Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supporting Information

For

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Band-edge modulated ZnO Pomegranates-on-Paper Photodetector

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Experimental: In order to explore the effect of ethanol solvent, paper-based ZnO ultraviolet (UV) detector was formed on graphite-on-paper (G-P) substrate by hydrothermal method with water as solvent (Figure S1). Firstly, the G-P substrate and ZnO seed layer were formed in the same way as mentioned in the main article. The nutrient solution for hydrothermal growth of ZnO was formed by mixing $Zn(CH_3COO)_2{\bullet}2H_2O$ aqueous solution (0.05 M, 15 ml) with hexamine aqueous solution (0.05 M, 15 ml). The corresponding hydrothermal growth of ZnO was performed at 90 ^oC for 12 h. To avoid the effect of gravity, the as-synthesized substrate was hung in the nutrient solution with its face down.

As for explorations on the effects of the following three factors including ultrasonic vibration during the formation of ZnO seed layer, the structure of ZnO nanomaterials and electrode parameter on the device performance (Figure S2-S4), spin-coating method was introduced. Detail procedures can be described as follows: At first, ZnO seed layer coated G-P substrate was fabricated in the same way as mentioned in main article. Secondly, different ZnO nanomaterials were formed and dissolved in ethanol solvent to form suspensions (10 M). Then they were spin-coated onto substrates at 3000 r min^{-1} for 15 min. In details, ZnO pomegranates were formed in the solution by solvothermal method as mentioned in the main article. ZnO nanorods were formed in the solution by hydrothermal method.[1] The device was formed by repeating the spin-coating procedure three times. To achieve a firm adhesion between ZnO nanomaterials and the substrate, the device was annealed at 150 ^{o}C for 30 min after each spin-coating procedure.

It is noteworthy that the characterizations of the devices mentioned in this supporting information are in the same way as mentioned in the main article.

Supporting Information, S1: Figure S1 shows the scanning electron microscope (SEM) images and X-ray diffraction spectrum (XRD) of the G-P based UV detector formed by hydrothermal method. It is obvious that porous ZnO nanomaterials with large size were formed on the whole G-P substrate. In its XRD spectrum, typical ZnO peaks were observed (JCPDS No. 36-1451) besides the peaks of graphite (solid circles) and paper substrate (hollow circles). The appearance of multiple peaks of ZnO verifies the formation of three dimensional ZnO nanostructure. Comparing with nanospheres formed by solvothermal method in the main article, it is rational to believe that ethanol should be responsible for the formation of ZnO pomegranates.

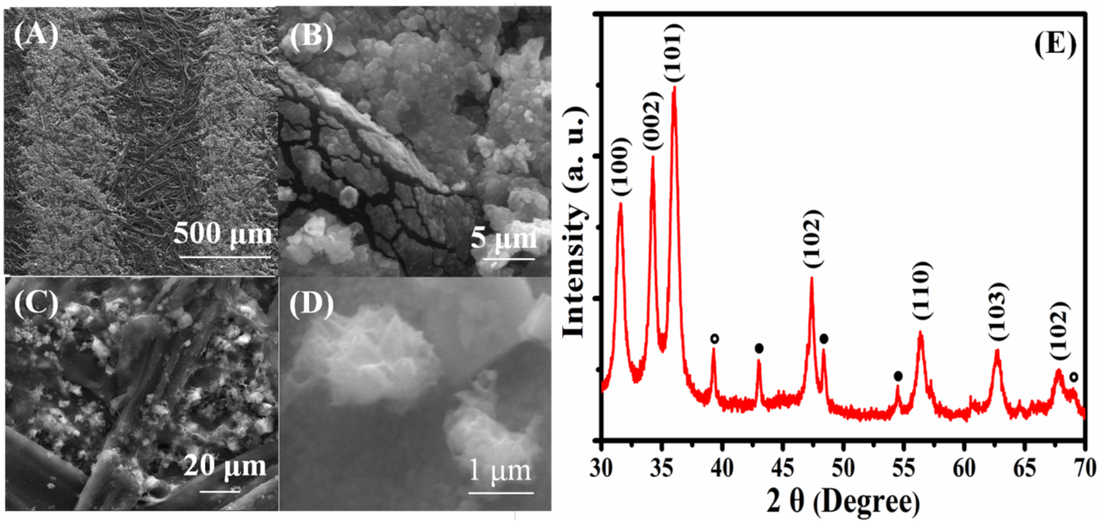

Figure S1. A) Low magnification SEM micrograph of the paper-based ZnO UV detector formed by hydrothermal method. B) SEM micrograph of ZnO grown on graphite electrode. C) and D) SEM micrographs of ZnO grown on paper spacing. E) XRD spectrum of the as-synthesized device.

