The Electrical Characteristics of Aluminum-Doped Zinc Oxide Nanorods and p-Type Silicon Heterojunctions

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ABSTRACT

In this study, aluminum-doped zinc oxide (Al-doped ZnO) nanorods which were prepared with doping aluminum nitrate (Al(NO3)3・9H2O) by solution growth method on p-type silicon substrate were fully characterized. First, ethyl alcohol (C2H5OH) was added to zinc acetate (Zn(CH3COO)2・2H2O) to form a 0.0075M mixed solution. This mixed solution was then used to form a seeding layer on silicon substrate by spin coating. Subsequently, mixed solutions using 0.02M hexamethylenetetramine (C6H12N4), 0.02M zinc nitrate hexahydrate (Zn(NO3)2・6H2O), and aluminum nitrate (Al(NO3)3・9H2O) of various concentrations were prepared. And the growth was carried out in the mixed solution at 90?C for two hours. As observed from field-emission scanning electron microscope (FE-SEM), the synthesized ZnO are hexagonal nanorods indeed. The chemical components of Al-doped ZnO nanorods were determined from energy diffraction spectroscopy (EDS) and are zinc, oxygen, and aluminum. The conductivity type for Al-doped ZnO nanorods is n-type indeed as was determined from Hall effect measurement, and the conductivity has been increased substantially by aluminum nitrate concentration; while mobility for majority carrier decreases with aluminum nitrate. As expected, the Al-doped ZnO nanorods prepared by aluminum nitrate of different concentrations also exhibit different I-V characteristics. In addition, the photoluminescence (PL) characteristic peak is in the range between 376.1nm and 379.4nm for Al-doped ZnO nanorods. Lastly, Al-doped ZnOnanorods were fabricated on a p-type silicon substrate to form a n-ZnO/p-Si heterojunction. This n-ZnO/p-Si heterojunction exhibits rectifying characteristics and its parameters such as reverse saturation current and ideality factor have been successfully determined.

Keywords : aluminum-doped zinc oxide (Al-doped ZnO)、Hall effect measurement、photoluminescence (PL)、n-ZnO/p-Si heterojunction

