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Tunable visible response of ZnO thin-film phototransistors with atomic layer deposition technique

Levent E. Aygün[1,2], Feyza Bozkurt-Oruc[1,2], Ali K. Okyay[1,2]
[1]*Department of Electrical and Electronics Engineering, Bilkent University, Ankara 06800, Turkey*
[2]*UNAM-Institute of Materials Science and Nanotechnology, Bilkent University, Ankara 06800, Turkey*
email: aygun@ee.bilkent.edu.tr, aokyay@ee.bilkent.edu.tr

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I. Introduction

ZnO based transparent thin film transistors [1-2] are extensively investigated recently due to their potential of replacing amorphous Si thin film transistors. Also, UV (ultra-violet) detecting properties of ZnO photodiodes are attracting increasing attention [3]. Phototransistors with ZnO channel layer deposited by high temperature RF magnetron sputtering system are demonstrated in the literature [4, 5]. However, such a high temperature process is not appropriate for flexible low cost substrates like polyethylene terephthalate (PET). On the other hand, with atomic layer deposition (ALD) technique highly conformal ZnO films can be deposited at low temperatures with unmatched large-area uniformity. In this work, we demonstrate an ALD based ZnO thin-film phototransistor (TFPT) with tunable photo response in the visible region.

II. Fabrication

Channel-last memory devices are fabricated on highly doped (10-18 milliohm-cm) p-type (111) Si wafer. 210-nm-thick PECVD-deposited SiO_2 layer is used for isolating devices from each other. After patterning and etching SiO_2 layer for gate openings, 15-nm-thick Al_2O_3 gate oxide layer is deposited at 250°C followed by 14-nm-thick ZnO channel deposited at 80°C. The top ZnO layer (channel) is patterned with photolithography and patterned by etching in sulfuric acid solution. A 100-nm-thick Al layer is thermally evaporated and patterned by photolithography and lift-off technique to form source and drain contacts. Highly doped Silicon substrate is used as a back-gate electrode. Various size channel length (2 - 150 μm) and width (10 - 100 μm) devices are fabricated.

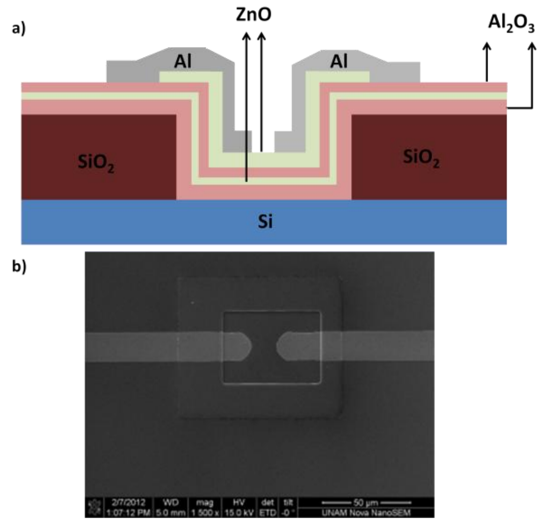

Figure 1: a) The schematic structure of ZnO thin-film phototransistor b) SEM image of the top view of the device

III. Measurement

The dark current-voltage (I-V) characteristics of devices are measured using Keithley 4200 SCS semiconductor parameter analyzer at room temperature. The dark responses of our devices exhibit 10^9 on-to-off ratio with a threshold voltage, V_{TH}, of 5 Volts. For photoresponse, the sample is illuminated with monochromated light using a 150W Xenon light source integrated with a monochromator. The monochromated light is chopped at 400 Hz and photocurrent is measured with Stanford Research System SR830 DSP lock-in Amplifier.

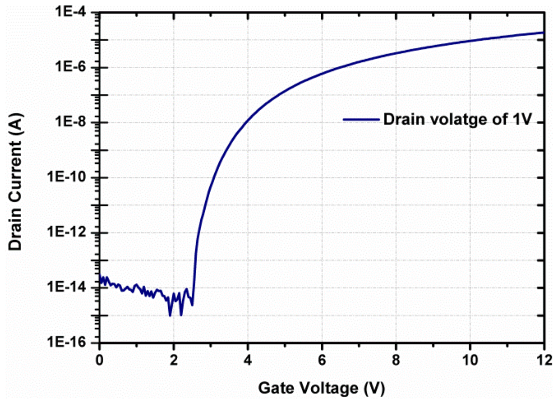

Figure 2: The dark current-voltage characteristics

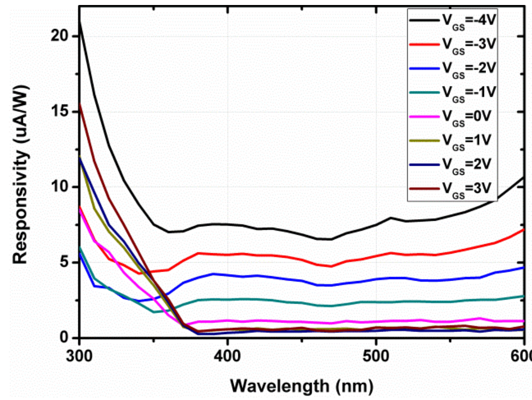

Figure 3: Measured spectral responsivity for various V_{GS} at constant V_{DS} of -3V

IV. Results and Discussion

The spectral responsivity measurement of our phototransistor is taken for V_{GS} (gate to source voltage) from -4V to 3V with a constant V_{DS} (drain to source voltage) of -3V, results are shown in Figure 3. We observe photocurrent contribution from photons with a higher energy than the band gap of ZnO (E_g of 3.3eV which corresponds to λ=375nm photons). As the magnitude of V_{GS} increases collected photocurrent also increases, attributed to the width-modulation of depletion region. For negative V_{GS} bias, photons with below-band-gap energy also contribute to the total measured photocurrent. This absorption mechanism can be associated with the natural mid-gap states of ZnO. As positive V_{GS} is applied, the mid-gap states accumulated with electrons owing to reverse band bending. Therefore, the absorption of visible photons is suppressed.

V. Conclusion

We fabricated TFPT with 14-nm-thick n-ZnO channel at 80°C by ALD technique. The drain to source photocurrent due to UV photons can be tuned by changing gate voltage. We also observed that the absorption of sub-bandgap photons could be prevented by operating at positive gate bias. This property could be used for light modulators for visible regime. Moreover, this could be applied to the smart glass technology for electrical voltage controlled transparency. Furthermore, solar-blind UV detectors could also be designed with this technology.

Acknowledgments

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