Supporting Information, S2: The effect of different ZnO nanostructures on the optoelectrical properties of the as-synthesized devices were explored by spin-coating ZnO nanomaterials with different morphologies onto ZnO seed layer coated G-P substrates. Figure S2 (A) and (B) are SEM micrographs of ZnO pomegranates and nanorods. In their I-V curves, a higher photocurrent is achieved for device with ZnO pomegranates as light absorption materials indicating that pomegranates -like ZnO nanostructure is a good choice for fabrications of high performance paper-based UV detectors. Besides the small photocurrent for nanorod-based ultraviolet detector, its I-V curve even did not go cross the (0, 0) spot. This may be caused by the zero drift of the testing equipment working under the current detection limit.

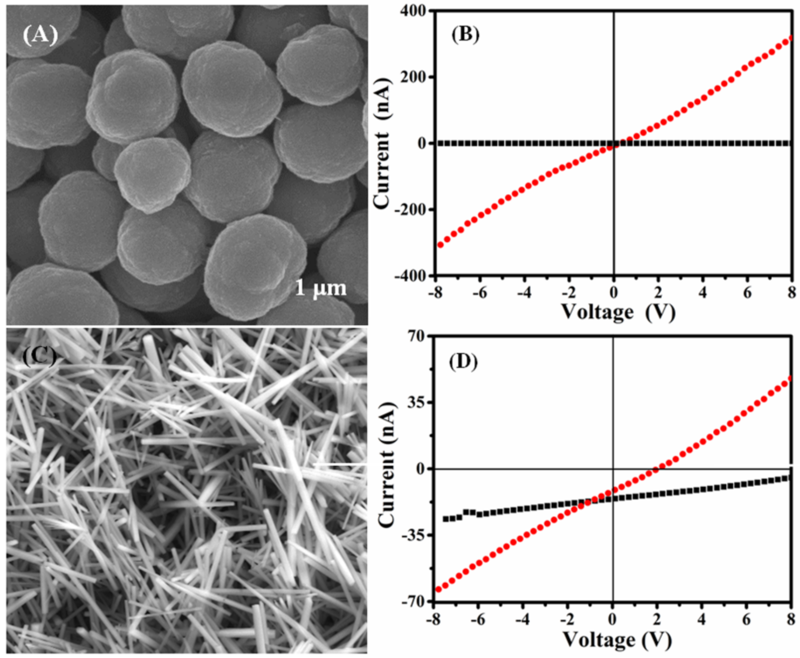

Figure S2. A) and B) SEM micrographs of pomegranates -like and rod-like ZnO nanostructures. C) and D) I-V curves of the G-P based ZnO UV detector with rod-like and pomegranates-like ZnO nanomaterials as light absorption materials, respectively.

Supporting Information, S3: The effect of the ultrasonic vibration during the formation of ZnO seed layer on the device performance is explored by their I-V and time response characterizations. Both devices were formed by spin-coating ZnO pomegranates onto the substrates, but ZnO seed layer in this section were formed on the G-P substrate with or without ultrasonic vibration. The higher photocurrent for device fabricated on ZnO seed layer formed with the assistance of ultrasonic vibration indicates that ultrasonic vibration contributes to the high performance paper-based UV detector. This may be caused by the firmer attachment of ZnO pomegranates on the G-P substrate. Besides, the firm attachment of ZnO seed layer may also facilitate the formation of ZnO nanomaterial on it and the thickness of ZnO nanomaterials is also increased. The relatively longer response time may be caused by the increased distance carrier travels between the two electrodes, but also will trap carriers at boundaries between them.

