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Increasing UV Photon Response of ZnO Sensor with Nanowires Array

Weiwei Wu†, Suo Bai†, Nuanyang Cui†, Fei Ma, Zhiyang Wei, Yong Qin*, and Erqing Xie

Institute of Nanoscience and Nanotechnology, Lanzhou University, 730000, China

Single nanowire (NW) is widely studied as UV sensor, chemical sensor, biosensor, etc. Through modifying the surface of nanowire, using Schottky contact and other methods, the sensitivity is greatly increased. But expensive equipment is needed to detect the very weak current. Increasing photon response is an effective way to detect the small signal with low price. Here we demonstrate a new method to largely enhance the photon response of ZnO UV sensor by utilizing NWs array. The photon response ΔI is increased from 0.14 μA to 3 μA when the amount of NWs increases from 2 to 41. And it can be further increased with increasing the amount of ZnO NWs. This gives an effective way to detect weak UV light with low precision equipment.

Keywords: UV Sensor, ZnO, Nanowire Integration, Enhance Photon Response.

1. INTRODUCTION

Zinc oxide (ZnO), a wide bandgap (3.37 ev) semiconductor with high excitation energy of 60 meV at room temperature, has attracted a great attention for applications such as light emitting diode (LED),[1] chemical sensor,[2] strain sensor,[3] ultraviolet (UV) photodetector,[4] solar cell,[5] power generation,[6, 7] and piezotronics.[8] For ultraviolet (UV) photon detection, high sensitivity, fast response time and reset time, good signal-to-noise ratio, and high photon response are desired.[9] Till now, many methods have been studied to improve these properties. Response and reset time of UV nanosensor are greatly enhanced by utilizing schottky contact.[4, 10] High humidity can shorten the reset time. But meanwhile, it decreases the photon response ΔI.[11] Surface functionalization and CdTe decorations are investigated to increase the photon response of ZnO UV sensor.[12, 13] However, little attention has been paid on improving the photon response through NWs array. In this paper, we fabricate UV sensors composed of different amount of parallel ZnO NWs, and investigate their I–V characteristics and UV response properties. A large enhancement of UV photon response with amount of parallel NWs has been observed.

2. SYNTHESIS AND CHARACTERIZATION

As shown in Figure S1, we use a horizontal double tube system to grow aligned ZnO NWs array. 0.81 g Zinc oxide and 0.12 g graphite are mixed together, and then grinded for more than 45 minutes. The mixture is placed into a reaction boat which is located at the sealed end of the small quartz tube. The (100) Si substrates, which are cleaned with HF, acetone and ethanol successively, are placed at the open end of the small tube. Then Ar and O_2 flow into the tube at a rate of 190 sccm and 10 sccm. And the system is pumped to maintain at 210 Pa pressure. Subsequently, the temperature of the furnace is ramped to 1050 °C at a rate of 50 °C/min. After heating at this temperature for 1.5 hours, the samples are cooled down to room temperature in the air. At last, a layer of grey-white product is achieved.

The samples are characterized using X-ray diffraction (XRD) (Rigaku D/Max-2400 X-ray Diffraction), scanning electron microscope (SEM) (Hitachi S-4800) and transmission electron microscope (TEM) (JEM 1200 EX).

Figures 1(a and b) show typical SEM images of the prepared samples. Figure 1(a) depicts the NWs are well aligned and their diameters are relatively uniform. From the inserted image in Figure 1(a), the diameter of those NWs can be determined to be about 200 nm. At the same time, hexagonal screw dislocation on the top of the NW indicates that the growth mechanism is vapor–solid (VS) process.[14] As shown in Figure 1(b), the NWs are straight and relatively vertical to the Si substrate, and their length is about 30 μm. Figure 1(c) is the TEM image of ZnO nanowire. And the insert is its selected-area electron diffraction (SAED), which reveals ZnO NW is single crystal wurtzite structure. Furthermore, XRD spectrum in Figure 1(d) confirms this crystal structure too. And the preferred orientation of (002) peak reveals that ZnO NWs grow along c-axis direction.

*Author to whom correspondence should be addressed.
†Authors with equal contribution.

