Morphology study of 1D ZnO nanorods

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Four kinds of new one-dimensional nanostructures, celery-shaped nanorods, needle-shaped nanorods, twist fold-shaped nanorods, and awl-shaped nanorods of ZnO, have been grown on single silicon substrates by an Au catalyst assisted thermal evaporation of ZnO and active carbon powders. The morphology and structure of the pre- pared nanorods are determined on the basis of field-emission scanning electron microscopy (FESEM) and x-ray diffraction (XRD). The photoluminescence spectra (PL) analysis noted that UV emission band is the band-to-band emission peak and the emission bands in the visible range are attributed to the oxygen vacancies, Zn interstitials, or impurities. The field-emission properties of four kinds of ZnO nanorods have been invested and the awl-shaped nanorods of ZnO have preferable characteristics due to the smallest emitter radius on the nanoscale in the tip in comparison with other nanorods. The growth mechanism of the ZnO nanorods can be explained on the basis of the vapor–liquid– solid (VLS) processes.

Keywords: ZnO; Morphology; Nanorod.

1. INTRODUCTION

One-dimensional nanostructures such as wires, rods, and tubes have become the focus of intensive research owing to their unique applications in mesoscopic physics and fabrication of nanoscale devices [1]. ZnO is an important member in II–VI group semiconductors. It has profound applications in optics, optoelectronics, sensors, and actuators due to its semiconducting, piezoelectric, and pyroelectric properties [2]. 1D ZnO nanostructures have attracted great interest in the past few years [2–4]. Extensive efforts have been made to synthesize ZnO nanostructures, such as nanowires [3], nanobelts [5], nanotubes [6], nanorings [7], etc., because nanostructural morphology is one of the important factors determining the properties [2]. Field emission is one of the most fascinating properties of semiconductor 1D nanomaterials and has been extensively studied due to its importance in view of the field emission flat display, x-ray sources, and microwave devices [8]. Field-emission properties of 1D ZnO nanostructures have been reported, such as well- aligned ZnO nanowires grown at low temperature [9], ZnO nanowires on a tungsten substrate [10], ZnO nanoneedle arrays [11, 12], tetrapodlike ZnO nanostructures [13], gallium-doped ZnO nanofiber arrays [14], and ZnO nanowires grown on carbon cloth [15]. These works revealed excellent field- emission properties of the ZnO nanostructures and shed light on potential applications in the near future [16].

In this paper, four new one-dimensional nanostructures, celery-shaped nanorods, needle shaped nanorods, twist fold-shaped nanorods and awl-shaped nanorods of ZnO, have been grown on single silicon substrates by an Au catalyst assisted carbothermal evaporation of ZnO and active carbon powders. The morphology and structure of the prepared nanorods are determined on the basis of field-emission scanning electron microscopy (FESEM) and x-ray diffraction (XRD). The photoluminescence spectra (PL) analysis noted that UV emission band is the band-to- band emission peak and the emission bands in the visible range are attributed to the oxygen vacancies, Zn interstitials, or impurities. The field-emission properties of four kinds of ZnO nanorods have been invested and the awl- shaped nanorods of ZnO have preferable characteristics due to smallest emitter radius on the nanoscale in the tip in comparison with other nanorods. The growth mechanism of the ZnO nanorods can be explained on the basis of the vapor– liquid–solid (VLS) processes.

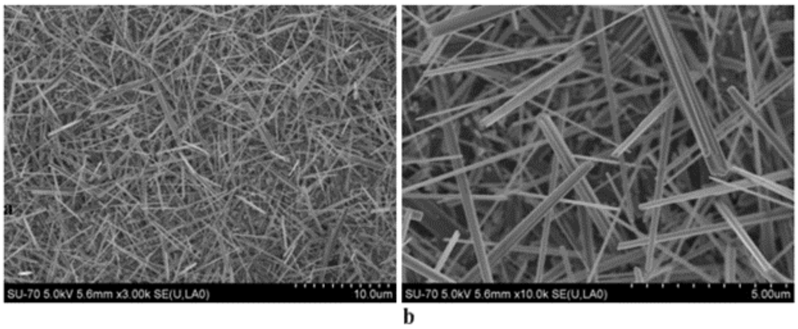

Fig. 1 (a), (b) The low magnified FESEM image of ZnO celery-shaped nanorods.

