The Effect of Plasma Treatments on the Field Emission Characteristics of SiOx Nanowires

洪違仁、李世鴻

E-mail: 9707390@mail.dyu.edu.tw

ABSTRACT

In this work, a layer of nickel was evaporated onto a (100) silicon substrate to induce the precipitation of silicon at 1000 ° C for 2 hours in order to grow SiOx nanowires. The thickness of nickel layer was varied to study its effects on the field emission characteristics of SiOx nanowires. As observed from SEM graphs, the average diameter of SiOx nanowires varies almost linearly with the thickness of catalyst Ni layer. It can be concluded that thicker Ni layer produces lager and fewer catalyst balls in the nucleation stage resulting in larger and fewer SiOx nanowires. These larger and fewer SiOx nanowires in turn emit less current due to lower curvature at the tip and lower quantity of emission sites. Therefore, the thickness of Ni layer must be kept to minimum in order to obtain decent field emission characteristics. Even so, the emitted currents from SiOx nanowires are still lower than those emitted from carbon nanotube. It is found in this study that the screening effect of SiOx nanowires can be effectively reduced and the tip can be modified by Ar plasma treatment so that electrons can emit easily from the tips. On the other hand, conglomeration phenomenon of SiOx nanowires is found after CF4 plasma treatment which increases the surface density of SiOx nanowires and the number of emission sites. Hence, the field emission characteristics of SiOx nanowires are enhanced and field emission characteristics comparable to those of carbon nanotubes are achieved after plasma post-treatment. These results clearly manifest the potential of using SiOx nanowire in field emitter applications, and this is quite different to what people might think. Keywords: SiOx nanowires, field emission, metal-induced precipitation, Si-Ni alloy

Keywords : SiOx nanowires ; field emission ; metal-induced ; Si-Ni alloy

Table of Contents

REFERENCES

[1] A. S. Edelstein and R. C. Cammarata, Chap. 1 in "Nanomaterails: Synthesis, Properties and Applications", Ed. by A. S. Edelstein and R. C. Cammarata, lOP Publishing. (1996).
[2] H. W. Kroto, J. R. Heath, S. C. O ' Brian, R. F. Curl, & R. E. Smalley, " C60: Buckminsterfullerene " , Nature. 318, pp. 162-163. (1985).
[3] W. Kratschmer, L. D. Lamb, K. Fostiropoulos, & D. R. Huffman, " A new form of carbon. Nature " , Solid C60. 347, pp. 354-358. (1990).
[4] A. Maiti, C. J., Brabec, C. Roland, &, J. Bernholc, " Theory of carbon nanotube growth " , Phys. Rev. Lett. 52, pp. 14850-14858. (1995).
[5] 林景崎，"奈米材料導論"，(2004)。
[6] T. C. Cheng,a_ J. Shieh, W. J. Huang, M. C. Yang, M. H. Cheng, H. M. Lin, and M. N. Chang, App. Phys. Lett. 88, pp. 263118. (2006).
[7] D. Whang, S. Jin, Y. Wu and C. M. Lieber, " Large-Scale Hierarchical Organization of Nanowire Arrays for Integrated Nanosystems " , Nano Lett. 3, pp. 1255-1259. (2003).
[8] J. Xiang, W. Lu, Y. Hu, Y. Wu, H. Yan ,and C. M. Lieber, " Ge/Si nanowire heterostructures as highperformance field-effect transistors " , Nature. 441, pp. 498-493. (2006).
[9] 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, pp. 1700. (1999).
[10] S. T. Purcell, V. T. Binh and N. Garcia, " 64 meV measured energy dispersion from cold field emission nanotips " , Appl. Phys. Lett. 67, pp. 436. (1995).
[11] W. A. Deheer, A. Chatelain and D. Ugarte, " A carbon nanotube field-emission electron source " , Science. 270, pp. 1179. (1995).
[12] Iijima S. " Helical microtubules of graphitic carbon " , Nature. 354, pp.56-58. (1991).
[13] 李元?，何?，唐先忠，等. "納米氧化錫的製程與特性測試"，實驗科學與技術，1, pp.61-62. (2003)。
[14] 田時開，江天府，楊興華，曾葆青，"碳納米管薄膜的製程及處理對場發射特性的影響"，電子科技大學學報，第36卷，第6期. (2006)。
[15] N. D. Jonge, Y. Lamy, K. Schoots, et al. " High brightness electron beam from a multi-walled carbon nanotube " , Nature. 420, pp. 393-395. (2002).
[16] 張兆祥，張耿明，侯士敏，等. "碳納米管的薄膜場發射"，真空科學技術學報，23, pp. 27-32. (2003)。
[17] W. Zhu, " Vacuum Microelectronics " , Wiley, New York. (2001).
[18] N. S. Xu, and S. Ejaz Huqb, Mater. Sci. Eng. 48, pp. 47. (2005).
[19] W. A. de Heer, A. Chatelain, and D. Ugarte, Science. 269, pp. 1179. (1995).
[20] Y. B. Li, Y. Bando, D. Golberg, and K. Kurashima, " Field emission from MoO3 nanobelts " , Appl. Phys. Lett. 81, pp. 5048. (2002).
[21] Y. Tu, Z. P. Huang, D. Z. Wang, J. G. Wen, and Z. F. Ren, " Growth of aligned carbon nanotubes with controlled site density " , Appl. Phys. Lett. 80, pp. 4018. (2002).
[22] G. Z. Yue, Q. Qiu, B. Gao, Y. Cheng, J. Zhang, H. Shimoda, S. Chang, J. P. Lu, and O. Zhou, " Generation of continuous and pulsed diagnostic imaging x-ray radiation using a carbon-nanotube-based field-emission cathode " , Appl. Phys. Lett. 81, pp. 355. (2002).
[23] C. S. Hsieh, G. Wang, D. S. Tsai, R. S. Chen, and Y. S. Huang, " Field emission characteristics of ruthenium dioxide nanorods " , Nanotechnology. 16, pp. 1885-1891. (2005).
[24] C. K. A. Frederick, 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, pp. 1700. (1999).
[25] D. Banerjee, S. H. Jo, and Z. F. Ren, Adv. Mater. Weinheim, Ger. 16, pp. 2028. (2004).
[26] J. Zhou, L. Gong, S. Z. Deng, J. Chen, J. C. She, N. S. Xu, R. Yang, and Z. Wang, " Growth and field-emission property of tungsten oxide nanotip arrays " , Appl. Phys. Lett. 87, pp. 223108. (2005).
[27] Y. H. Tang, X. H. Sun, F. C. K. Au, L. S. Liao, H. Y. Peng, C. S. Lee, S. T. Lee, and T. K. Sham, " Microstructure and field-emission characteristics of boron-doped Si nanoparticle chains " , Appl. Phys. Lett. 79, pp. 1673. (2001).
[28] M. Lu, M. K. Li, L. B. Kong, X. Y. Guo, and H. L. Li, " Synthesis and characterization of well-aligned quantum silicon nanowires arrays " ,