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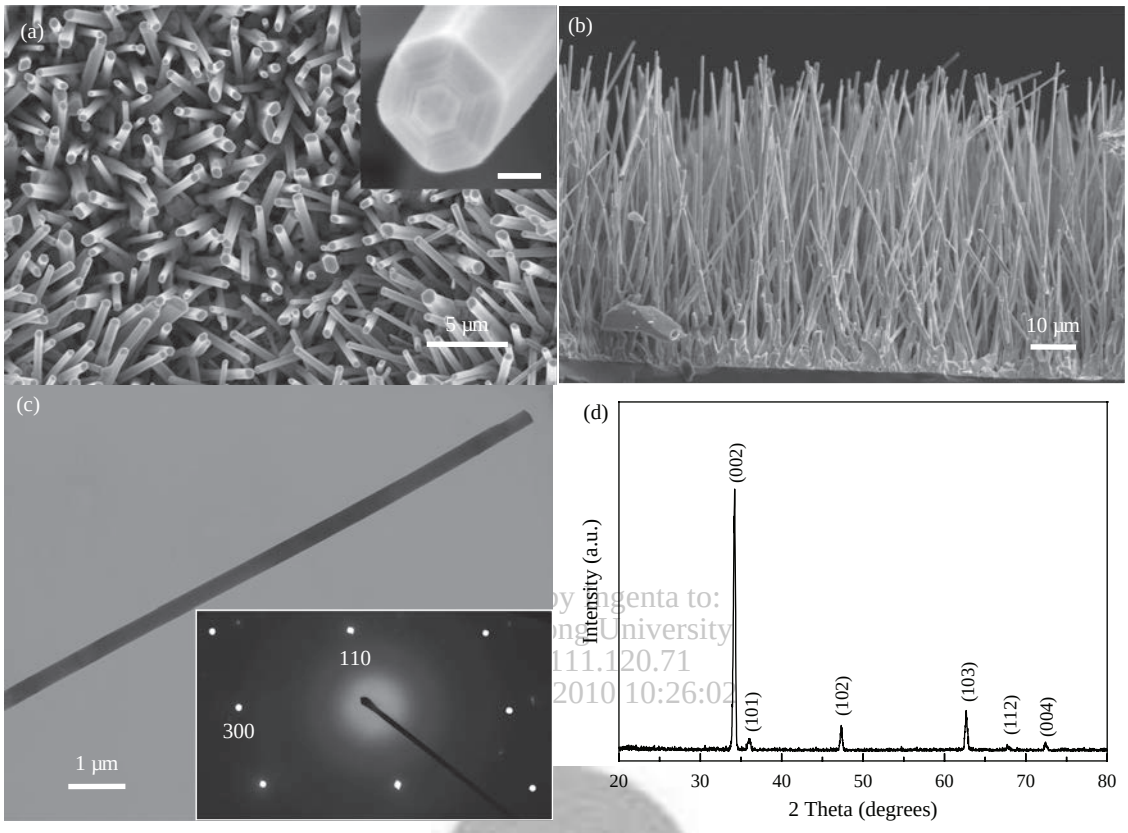

Fig. 1. (a) A low magnification top-view SEM image of ZnO NWs array. The insert is a high magnification top-view SEM image of single ZnO NW, and the scale bar is 100 nm. (b) A sectional image of NWs array. (c) TEM images of ZnO NW, and the insert is the selected-area electron diffraction (SAED). (d) XRD spectrum of hexagonal structure ZnO.

3. DEVICE FABRICATION AND UV RESPONSE

Three steps process is used to fabricate ZnO UV sensor composed of NWs array. First, a glass slide slightly rubs the aligned NWs array on Si substrate as shown in Figure 2(a). As a result, some NWs transfer from Si substrate to glass slide because of friction, and those NWs align along approximately same direction (Fig. 2(b)). Second, the slide with ZnO NWs is spin coated with DNR-L300 negative photoresist at a speed of 3000 rpm for 40 seconds. Then it is baked at 90 °C for 40 minutes. After that it is patterned with photolithography and developed with DPD-200 developer. Third, thermal evaporator or magnetron sputtering is used to deposit aluminum (Al) on the slide. After liftoff with acetone, ZnO UV sensor consisting of NWs patterned with two Al electrodes is fabricated as shown in the Figure 2(c).