2. EXPERIMENTAL

The synthesis of these ZnO nanorods is minutely depicted as follows. The Au layer (about 10 nm in thickness) is de- posited on single silicon (001) substrates with an area of 5 mm2 by sputtering. Note that we do not find that silver plays any catalyst role in the synthesis of ZnO nanorods in our case. The active carbon and ZnO powders (both 99.99 %) are mixed in a 1:1 weight ratio and placed into a small quartz tube. The four Si substrates covered by Au are put near the mixture of carbon and ZnO inside the small quartz tube. Then the small quartz tube is pulled into a large quartz tube, and together they are inserted in a horizontal tube electric furnace. The whole system is evacuated by a vacuum pump for 20 minutes, then the Argon gas is guided into the system at 50 sccm, and the pressure is kept at 350 Torr. Afterward, the system is rapidly heated up to 1030 °C from the room temperature and kept at the temperature for 1 hour. Finally, the system is cooled down to the room temperature in several hours. When four substrates are taken out, we can see gray production on substrates. Field emission scanning electron microscopy (FESEM) and x-ray diffraction (XRD) are employed to identify the morphology and structure of the synthesized productions. Note that we can easily repeat the experimental results, suggesting that our method is flexible and reproducible.

3. RESULTS AND DISCUSSION

Morphologies of the synthesized ZnO nanorods in four substrates are shown as Figs. 1–4. The celery-shaped nanorods of ZnO are shown in Fig. 1. Figure 1(a), (b) is a low- magnified FESEM image. Figure 1(c), (d) is a high magnified FESEM image, from which the morphologies of the celery-shaped nanorods of ZnO are clearly displayed and the size of the celery-shaped nanorods of ZnO is about 300–400 nm. The needle-shaped nanorods of ZnO are shown in Fig. 2. Figure 2(a), (b) is a low-magnified FESEM image. Figure 2(c), (d) is a high magnified FESEM image, from which the morphologies of the needle-shaped nanorods of ZnO are clearly displayed. The average size of the needle- shaped nanorods of ZnO is about 150–200 nm, and the tip of the needle-shaped nanorods of ZnO is about 50 nm. The twist fold-shaped nanorods of ZnO are shown in Fig. 3. Figure 3(a), (b) is a low-magnified FESEM image. Figure 3(c), (d) is a high magnified FESEM image, from which the morphologies of the twist fold-shaped nanorods of ZnO are clearly displayed. The average size of the twist fold-shaped nanorods of ZnO is about 100 nm, and the tip of the twist fold-shaped nanorods of ZnO is about 25 nm. The awl- shaped nanorods of ZnO are shown in Fig. 4. Figure 4(a), (b) is a low-magnified FESEM image. Figure 4(c), (d) is a high magnified FESEM image, from which the morphologies of the awl-shaped nanorods of ZnO are clearly displayed. The average size of the awl-shaped nanorods of ZnO is about 80–100 nm, and the tip of the awl-shaped nanorods of ZnO is about 10 nm.

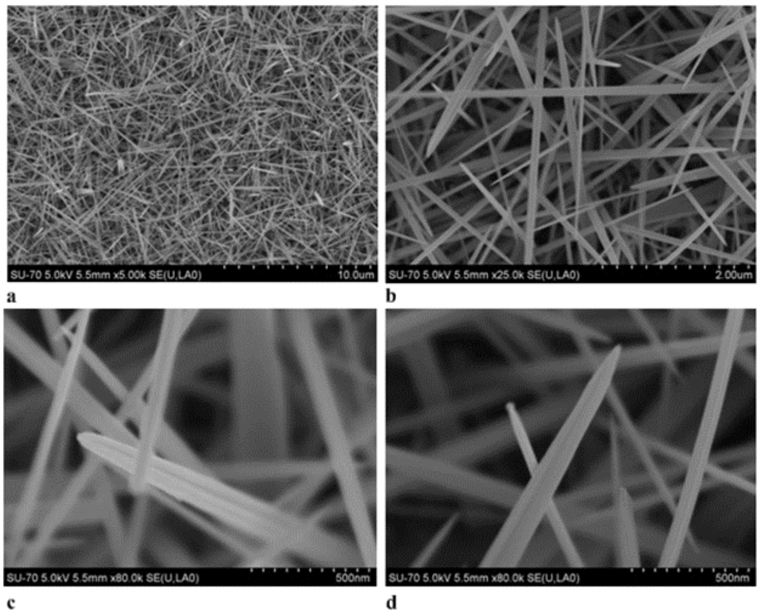

Fig. 2 (a), (b) The low magnified FESEM image of ZnO needle-shaped nanorods. (c), (d) The high magnified FESEM image of ZnO needle-shaped nanorods.