Composites. 35, pp. 179. (2004).
[29] A. M. Morales, and C. M. Lieber, “ A Laser Ablation Method for the Synthesis of Crystalline Semiconductor Nanowires ”, Science. 279, pp. 208-211. (1998).
[30] 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, pp. 224-228. (2000).
[31] S. T. Lee, Y. F. Zhang, N. Wang, Y. H. Tang, I. Bello, C. S. Lee, and Y. W. Chung, “ Semiconductor nanowires from oxides ”, Mater. Res. 14, pp. 4503-4507. (1999).
[32] Z. L. Wang, R. P. Gao, Z. W. Pan, and Z. R. Dai, “ Nano-scale mechanics of nanotubes,nanowires, and nanobelts ”, Adv. Eng. Mater. 3, pp. 657. (2001).
[33] C. X. Xu, and X. W. Sun, “ Field emission from zinc oxide nanopins ”, Appl. Phys. Lett. 83, pp. 3806. (2003).
[34] J. Niu, J. Sha, X. Ma, J. Xu, and D. Yang, “ Array-orderly single crystalline silicon nano-wires ”, Chem. Phys. Lett. 367, pp. 528-532. (2003).
[35] L. Gangloff, E. Minoux, K. B. K. Teo, P. Vincent, V. T. Semet, V. T. Binh, M. H. Yang, I. Y. Y. Bu, R. G. Lacerda, G. Pirio, J. P. Schnell, D. Pribat, D. G. Hasko, G. A. J. Amaratunga, W. I. Milne, and P. Legagneux, Nano Lett. 4, pp. 1575. (2004).
[36] L. Dvorson, G. Sha, I. Kymissis, C. Y. Hong, and A. Akinwande, “ Electrical and optical characterization of field emitter tips with integrated vertically stacked focus ”, IEEE Trans. Electron Devices. 50, pp. 2548-2558. (2003).
[37] S. Itoh, M. Tanaka, and T. Tonegawa, “ Development of field emission displays ”, J. Vac. Sci. Technol. 22, pp.1362-1366. (2004).
[38] Y. Cui, and Charles M. Lieber, “ Functional nanoscale electronic devices assembled using silicon nanowire building blocks “, Science. 291, pp. 851-853. (2001).
[39] Baoqing. Zeng, Guangyong. Xiong, Shuo. Chen, S. H. Jo, W. Z. Wang, D. Z. Wang, and Z. F. Ren, “ Field emission of nanowires ”, App. Phys. Lett. 88, pp. 213108. (2006).
[40] T. C. Cheng, J. Shieh, W. J. Huang, M. C. Yang, M. H. Cheng, “ Hydrogen plasma dry etching method for field emission application ”, App. Phys. Lett. 88, pp. 263118. (2006).
[41] M. J. Yang, J. Shieh, S. L. Hsu, I. J. Huang, C. C. Leu, S. W. Shen, T. Y. Huang, P. Lehnen, and C. H. Chien, “ Low-temperature growth of polycrystalline Ge films on SiO2 substrate by HDPCVD ”, Electrochem. Solid-State Lett. 8, pp. C74. (2005).
[42] 楊閔智，謝健，許瓊姿，鄭宗杰，”以氫電漿乾式蝕刻法製作準直矽奈米草陣列”，奈米通訊.第十二卷第三期.pp. 44-49。
[43] M. C. Yang, J. Shieh, C. C. Hsu, and T. C. Cheng, “ Well-aligned silicon nanograss fabricated by hydrogen plasma dry etching ”, Electrochem. Solid- State Lett. 8, pp. C131. (2005).
[44] R. H. Fowler, and L. Nordheim, Proc. R. Soc. London. 119, pp. 137. (1928).
[45] S. Sadewasser, Th. Glatzel, M. Rusu, A. Jager-Waldau, and M. Ch. Lux-Steiner, “ High-resolution work function imaging of single grains of semiconductor surfaces ”, Appl. Phys. Lett. 80, pp. 2979. (2002).
[46] J. M. Bonard, K. A. Dean, B. F. Coll, and C. Klinke, “ Field Emission of Individual Carbon Nanotubes in the Scanning Electron Microscope ”, Phys. Rev. Lett. 89, pp. 197602. (2002).
[47] J. M. Bonard, K. A. Dean, B. F. Coll, and C. Klinke, Phys. Rev. Lett. 89, pp. 197602. (2002).
[48] M. C. Rossi, S. Salvatori, P. Ascarelli, E. Cappelli, and S. Orlando, “ Effect of nanostructure and back contact material on the field emission properties of carbon films ”, Diamond Relat. Mater. 11, pp. 819-823. (2002).
[49] 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, pp. 1700. (1999).
[50] C. J. Edgcombe, and U. Valdre', Philos. Mag. 82, pp. 987. (2002).
[51] C. A. Spindt, I. Brodie, L. Humphrey, and E. R. Westerberger, J. App. Phys.Lett. 47, pp. 5248. (1976).
[52] E. Minoux, O. Groening, K. B. J. Teo, S. H. Dalal, L. Gangloff, J. P. Schnell, L.Hudanski, I. Y. Y. Bu, P. Vincent, P. Legagneux, G. A. J. Amaratunga, and W. I. Milne, Nano Lett. 5, pp. 2135. (2005).
[53] C. N. R. Rao, F. L. Deepak, G. Gundiah, and A. Gorindarj, Prog. Solid State Chem. 31, pp. 5. (2003).
[54] R. S. Wagner, and W. C. Ellis, “ Vapor-liquid-solid mechanism of single crystal growth ”, App. Phys. Lett. 4, pp. 89. (1964).
[55] R. S. Wagner, and W. C. Ellis, Trans. Met. Soc. AIME. 233, pp. 1053. (1965).
[56] R. S. Wagner, “ Whisker technology ”, Edited by App. Phys. Lett., Wiley New York. 3, pp. 47-119. (1970).
[57] Y. Wu and P. Yang, J. Am.Chem. ” Direct observation of vapor-liquid-solid nanowire growth ”, Science. 123, pp. 3165-3166. (2001).
[58] Y. W. Wang, C. H. Liang, G. W. Meng, X. S. Peng, and L. D. Zhang, J. Matter. Chem. 12, pp. 651. (2002).
[59] D. P. Yu, Q. L. Hang, Y. Ding, H. Z. Zhang, Z. G. Bai, J. J. Wang, Y. H. Zou, W. Qian, G. C. Xiong, and S. Q. Feng, “ Amorphous silica nanowires: Intensive blue light emitters ”, Appl. Phys. Lett. 73, pp. 3076. (1998).
[60] H. F. Zhang, C. M. Wang, Edgar C. Buck, and L. S. Wang, “ Synthesis, characterization, and manipulation of helical SiO2 Nanosprings ”, Nano Lett. 3, pp. 577-580. (2003).
[61] X. C. Wu, W. H Song, K. Y. Wang, T. Hu, B. Zhao, Y. P. Sun, and J. J. Du, “ Preparation and photoluminescence properties of amorphous silica nanowires ”, Chem. Phys. Lett. 336, pp. 53. (2001).