Before the measurement of UV response, we first count the amount of the NWs in the sensor. Then I–V curve and UV response are tested for the sensor with this amount of NWs. Later on, we damage some NWs (Figs. 2(f and g)) and measure the sensor with the remained NWs. Following the same procedure, we measured the UV response of ZnO UV sensor composed of 41 NWs, 8 NWs and 2 NWs separately.

As shown in Figure 3, I–V characteristics of our device are relatively linear under dark (a) and UV illumination (b). It reveals that the contact between metal and semiconductor is ohmic contact. This is because that the work function of Al is lower than the electron affinity of ZnO. The resistance of the device is an effective resistance of all ZnO NWs connected in parallel. So the resistance of the device decreases with the amount of parallel NWs. As shown in Figure 3(b), when the UV light is on, the resistance of the device sharply decreases. This maybe ascribe to the surface oxygen adsorption of ZnO NWs and the electron–hole pairs generated by UV light in NWs.[15–18] When UV light is off, the oxygen molecules are absorbed on the surface of ZnO NWs and capture free electron from n-type ZnO $[O_2(g) + e^- \rightarrow O_2^-]$. So, a low conductivity depletion which is composed of O_2^- covers the ZnO NWs surface. When the UV light is on, the photon energies which are above ZnO band gap will generate electron-hole pairs $[h\nu \rightarrow e^- + h^+]$. Photo-hole migrate to the surface and discharge the layer of O_2^-. The unpaired electrons accumulate gradually with time until desorption and readsorption of O_2 reach an equilibrium state. For our n-type ZnO, as the increasing of unpaired electron concentration, the resistance decreases.

The UV response curve is shown in Figure 4. The photon response ΔI of the sensor composed of only 2 NWs

