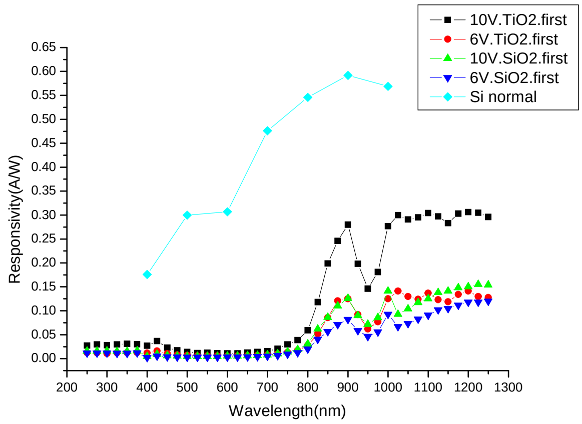

Fig.4. Comparison of photo responsivity between a fabricated MIS device of 10 layers TiO_2/SiO_2 dielectrics and a standard Si based photo detector (ET2020).

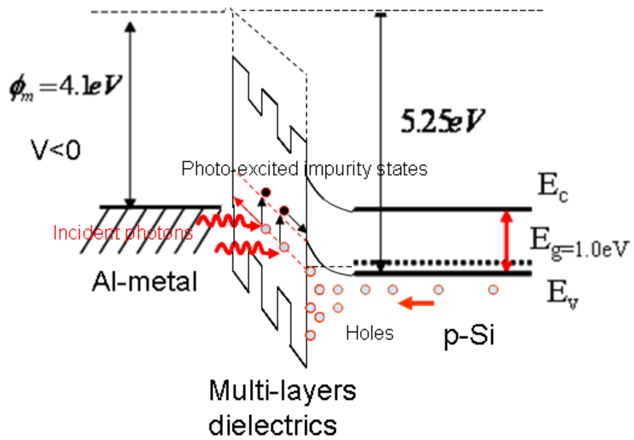

Fig.5, Channels of photo excited carriers tunneling through impurity states inside the band gap of the multi-dielectric layers.

Acknowledgements

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