[62] Y. J. Chen, J. B. Li, Y. S. Han, Q. M. Wei, and J. H. Dai, " A novel morphology of SiOx nanowires with a modified " , App. Phys. Lett. 74, pp. 433-435. (2002).
[63] J. C. Wang, C. Z. Zhan, and F. G. Li, " The synthesis of silica nanowire arrays " , Solid State Commun. 125, pp. 629-631. (2003).
[64] Z. W. Pan, Z. R. Dai, C. Ma, and Z. L. Wang, J. Am, Chem. Soc. 124, pp. 1817. (2002).
[65] S. H. Sun, G. W. Meng, M. G. Zhang, Y. T. Tian, T. Xie, and L. D. Zhang, Solid State Commun. 128, pp. 287. (2003).
[66] J. Hu, Y. Bando, J. Zhan, X. Yuan, T. Sekiquchi, and D. Golberg, Adv. Matter. 17, pp. 971. (2005).
[67] S. T. Lee, N. Wang, Y. F. Zhang, and Y. H. Tang, " Oxide-assisted semiconductor nanowire growth " , MRS Bull. 24, pp 36-42. (1999).
[68] S. T. Lee, Y. F. Zhang, N. Wang, Y. H. Tang, I. Bello, C. S. Lee, and Y. W. Chung, and Y. W. Chung, J. Mater. Res. 14, pp. 4503. (1999).
[69] N. Wang, Y. H. Tang, Y. F. Zhang, C. S. Lee, and S. T. Lee, Phys. Rev. 58, pp. R16024. (1998).
[70] T. S. Chu, R. Q. Zhang, and H. F. Cheung, " Geometric and electronic structures of silicon oxide clusters " J. Phys. Chem. 105, pp. 1705-1709. (2001).
[71] R. Q. Zhang, Y. Lifshitz, and S. T. Lee, Adv. Matter. 15, pp. 635. (2003).
[72] X. M. Meng, J. Q. Hu, Y. Jiang, C. S. Lee, and S. T. Lee, " Oxide-assisted growth and characterization of Ge/SiOx nanocables " , App. Phys. Lett. 83, pp. 2241. (2003).
[73] Y. Cui, L. J. Lauhon, M. S. Gudiksen, J. F. Wang, C. M. Lieber, " Diameter-controlled synthesis of single-crystal silicon nanowires " , App. Phys. Lett. 78, pp. 2214. (2001).
[74] G. W. Zhou, H. Li, H. P. Sun, D. P. Yu, Y. Q. Wang, X. J. Huang, L. Q. Chen, and Z. Zhang, App. Phys. Lett. 75, pp. 2447. (1999).
[75] D. D. D. Ma, C. S. Lee, F. C. K. Au, S. Y. Tong, S. T. Lee, " Small-diameter silicon nanowire surfaces " , Science. 299, pp. 1874. (2003).
[76] Y. F. Zhang, Y. H. Tang, N. Wang, C. S. Lee, I. Bello, and S. T. Lee, " Germanium nanowires sheathed with an oxide layer " , Phys. Rev. 61, pp. 4518-4521. (2000).
[77] W. S. Shi, Y. F. Zheng, N. Wang, C. S. Lee,and S. T. Lee, " Microstructures of gallium nitride nanowires synthesized by oxide-assisted method " , Chem. Phys. Lett. 345, pp. 377-380. (2001).
[78] H. Y.Peng, X. T. Zhou, N. Wang, Y. F. Zheng, L. S. Liao, W. S. Shi, C. S. Lee,and S. T. Lee, Chem. Phys. Lett. 327, pp. 263. (2000).
[79] W. S. Shi, Y. F. Zheng, N. Wang, C. S. Lee, and S. T. Lee, Adv. Matter. 13, pp. 591. (2001).
[80] W. S. Shi, Y. F. Zheng, N. Wang, C. S. Lee, and S. T. Lee, " Oxide-assisted growth and optical characterization of gallium-arsenide nanowires " , App. Phys. Lett. 78, pp. 3304. (2001).