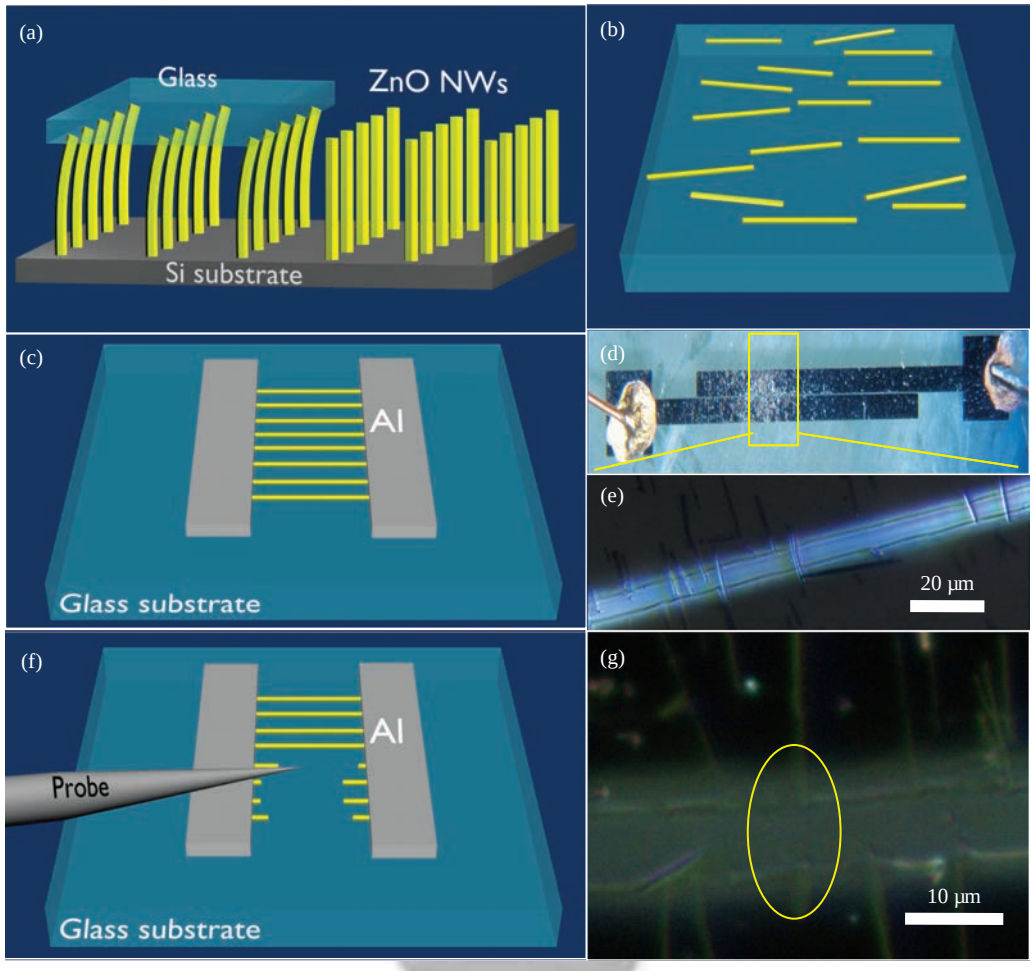

Fig. 2. (a–c), Schematics of the device fabrication process. (d) Optical microscopy image of the device. (e) Enlarged image of the yellow rectangle part in Figure (d). (f) Schematic of damaging NWs with a probe. (g) Optical image of the device after some NWs are damaged, and the yellow circle shows one NW is damaged at the middle and the two ends still remained in the electrodes.

is 0.14 μA. As the amount of parallel NWs increase to 8, the ΔI reaches to 0.6 μA. And the photon response ΔI dramatically increase to 3 μA when the amount of parallel NWs increase to 41. Obviously, the photon response ΔI almost increase 20 times when the amount of parallel NWs increases from 2 to 41, which is further shown in the inserted in Figure 4. Increasing the amount of NWs in UV sensor should be an effective way to largely enhance the photon response of the sensor. And it will hugely decrease the cost of commercial UV sensor.

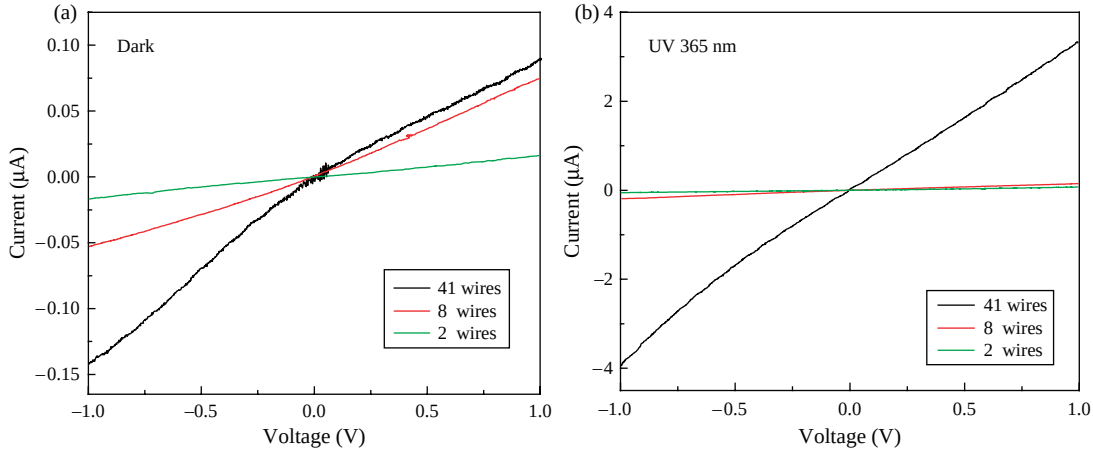

Fig. 3. The corresponding *I–V* characteristics under dark and UV illumination, and the amount of nanowires in the device is 41, 8 and 2, respectively.

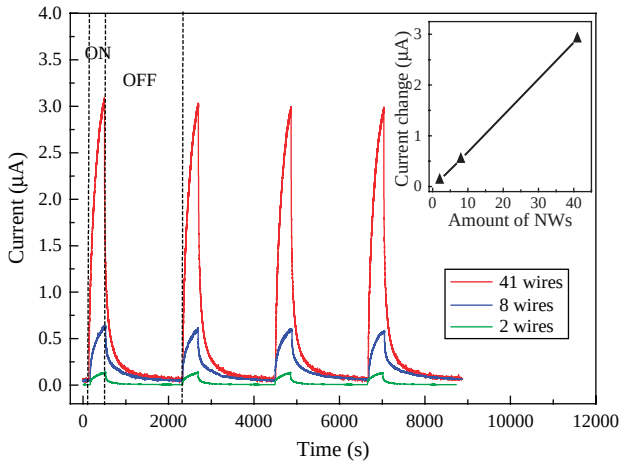

Fig. 4. The UV response curves of ZnO NWs with different amount NWs. The insert shows the relationship between current change and the amount of NWs.