Table of Contents

REFERENCES

[1]A. P. Alivisatos, Semiconductor clusters, nanocrystals, and quantum dots, Science, New Series, 271 (1996) 933.
[2] http://www.almaden.ibm.com/via/stm/corral.html.
[3]S. Iijima, Helical microtubules of graphitic carbon, Nature, 354 (1991) 56.
[4]H. D. Sun, T. Makino, Y. Segawa, M. Kawasaki, A. Ohtomo, K. Tamura and H. Koinuma, Enhancement of exciton binding energies in ZnO/ZnMgO multiquantum wells, Appl. Phys., 91 (2002) 1993.
[5]R. Wang, L. H. King and A. W. Sleight, Highly conducting transparent thin films based on zinc oxide, J. Mater., 11 (1996) 1659.
[6]Z. L. Wang, X. Y. Kong, Y. Ding, P. X. Gao, W. L. Hughes, R. Yang and Y. Zhang, Semiconducting and piezoelectric oxide nanostructures induced by polar surfaces, Adv. Funct. Mater., 14 (2004) 943.
[7]F. Vigue, P. Vennegues, S. Vezian, M. Laugt and J. -P. Faurie, Defect characterization in ZnO layers grown by plasma-enhanced molecular beam epitaxy on (0001) sapphire substrates, Appl. Phys. Lett., 79 (2001) 194.
[8]H. L. Hartnagel, A. K. Jain and C. Jagadish, Semiconducting transparent thin films, Institute of Physics Publication, 17 (1995) 219.
[9]A. Wei, W. Sun, C. X. Xu, Z. L. Dong, Y. Yang, S. T. Tan and W. Hung, Growth mechanism of tubular ZnO formed in aqueous solution, Nanotechnology, 17 (2006) 1740.
[10]Z. M. Liaoa, H. Z. Zhangb, Y. B. Zhoua, J. Xua, J. M. Zhang and Da-Peng Yua, Surface effects on photoluminescence of single ZnO nanowires, Phys. Lett., 372 (2008) 4505.
[11]K. Yu, Z. Jin, X. Liu, Z. Liu and Y. Fu, Synthesis of size-tunable ZnO nanorod arrays from NH3 · H2O/ZnNO3 solutions, Mater. Lett., 61 (2007) 2775.
[12]Y. S. Cui, S. Y. Zhang, J. Chen, D. P. Yu, S. L. Zhang, L. Niu and J. Z. Jiang, Study on the quantum confinement effect onultraviolet photoluminescence of crystalline ZnO nanoparticles with nearly uniform size, Appl. Phys. Lett., 90 (2007) 263113.
[13]林素霞，「氧化鋅薄膜的特性改良及應用之研究」，國立成功大學材料科學及工程研究所博士論文，2003年。
[14] O. Lupan, S. Shishiyanu, V. Ursaki, H. Khallaf, L. Chow, T. Shishiyanu,V. Sontea, E. Monaico and S. Railean, Synthesis of nanostructured Al-doped zinc oxide films on Si for solar cells applications, Sol. Energy Mater. Sol. Cells, 93 (2009) 1417.
[15]楊明輝，「金屬氧化物透明導電材料的基本原理」，工業材料，179期，133頁，2001年。
[16]W. Tang and D. C. Cameron, Aluminum-doped zinc oxide transparent conductors deposited by the sol-gel process, Thin Solid Films, 238 (1994) 83.
[17]T. Schuler and M. A. Aegerter, Optical, electrical and structural properties of sol-gel ZnO:Al coatings, Thin Solid Films, 351 (1999) 125.
[18]S. B. Majumder, M. Jain, P. S. Dobal and R. S. Katiyar, Investigations on solution derived aluminum doped zinc oxide thin films, Mater. Sci. Eng. B, 103 (2003) 16.
[19]Jin-Hong Lee and Byung-Ok Park, Transparent conducting ZnO:Al,In,Sn thin films deposited by the sol-gel method, Thin Solid Films, 426 (2003) 94.
[20]V. Musat, Teixeira, E. Fortunato, R. C. C. Monteiro and P. Vilarinho, Al-doped ZnO thin films by sol-gel method, Surf. Coat. Technol., 180 (2004) 659.
[21]G. G. Valle, P. Hammer, S. H. Pulcinelli and C. V. Santilli, Transparent and conductive ZnO:Al thin films prepared by sol-gel dip-coating, J. Euro. Ceram. Soc., 24(6) (2004) 1009-1013.
[22]G. K. Paul and S. K. Sen, Sol-gel preparation, characterization and studies on electrical and thermoelectrical properties of gallium doped zinc oxide films, Mater. Lett., 57 (2002) 742.
[23] H. Gomeza, A. Maldonadoa, M. dela, L. Olveraa and D. R. Acosta, Gallium-doped ZnO thin films deposited by chemical spray, Sol. Energy Mater. Sol. Cells, 87 (2005) 107.
[24]K. Y. Cheong, Norani Muti and S. Roy Ramanan, Electrical and optical studies of ZnO:Ga thin films fabricated via the sol-gel technique, Thin Solid Films, 410 (2002) 142.
[25]Xuhu Yu, Jin MaT, Feng Ji, Yuheng Wang, Xijian Zhang and Honglei Ma, Influence of annealing on the properties of ZnO:Ga films prepared by radio frequency magnetron sputtering, Thin Solid Films, 483 (2005) 296.
[26]Seung-Yup Lee and Byung-Ok Park, Electrical and optical properties of In2O3-ZnO thin films prepared by sol-gel method, Thin Solid Films, 484 (2005) 184.
[27]E. J. Luna-Arredondo, A. Maldonado, R. Asomoza, D. R. Acosta, M. A. Melendez-Lira and M. de la L. Olvera, Indium-doped ZnO thin films deposited by the sol-gel technique, Thin Solid Films, 490 (2005) 132.
[28]H. T. Cao, C. Sun, Z. L. Pei, A. Y. Wang, L. S. Wen, R. J. Hong and X. Jiang, Properties of transparent conducting ZnO:Al oxide thin films and their application for molecular organic light-emitting diodes, J. Mater. Sci.: Mater. Electron., 15 (2004) 169.
[29]I. Sieber, N. Wanderka, I. Uran, I. Dorfel, E. Schierhom, F. Fenske and W. Fuhs, Electron microscopic characterization of reactively sputtered ZnO films with different Al-doping levels, Thin Solid Films, 330 (1998) 108.
[30]D. H. Zhang, T. L. Yang, Q. P. Wang and D. J. Zhang, Electrical and optical properties of Al-doped transparent conducting ZnO films