[81] W. S. Shi, Y. F. Zheng, N. Wang, C. S. Lee, and S. T. Lee, J. Vac, Sci. Technol. 19, pp. 1115. (2001).
[82] J. Q. Hu, X. L. Ma, Z. Y. Xie, N. B. Wong, C. S. Lee, I. Bello, and S. T. Lee, Chem. Phys. Lett. 344, pp. 97. (2001).
[83] Y. H. Tang, N. Wang, Y. F. Zhang, C. S. Lee, I. Bello, and S. T. Lee, " Synthesis and characterization of amorphous carbon nanowires " , Appl. Phys. Lett. 75, pp. 2921. (1999).
[84] K. H. Lee, S. W. Lee, R. R. Vanflee, and W. Sigmund, Chem. Phys. Lett. 376, pp. 498. (2003).
[85] 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, pp. 803-808. (2001).
[86] L. Dai, X. L. Chen, T. Zhou, and B. Q. Hu, " Aligned silica nanofibres " , J. Phys.:Condens. Matter. 14, pp. L473. (2002).
[87] 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, pp. 625-627. (2003).
[88] T. J. Trentler, K. M. Hickman, S. C. Goel, Ann M. Viano, Patrick C. Gibbons, and W. E. Buhro, " Solution-liquid-solid growth of crystalline III-V semiconductors: An analogy to vapor-liquid-solid growth " , Science. 270, pp. 1791-1974. (1995).
[89] X. Lu, T. Hanrath, K. P. Johnston, and B. A. Korgel, " Growth of single crystal silicon nanowires in supercritical solution from tethered gold particles on a silicon substrate " , Nano Lett. 3, pp. 93-99. (2003).
[90] Y. J. Xing, Z. H. Xi, Z. Q. Xue, and D. P Yu, Chin. Phys. Lett. 20, pp. 700. (2003).
[91] Y. J. Xing, Z. H. Xi, D. P. Yu, Q. L. Hang, H. F. Yan, S. Q. Feng, and Z. Q. Xue, " Growth of silicon nanowires by heating Si substrate " , Chin. Phys. Lett. 19, pp. 240. (2002).
[92] 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 structures With SiOx nanowires on their surface " , Appl. Phys. Lett. 76, pp. 999-1002. (2003).
[93] B. T. Park, and K. Yong, " Controlled growth of core – shell Si – SiOx and amorphous SiO2 nanowires directly from NiO/Si " , Nanotechnology. 15, pp. S365-370. (2004).
[94] M. Paulose, O. K. Varghese, and C. A. Grimes, J. Nanosic. Nanotech. 3, pp. 341. (2003).
[95] K. H. Lee, H. S. Yang, K. H. Baik, J. Bang, R. R. Vanfleet, and W. Sigmund, " Direct growth of amorphous silica nanowires by solid state transformation of SiO2 films " , Chem. Phys. Lett. 383, pp. 380. (2004).
[96] H. Hanamura, H. Itoh, Y. Shimogaki, J. Aoyama, T. Yoshimi, J. Ueda, and H. Komiyama, Thin Solid Films. 320, pp. 31. (1998).
[97] Lieberman, M. A., and A. J. Lichtenberg, " Principles of Plasma Discharges and Materials Processing " , John Wiley & Sons Inc. (1994).
[98] H. Xiao, " Introduction to Semiconductor Manufacturing Technology, " Prentice Hall Inc. (2001).