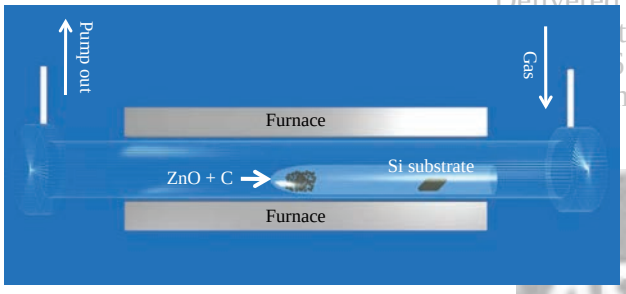

Fig. S1. The schematic of the synthesis system.

The reset time (τ), the current need to recover to 1/e (37%) of the maximum of the photon current, is also an import factor of UV sensor.[19] As shown in the Figure S2, the reset time of the 41 NWs, 8 NWs, 2 NWs sensor is 42, 205 and 50 seconds respectively. The reset time of the sensor consists of 8 NWs is longer than the others. The possible reason is because of the diameter difference of NWs. The diameter of the ZnO NWs is not strictly uniform and small NWs have relative larger surface ratio compared with large NWs. Smaller size NWs has a shorter reset time,[16] Thus, when larger NWs remained in the sensor, its reset time will become longer.

4. CONCLUSION

In summary, we successfully developed a procedure to fabricate ZnO UV sensor composed with many NWs. The UV response properties of the sensor consisting of different amount of NWs were studied. Increasing the amount of NWs is proved to be an effective method to enhance the photo response of UV sensor. This gives a new way to greatly improve the properties of UV sensor with low cost.

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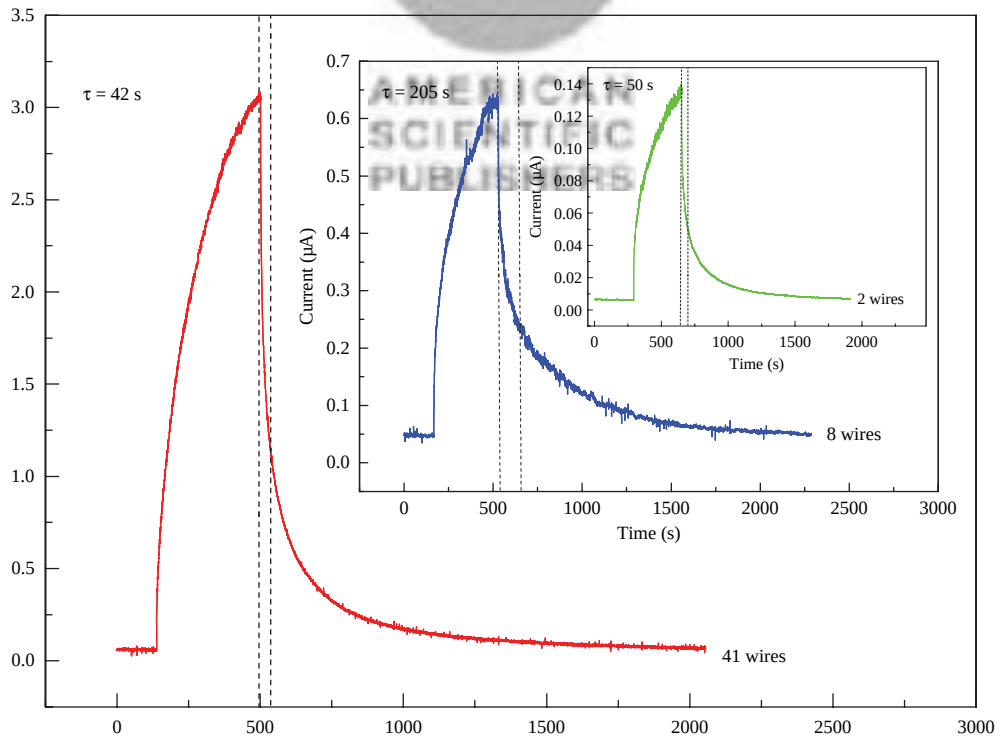

Fig. S2. The reset time of devices composed of different amount NWs.

