Growth of silicon nanowires and germanium nanowires via a solid -liquid-solid mechanism

李麗英、李世鴻

E-mail: 322127@mail.dyu.edu.tw

ABSTRACT

Up to the present time, Si nanowires (SiNWs) and Ge nanowires (GeNWs) have been successfully synthesized using metal as catalyst by a solid-liquid-solid (SLS) growth mechanism. The characterization of nanowires and its application in field emission have been studied. In this work, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) images were used to observe the surface morphology and geometric structure, energy dispersive spectrometer (EDS) was used to identify and analyze the chemical composition on the surface of nanowires. In this task, direct growth of SiNWs from silicon substrate with a Ni thin film (5-25 nm) at a temperature of 1000°C is successfully achieved, and direct growth of GeNWs from germanium substrate with an Au thin film (1-9 nm) at a temperature in the range of 550°C-650°C is achieved as well. The minimum average diameter of SiNWs and the minimum average diameter of GeNWs are found to be about 45.5 nm and 38.5 nm, respectively. Both SiNWs and GeNWs are long (up to several micrometers in length). Compared with GeNWs, SiNWs are even longer, thus have a larger aspect ratio than that of GeNWs. The SiNWs are crooked, while the GeNWs are straight. Obviously, the morphologies of both nanowires are not exactly the same. Nevertheless, it is identified that both kinds of nanowires are surrounded by an amorphous outer oxide shell layer. The composition of corresponding oxide layers for SiNWs and GeNWs are SiOx and GeOx (x