[99] 李世鴻著，積體電路製程技術 ”， 五南圖書出版公司印行，(1998)。
[100] C. H. Liang, G. W. Meng, L. D. Zhang, Y. C. Wu, Z. Cui, “ Large-scale synthesis of β-SiC nanowires by using mesoporous silica embedded with Fe nanoparticles ” , Chem Phys Lett. 329, pp. 323-328. (2000).
[101] D. C. Bell, Y. Wu, C. J. Barrelet, S. Gradecak, J. Xiang, B. P. Timko, and C. M. Lieber, Microse. Res. Tech. 64, pp. 373. (2004).
[102] H. Takikawa, M. Yatsuki, and T. Sakakibara, “ Synthesis of silicon oxide nanofibers by sublimation of SiC in medium vacuum with oxygen flow ” , Jpn. J. Appl. Phys. 38, pp. L401. (1999).
[103] Y. W. Zhu, F. C. Cheong , T. Yu, X. J. Xu, C. T. Lim, J. T. L. Thong, Z. X. Shen, C. K. Ong, Y. J. Liu, A. T. S. Wee, C. H. Sow, “ Effects of CF4 plasma on the field emission properties of aligned multi-wall carbon nanotube films ” , Carbon. 43, pp. 395-400. (2005).
[104] 許博凱著，奈米碳管電漿後處理對場發射特性之影響 ”， 大葉大學碩士論文，(2007)。
[105] 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 ” , App. Phys. Lett. 86, pp. 133112. (2005).