References and Notes

1. A. Tsukazaki, T. Onuma, M. Ohtani, T. Makino, M. Sumiya, K. Ohtani, S. F. Chichibu, S. Fuke, Y. Segawa, H. Ohno, H. Koinuma, and M. Kawasaki, *Nat. Mater.* 4, 42 **(2005)**.
2. C. S. Lao, Q. Kuang, Z. L. Wang, M. C. Park, and Y. L. Deng, *Appl. Phys. Lett.* 90, 262107 **(2007)**.
3. J. Zhou, Y. D. Gu, P. Fei, W. J. Mai, Y. F. Gao, R. S. Yang, G. Bao, and Z. L. Wang, *Nano Lett.* 8, 3035 **(2008)**.
4. J. Zhou, Y. D. Gu, Y. F. Hu, W. J. Mai, P. H. Yeh, G. Bao, A. K. Sood, D. L. Polla, and Z. L. Wang, *Appl. Phys. Lett.* 94, 191103 **(2009)**.
5. M. Law, L. E. Greene, J. C. Johnson, R. Saykally, and P. Yang, *Nat. Mater.* 4, 455 **(2005)**.
6. Z. L. Wang and J. H. Song, *Science* 312, 242 **(2006)**.
7. Y. Qin, X. D. Wang, and Z. L. Wang, *Nat.* 451, 809 **(2008)**.
8. Z. L. Wang, *Adv. Funct. Mater.* 18, 3553 **(2008)**.
9. L. Luo, Y. F. Zhang, S. S. Mao, and L. W. Lin, *Sens. Actuators, A* 127, 201 **(2006)**.
10. T. Y. Wei, C. T. Huang, B. J. Hansen, Y. F. Lin, L. J. Chen, S. Y. Lu, and Z. L. Wang, *Appl. Phys. Lett.* 96, 013508 **(2010)**.
11. Y. B. Li, F. D. Valle, M. Simonnet, I. Yamada, and J. J. Delaunay, *Appl. Phys. Lett.* 94, 023110 **(2009)**.
12. C. S. Lao, M. C. Park, Q. Kuang, Y. Deng, A. K. Sood, D. L. Polla, and Z. L. Wang, *J. Am. Chem. Soc.* 129, 12096 **(2007)**.
13. R. S. Aga, D. Jowhar, A. Ueda, Z. Pan, W. E. Collins, R. Mu, K. D. Singer, and J. Shen, *Appl. Phys. Lett.* 91, 232108 **(2007)**.
14. C. Geng, Y. Jiang, Y. Yao, X. M. Meng, J. A. Zapien, C. S. Lee, Y. Lifshitz, and S. T. Lee, *Adv. Funct. Mater.* 14, 589 **(2004)**.
15. Y. Z. Jin, H. P. Wang, B. Q. Sun, J. C. Blakesley, and N. C. Greenham, *Nano Lett.* 8, 1649 **(2008)**.
16. C. Soci, A. Zhang, B. Xiang, S. A. Dayeh, D. P. R. Aplin, J. Park, X. Y. Bao, Y. H. Lo, and D. Wang, *Nano Lett.* 7, 1003 **(2007)**.
17. B. H. Kind, H. Yan, B. Messer, M. Law, and P. Yang, *Adv. Mater.* 14, 158 **(2002)**.
18. K. Keem, H. Kim, G. T. Kim, J. S. Lee, B. Min, K. Cho, M. Y. Sung, and S. Kim, *Appl. Phys. Lett.* 84, 4376 **(2004)**.
19. J. B. K. Law and J. T. L. Thong, *Appl. Phys. Lett.* 88, 133114 **(2006)**.

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