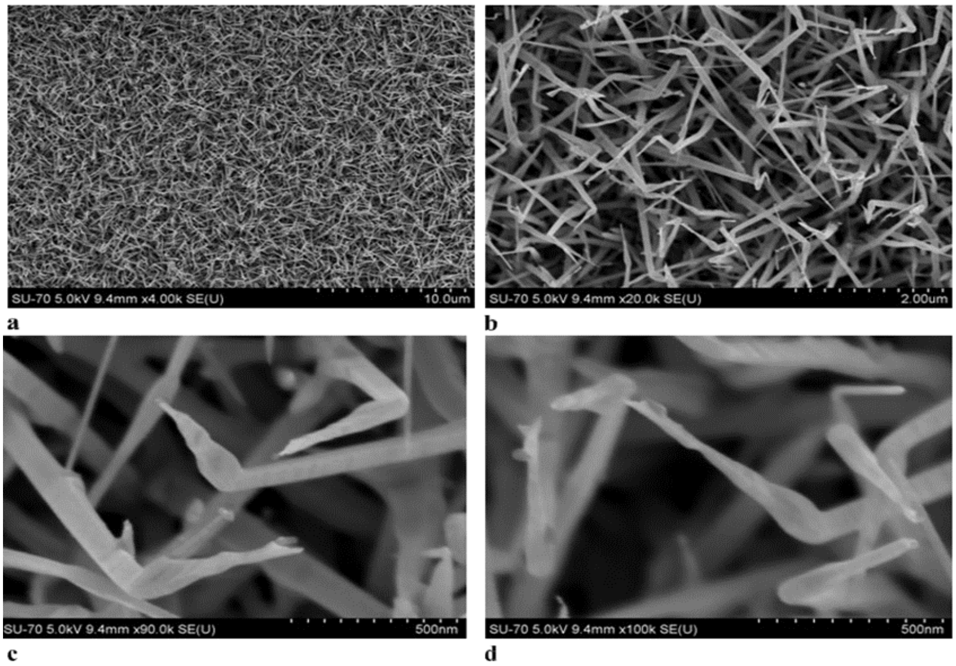

Fig. 3 (a), (b) The low magnified FESEM image of ZnO twist fold-shaped nanorods. (c), (d) The high magnified FESEM image of ZnO twist fold-shaped nanorods.

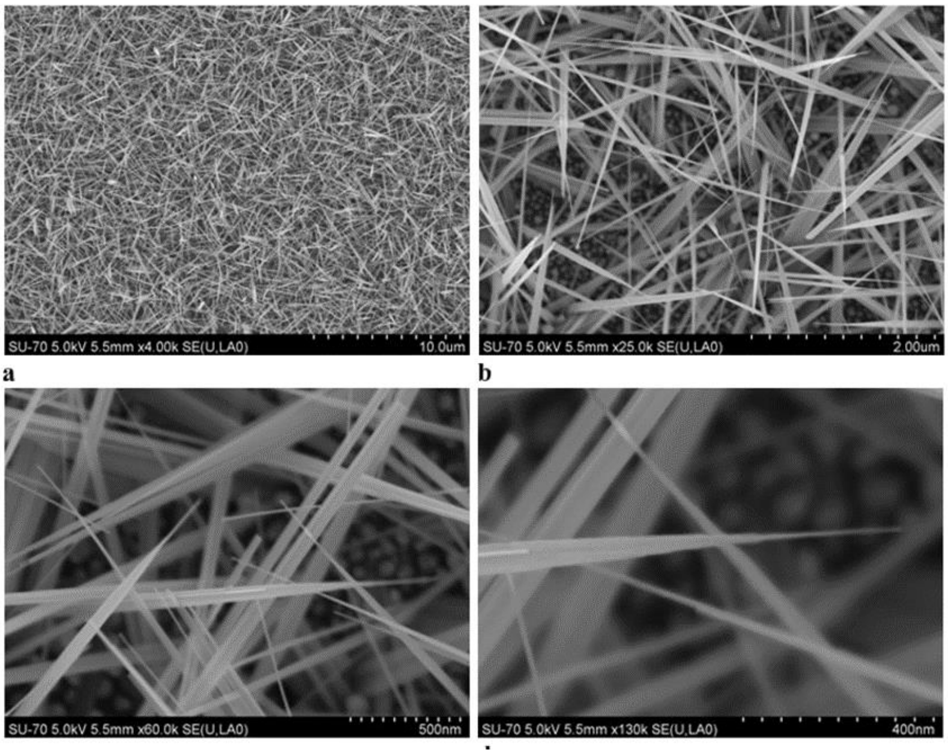

Fig. 4 (a), (b) The low magnified FESEM image of ZnO awl-shaped nanorods. (c), (d) The high magnified FESEM image of ZnO awl-shaped nanorods.