Keywords : Si nanowires、Ge nanowires、field emission

Table of Contents

REFERENCES

[1]R. Wang, G. Zhou, Y. Liu, S. Pan, H. Zhang, D. Yu, and Z. Zhang, Raman spectral study of SiNWs: High-order scattering and phonon confinement effects, Phys. Rev. B 61 (2000) 16827-16832.
[2]S. C. Tsang, Y. K. Chen, P. J. F. Harris, and M. L. H. Green, A simple chemical method of opening and filling carbon nanotubes, Nature 372 (2002) 159 – 162.
[3]W. K. Hsu, M. Terrones, H. Terrones, N. Grobert, A. I. Kirkland, J. P. Hare, K. Prassides, P. D. Townsend, K. W. Kroto, and D. R. M. Walton, Electrochemical formation of novel nanowires and their dynamic effects, Chem. Phys. Lett. 284 (1998) 177-183.
[4]Y. Wu, R. Fan, and P. Yang, Block-by-block growth of single-crystalline Si/SiGe superlattice nanowires, Nano Lett. 2 (2002) 83 – 86.
[5]R. N. Musin and X-Q. Wang, Structural and electronic properties of epitaxial core-shell nanowire heterostructures, Phys. Rev. B 71 (2005) 155318-155321.
[6]Ajay Agarwal, K. Buddharaju, I. K. Lao, N. Singh, N. Balasubramanian, and D. L. Kwong, Silicon nanowire sensor array using top – down CMOS technology, Sensors and Actuators A 145 – 146 (2008) 207 – 213.
[7]Inkyu Park, Zhiyong Li, Xuema Li, Albert P. Pisano, and R. Stanley Williams, Towards the silicon nanowire-based sensor for intracellular biochemical detection, Biosens. & Bioelectron. 22 (2007) 2065 – 2070.
[8]M. Hofheinz, X. Jehl, M. Sanquer, G. Molas, M. Vinet, and S. Deleonibus, Simple and controlled single electron transistor based on doping modulation in silicon nanowires, Appl. Phys. Lett. 89 (2006) 143504-143506.
[9]J. Zhang, Y. Yang, F. Jiang, J. Li, B. Xu, S. Wang, and X. Wang, Fabrication of semiconductor CdS hierarchical nanostructures, J. Cryst. Growth 293 (2006) 236 – 241.
[10]T. Q. Jia, H. X. Chen, M. Huang, X. J. Wu, F. L. Zhao, M. Baba, M. Suzuki, H. Kuroda, J. R. Qiu, R. X. Li, and Z. Z. Xu, ZnSe nanowires grown on the crystal surface by femtosecond laser ablation in air, Appl. Phys. Lett. 89 (2006) 101116-101118.
[11]J. C. Harmand, G. Patriarche, N. P?臆??Laperne, M-N. M?臆at-Combes, L. Travers, and F. Glas, Analysis of vapor – liquid – solid mechanism in Au-assisted GaAs nanowire growth, Appl. Phys. Lett. 87 (2005) 203101-203103.
[12]H. D. Park, S. M. Prokes, M. E. Twigg, R. C. Cammarata, and A-C. Gaillot, Si assisted growth of InAs nanowires, Appl. Phys. Lett. 89 (2006) 223125-223127.
[13]Z. G. Bai, D. P. Yu, H. Z. Zhang, Y. Ding, Y. P. Wang, X. Z. Gai, Q. L. Hang, G. C. Xiong, and S. Q. Feng, Nano-scale GeO2 wires synthesized by physical evaporation, Chem. Phys. Lett. 303 (1999) 311 – 314.
[14]H. Z. Zhang, Y. C. Kong, Y. Z. Wang, X. Du, Z. G. Bai, J. J. Wang, D. P. Yu, Y. Ding, Q. L. Hang, and S. Q. Feng, Ga2O3 nanowires prepared by physical evaporation, Solid State Communications 109 (1999) 677 – 682.
[15]Hyun D. Park and S. M. Prokes, Study of the initial nucleation and growth of catalyst-free InAs and Ge nanowires, Appl. Phys. Lett. 90 (2007) 203104-1~203104-3.
[16]Hwa Young Kim, Jeunghee Park, and Hyunik Yang, Synthesis of silicon nitride nanowires directly from the silicon substrates, Chem. Phys. Lett. 372 (2003) 269-274.
[17]Bohr-Ran Huang, Jung-Fu Hsu, Chien-Sheng Huang, Yu-Tai Shih, and Kao-Sheng Lu, Silicon nanowire networks for the application of field effect phototransistor, Mater. Sci. Eng. C 27 (2007) 1197 – 1200.
[18]H. C. Lin, M. H. Lee, C. J. Su, T. Y., Huang, C. C. Lee, and Y. S. Yang, A simple and low-cost method to fabricate TFTs with poly-Si nanowire channel, IEEE Electron Device Lett. 26 (2005) 643-645.
[19]Q. H. Wang, A. A. Setlur, J. M. Lauerhaas, J. Y. Dai, E. W. Seeling and R. P. H. Chang, A nanotube-based field-emission flat panel display, Appl. Phys. Lett. 72 (1998) 2912-2913.
[20]A. I. Klimovskaya, O. E. Raichev, A. A. Dadykin, Yu. M. Litvina, P. M. Lytvyn, I. V. Prokopenko, T. I. Kaminsc, S. Sharmac, and Yu. Moklyak, Quantized field-electron emission at 300K in self-assembled arrays of silicon nanowires, Physica E 37 (2007) 212 – 217.
[21]Y. Maeda, N. Tsukamoto, Y. Yazawa, Y. Kanemitsu, and Y. Masumoto, Visible photoluminescence of Ge microcrystals embedded in SO2 glassy matrices, Appl. Phys. Lett. 59 (1991) 3168.
[22]R. S. Wagner and W. C. Ellis, Vapor-liquid-solid mechanism of single crystal growth and its application to silicon, Appl. Phys. Lett. 4 (1964) 89-90.
[23]J. Westwater, D. P. Gosain, S. Tomiya, and S. Usui, Growth of silicon nanowires via gold /silane vapor-liquid-solid reaction, J. Vac. Sci. Tech. B 15 (1997) 554-557.
[24]Y. Zhang, N. Wang, R. He, J. Liu, X. Zhang, and J. Zhu, A simple method to synthesize Si3N4 and SiO2 nanowires from Si or Si/SiO2 mixture, J. Cryst. Growth 233 (2001) 803-808.