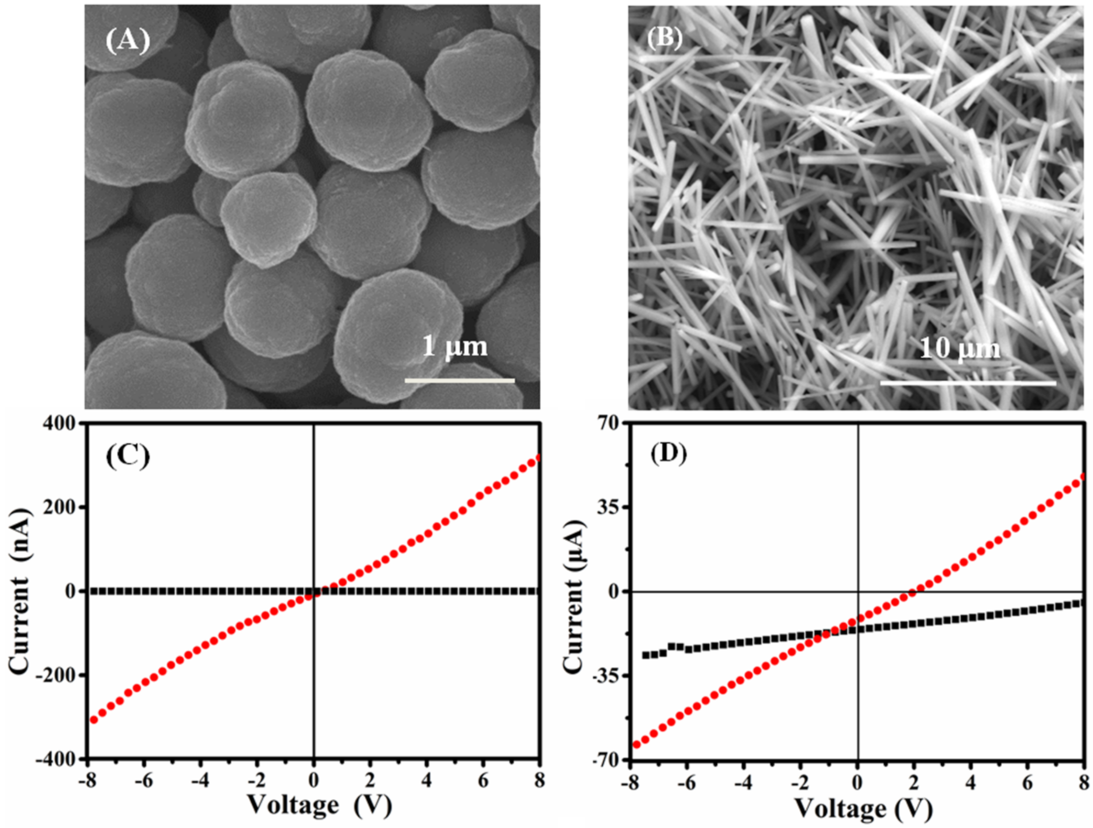

Figure S3. A) and B) I-V curve and time response spectrum of device fabricated on ZnO seed layer formed with the assistance of ultrasonic vibration. C) and D) I-V curve and time response spectrum of device fabricated on ZnO seed layer formed without the assistance of ultrasonic vibration.

Supporting Information, S4: The effect of the width of electrodes on the device performance was explored by variations in their time response spectra. The interdigital electrodes of G-P substrate were with the same spacing distance between electrodes (1 mm), but different electrode widths. The devices were fabricated by spin-coating ZnO pomegranates onto the as-synthesized substrate as mentioned in the experimental section. The device with small width electrodes shows quicker response indicating that the well-defined parameters of interdigital electrodes are another key factor for high performance paper based devices. Consequently, the introduction of ink-printed electrodes may further improve the detector's performance.

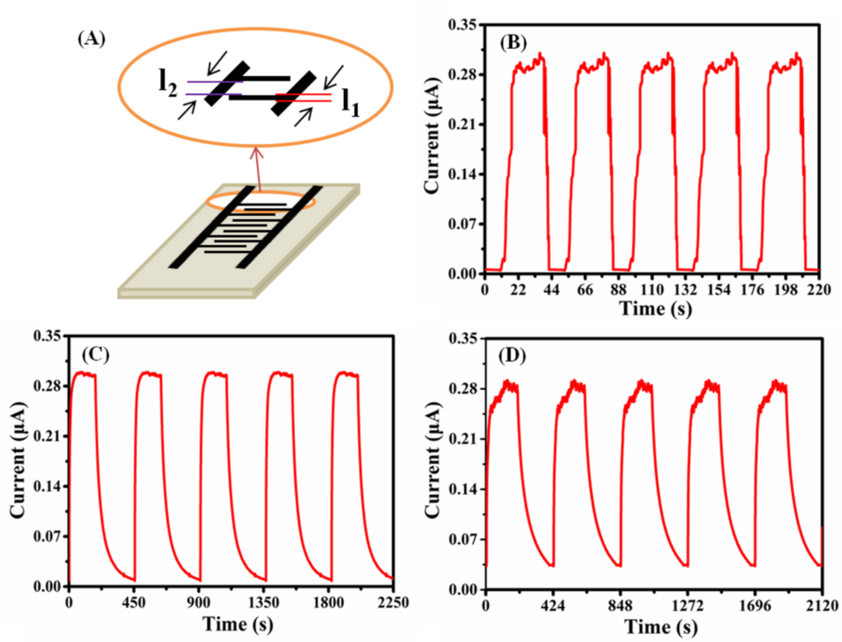

Figure S4. A) Schematic view of graphite electrodes on paper. l_1 and l_2 refer to the width of electrode and spacing section between electrodes. B), C) and D) Time response spectra of devices formed on the G-P substrate with different electrode widths: 0.15 mm, 0.3 mm and 1 mm.

[1] H. L. Li, S. J. Jiao, S. S. Bai, H. T. Li, S. Y. Gao, J. Z. Wang, Q. J. Yu, F. Y. Guo, L. C. Zhao, *Phys. Status. Solidi A* **2014**, *211*, 595.