4. CONCLUSIONS

In summary, four kinds of new one-dimensional nanostructures, celery-shaped nanorods, needle-shaped nanorods, twist fold-shaped nanorods, and awl-shaped nanorods of ZnO, have been grown on single silicon substrates by an Au catalyst assisted carbothermal evaporation of ZnO and active carbon powders. The morphology and structure of the prepared nanorods are determined on the basis of field- emission scanning electron microscopy (FESEM) and x- ray diffraction (XRD). The photoluminescence spectra (PL) analysis noted that UV emission band is the band-to-band emission peak and the emission bands in the visible range are attributed to the oxygen vacancies, Zn interstitials, or im- purities. The field-emission properties of four kinds of ZnO nanorods have been invested and the awl-shaped nanorods of ZnO have preferable characteristics due to the smallest emitter radius on the nanoscale in the tip in comparison with other nanorods. The growth mechanism of the ZnO nanorods can be explained on the basis of the vapor–liquid– solid (VLS) processes.

References

[1] B. Wang, Y.H. Yang, C.X. Wang, G.W. Yang, J. Appl. Phys. 98, (2005) 073520
[2] J.X. Wang, X.W. Sun, A. Wei, Y. Lei, X.P. Cai, C.M. Li, Z.L. Dong, Appl. Phys. Lett. 88 (2006) 233106
[3] Y. Li, G.W. Meng, L.D. Zhang, F. Phillipp, Appl. Phys. Lett. 76 (2000) 2011
[4] C.X. Xu, X.W. Sun, Z.L. Dong, M.B. Yu, Appl. Phys. Lett. 85 (2004) 3878
[5] Z.W. Pan, Z.R. Dai, Z.L. Wang, Science 291 (2001) 947
[6] W.Z. Xu, Z.Z. Ye, D.W. Ma, H.M. Lu, L.P. Zhao, B.H. Zhao, X.D. Yang, Z.Y. Xu, Appl. Phys. Lett. 87 (2005) 093110
[7] P.X. Gao, Y. Ding, W.J. Mai, W.L. Hughes, C.S. Lao, Z.L. Wang, Science 309 (2005) 1700
[8] B. Wang, Y.H. Yang, C.X. Wang, N.S. Xu, G.W. Yang, J. Appl. Phys. 98 (2005) 124303
[9] C.J. Lee, T.J. Lee, S.C. Lyu, Y. Zhang, H. Ruh, H.J. Lee, Appl. Phys. Lett. 81 (2002) 3648
[10] L.F. Dong, J. Jiao, D.W. Tuggle, J.M. Petty, S.A. Elliff, M. Coul- ter, Appl. Phys. Lett. 82 (2003) 1096
[11] Y.W. Zhu, H.Z. Zhang, X.C. Sun, S.Q. Feng, J. Xu, Q. Zhao, B. Xi- ang, R.M. Wang, D.P. Yu, Appl. Phys. Lett. 83 (2003) 144
[12] H.Z. Zhang, R.M. Wang, Y.W. Zhu, J. Appl. Phys. 96 (2004) 624
[13] Q.H. Li, Q. Wan, Y.J. Chen, T.H. Wang, H.B. Jia, D.P. Yu, Appl. Phys. Lett. 85 (2004) 636
[14] Halima Mazari, Kheira Ameur, Aicha Boumesjed, Reski Khelifi, Sedik Mansouri, Nadia Benseddik, Nawal Benyahya, Zineb Benamara, Jean-Marie Bluet, Exp. Theo. NANOTECHNOLOGY 4 (2020) 49
[15] Bassam Ramadhn Sarheed, Muhammed Abdul gafor, Mustafa. R. Al-Shaheen, Mohammed R. Alshaheen, Exp. Theo. NANOTECHNOLOGY 4 (2020) 59
[16] M. C. Benesten, C. J. Thordor, C. Anderson, Exp. Theo. NANOTECHNOLOGY 4 (2020) 67