[25]L. Dai, X. L. Chen, T. Zhou, and B. Q. Hu, Aligned silica nanofibres, J. Phys. Condens. Matter. 14 (2002) 473-477.
[26]L. Dai, X. L. Chen, J. K. Jian, W. J. Wang, T. Zhou, and B. Q. Hu, Strong blue photoluminescence from aligned silica nanofibers, Appl. Phys. Lett. 76 (2003) 625-627.
[27] J. D. Holmes, K. P. Johnston, R. C. Doty, and B. A. Korgel, Control of thickness and orientation of solution-grown silicon nanowires, Science 287 (2000) 1471-1473.
[28]Timothy J. Trentler, Kathleen M. Hickman, Subhash C. Goel, Ann M. Viano, Patrick C. Gibbons, and William E. Buhro, Solution-liquid-solid growth of crystalline III-V semiconductors: an analogy to vapor-liquid-solid growth, Science 270 (1995) 1791-1794.
[29]H. F. Yan, Y. J. Xing, Q. L. Hang, D. P. Yu, Y. P. Wang, J. Xu, Z. H. Xi, and S. Q. Feng, Growth of amorphous silicon nanowires via a solid-liquid-solid mechanism, Chem. Phys. Lett. 323 (2000) 224-228.
[30]Y. J. Xing, Z. H. Xi, Z. Q. Xue, and D. P Yu, Diameter modification of Si nanowires via catalyst size, Chinese. Phys. Lett. 20 (2003) 700.
[31]S. H. Sun, G. W. Meng, T. Gao, M. G. Zhang, Y. T. Tian, X. S. Peng, Y. X. Jin, and L. D. Zhang, Micrometer-sized Si-Sn-O novel structures with SiONWs on their surfaces, Appl. Phys. A: Mater. Sci. & Processing 76 (2003) 999-1002.
[32]C. Y. Wang, L. H. Chan, D. Q. Xiao, T. C. Lin, and H. C. Shih, Mechanism of solid-liquid-solid on the silicon oxide nanowire growth, J. Vac. Sci. Technol. B 24 (2006) 613-617.
[33]B. T. Park and K. Yong, Controlled growth of core – shell Si – SiOx and amorphous SiO2 nanowires directly from NiO/Si, Nanotechnology 15 (2004) 365-370.
[34]M. Paulose, O. K. Varghese, and C. A. Grimes, Synthesis of gold-silica composite nanowires through solid-liquid-solid phase growth, J. Nanosci. Nanotech. 3 (2003) 341-345.
[35]D. P. Yu, C. S. Lee, I. Bello, G. W. Zhou, Z. G. Bai, Z. Zhang, and S. Q. Feng, Synthesis of nano-scale silicon wires by excimer laser ablation at high temperature, Solid State Commun. 105 (1998) 403-407.
[36]G. Zhou, Z. Zhang, and D. P. Yu, Growth morphology and micro-structural aspects of Si nanowires synthesized by laser ablation, J. Cryst. Growth 197 (1999) 129-135.
[37]Y. F. Zhang, Y. H. Tang, N. Wang, D. P. Yu, C. S. Lee, I. Bello, and S. T. Lee, Silicon nanowires prepared by laser ablation at high temperature, Appl. Phys. Lett. 72 (1998) 1835-1837.
[38]Y. Q. Chen, K. Zhang, B. Miao, B. Wang, and J. G. Hou, Temperature dependence of morphology and diameter of silicon nanowires synthesized by laser ablation, Chem. Phys. Lett. 358 (2002) 396 – 400.
[39]N. Fukata, T. Oshima, N. Okada, T. Kizuka, T. Tsurui, S. Ito, and K. Murakami, Phonon confinement in silicon nanowires synthesized by laser ablation, Physica B : Condensed Matter. 376 – 377 (2006) 864 – 867.
[40]J. L. Liu, S. J. Cai, G. L. Jin, S. G. Thomas, and K. L. Wang, Growth of Si whiskers on Au/Si (111) substrate by gas source molecular beam epitaxy (MBE), J. Cryst. Growth 200 (1999) 106-111.
[41]L. Schubert, P. Werner, N. D. Zakharov, G. Gerth, F. M. Kolb, L. Long, and U. Go sele, Silicon nanowhiskers grown on (111) Si substrates by molecular-beam epitaxy, Appl. Phys. Lett. 84 (2004) 4968-4970.
[42]Z. G. Bai, D. P. Yu, H. Z. Zhang, Y. Ding, Y. P. Wang, X. Z. Gai, Q. L. Hang, G. C. Xiong, and S. Q. Feng, Nano-scale GeO2 wires synthesized by physical evaporation, Chem. Phys. Lett. 303 (1999) 311 – 314.
[43]D. P. Yu, Z. G. Bai, Y. Ding, Q. L. Hang, H. Z. Zhang, J. J. Wang, Y. H. Zou, W. Qian, G. C. Xiong, H. T. Zhou, and S. Q. Feng, Nanoscale silicon wires synthesized using simple physical evaporation, Appl. Phys. Lett. 72 (1998) 3458-3460.
[44]D. P. Yu, Y. J. Xing, Q. L. Hang, H. F. Yan, J. Xu, Z. H. Xi, and S. Q. Feng, Controlled growth of oriented amorphous silicon nanowires via a solid-liquid-solid (SLS) mechanism, Physica E 9 (2001) 305 – 309.
[45]J. Niu, J. Sha, and D. Yang, Silicon nanowires fabricated by thermal evaporation of silicon monoxide, Physica E 23 (2004) 131-134.
[46]V. Sivakov, F. Heyroth, F. Falk, G. Andra, and S. Christiansen, Silicon nanowire growth by electron beam evaporation: Kinetic and energetic contributions to the growth morphology, J. Cryst. Growth 300 (2007) 288 – 293 [47]K. Q. Peng, Y. J. Yang, S. P. Gao, and J. Zhu, Synthesis of large-area silicon nanowire arrays via self-assembling nanoelectrochemistry, Adv. Mater. 14 (2002) 1164 – 1167.
[48]K. Q. Peng, Y. J. Yang, S. P. Gao, and J. Zhu, Dendrite-assisted growth of silicon nanowires in electroless metal deposition, Adv. Funct. Mater. 13 (2003) 127 – 132.
[49]K. Q. Peng and J. Zhu, Morphological selection of electroless metal deposits on silicon in aqueous fluoride solution, Electrochimica Acta 49 (2004) 2563-2568.
[50]Y. L. Chueh, L. J. Chou, S. L. Cheng, J. H. He, W. W. Wu, and L. J. Chen, Synthesis of taperlike Si nanowires with strong field emission, Appl. Phys. Lett. 86 (2005) 133112-1~133112-3.
[51]Y-L. Chueh, C. N. Boswell, C-W. Yuan, S. J. Shin, K. Takei, J. C. Ho, H. Ko, Z. Fan, E. E. Haller, D. C. Chrzan, and A. Javey, Nanoscale structural engineering via phase segregation: Au-Ge System, Nano Lett. 10 (2010) 393-397.
[52]N. O. V. Plank, L. Jiang, and R. Cheung, Fluorination of carbon nanotubes in CF4 plasma, Appl. Phys. Lett. 83(12) (2003) 2426 – 2428.
[53]T. C. Cheng, J. Shieh, W. J. Huang, M. C. Yang, and M. H. Cheng, Hydrogen plasma dry etching method for field emission application, Appl. Phys. Lett. 88 (2006) 263118-263120.

[54]S. F. Lee, Y. P. Chang, and L.Y. Lee, Enhancement of field emission characteristics for multi-walled carbon nanotubes treated with a mixed solution of chromic trioxide and nitric acid, Acta Physico-Chimica Sinica 24 (2008) 1411-1416.
[55]M. Sekine, Dielectric film etching in semiconductor device manufacturing: Development of SiO2 etching and the next generation plasma reactor, Appl. Surf. Sci. 192 (2002) 270-298.
[56]K. Ishikawa, M. Okigawa, Y. Ishikawa, S. Samukawa, and S. Yamasaki, In vacuo measurements of dangling bonds created during Ar-diluted fluorocarbon plasma etching of silicon dioxide films, Appl. Phys. Lett. 86 (2005) 264104-264106.
[57]R. Knizikevi?ius, Simulation of Si and SiO2 etching in CF4 plasma, Vacuum 82 (2008) 1191 – 1193.
[58]Chun Li, Guojia Fang, Su Sheng, Zhiqiang Chen, Jianbo Wang, Shuang Ma, Xingzhong Zhao, Raman spectroscopy and field electron emission properties of aligned silicon nanowire arrays, Physica E 30 (2005) 169-173.
[59]Ha Jin Kim, In Taek Han, Young Jun Park, Jong Min Kim, Jong Bong Park, Bum Kwon Kim, and Nae Sung Lee, Synthesis of hybrid multiwall carbon nanotubes and their enhanced field emission properties, Chem. Phys. Lett. 396 (2004) 6 – 9.
[60]Y-M. Shyu and F. C-N. Hong, Low-temperature growth and field emission of aligned carbon nanotubes b chemical vapor deposition, Mater. Chem. Phys. 73 (2001) 223-227.
[61]F. C. K. Au, K. W. Wong, Y. H. Tang, Y. F. Zhang, I. Bello, and S. T. Lee, Electron field emission from silicon nanowires, Appl. Phys. Lett. 75 (1999) 1700.