deposited on organic substrate by RF sputtering, Mater. Chem. Phys., 68 (2001) 233.
[31]N. Naghavi, A. Rougier, C. Marcel, C. Guery, J. B. Leriche and J. M. Tarascon, Characterization of indium zinc oxide thin films prepared by pulsed laser deposition using a Zn3In2O6 target, Thin Solid Films, 360 (2000) 233.
[32]Z. Q. Xu, H. Deng, Y. Li, Q. H. Guo and Y. R. Li, Characteristics of Al-doped c-axis orientation ZnO thin films prepared by the sol-gel method, Mater. Resea. Bull., 41 (2006) 354.
[33]Toshio Tsuchiya, Tomohiro Emoto and Tadanori Sei, Preparation and properties of transparent conductive thin by the sol-gel process, J. Non-Cryst. Solids, 178 (1994) 327.
[34]Z. W. Pan, Z. R. Dai and Z. L. Wang, Nanobelts of semiconducting oxides, Sci., 291 (2001) 1947.
[35]Y. C. Kong, D. P. Yu, B. Zhang, W. Fang and S. Q. Feng, Ultraviolet-emitting ZnO nanowires synthesized by a physical vapor deposition approach, Appl. Phys. Lett., 78 (2001) 407.
[36]J. H. Choi, H. Tabata and T. Kawai, Initial preferred growth in zinc oxide thin films on Si and amorphous substrates by a pulsed laser deposition, J. Cryst. Growth, 226 (2001) 493.
[37]J. Y. Lee, Y. S. Choi, J. H. Kim, M. O. Park and S. Im, Optimizing n-ZnO/p-Si heterojunctions for photodiode applications, Thin Solid Films, 403 (2002) 553.
[38]W. I. Park, D. H. Kim, S. W. Jung and G. Yi, Metal organic vapor-phase epitaxial growth of vertically well-aligned ZnO nanorods, Appl. Phys. Lett, 80 (2002) 4232.
[39]C. L. Wu, Li Chang, H. G. Chen, C. W. Lin, T. F. Chang, Y. C. Chao and J. K. Yan, Enhancing nano-crystalline silicon thin film crystallization fraction performance with argon and hydrogen annealing, Thin Solid Films, 498 (2006) 137.
[40]Q. Li, V. Kumar, Y. Li, H. Zhang, T. J. Marks and R. P. H. Chang, Fabrication of ZnO nanorods and nanotubes in aqueous solutions, Chem. Mater., 17 (2005) 1001.
[41]林坰青，「利用熱蒸鍍法合成摻雜鋁之氧化鋅奈米結構與特性探討」，國立清華大學材料科學工程學系碩士論文，2007年。
[42]Te-Hua Fang and Shao-Hui Kang, Physical properties of ZnO:Al nanorods for piezoelectric nanogenerator application, Curr. Nanosci., 6 (2010) 000.
[43]L. Vayssieres, Growth of arrayed nanorods and nanowires of ZnO from aqueous solution, Adv. Mater, 15 (2003) 464.
[44]K. K. Kim, H. Tampo, J. O. Song, T. Y. Seong, S. J. Park, J. M. Lee, S. W. Kim, S. Fujita and S. Niki, Effect of rapid thermal annealing on Al doped n-ZnO films grown by RF-magnetron sputtering, Jpn. J. Appl. Phys., 44 (2005) 4776.
[45]A. Teke, U. Ozgur, S. Dogan, X. Gu, H. Morkoc, B. Nemeth, J. Nause and H. Everitt, Excitonic fine structure and recombination dynamics in single crystalline ZnO, Phys. Rev. B, 70 (2004) 195207.
[46]J. D. Ye, S. L. Gu, S. M. Zhu, W. Liu, S. M. Liu , R. Zhang, Y. Shi and Y. D. Zheng, Electroluminescent and transport mechanisms of n-ZnO/p-Si heterojunctions, Appl. Phys. Lett., 88 (2006) 182112.
[47]劉全璞，「一維氧化鋅奈米材料摻雜技術研究」，國立成功大學材料科學及工程學系，2009年。
[48]K. Govender, D. S. Boyle, P. B. Kenway and P. O ’ Brien, Understanding the factors that govern the deposition and morphology oh thin films of ZnO from aqueous solution, J. Mater. Chem., 14 (2004) 2575.
[49]S. Bethke, H. Pan and B. W. Wessels, Luminescence of heteroepitaxial zinc oxide, Appl. Phys. Lett., 52 (1998) 138.
[50]Z. Zhou, W. Peng, S. Ke and H. Deng, Tetrapod-shaped ZnO whisker and its composites, J. Mater. Process. Technol., 89 (1999) 415.
[51]M. Satoh, N. Tanaka, Y. Ueda, S. Ohshio and H. Saitoh, Epitaxial growth of zinc oxide whiskers by chemical-vapor deposition under atmospheric pressure, Jpn. J. Appl. Phys., 38 (1999) 586.
[52]M. H. Hwang, Room-temperature ultraviolet nanowire nanolasers, Science, 292 (2001) 1897.
[53]Y. W. Wang, L. D. Zhang, G. Z. Wang, X. S. Peng, Z. Q. Chu and C. H. Liang, Catalytic growth of semiconducting zinc oxide nanowires and their photoluminescence properties, J. Cryst. Growth, 234 (2002) 171.
[54]P. Yang, H. Yan, S. Mao, R. Russo, J. Johnson, R. Saykally, N. Morris, J. Pham, R. He and H. J. Choi, Controlled growth of ZnO nanowires and their optical properties, Adv. Funct. Mater., 12 (2002) 323.
[55]S. C. Lyu, Y. Zhang, H. Ruh, H. J. Lee, H. W. Shim, E. K. Suh and C. J. Lee, Low temperature growth and photoluminescence of well-aligned zinc oxide nanowires, Chem. Phys. Lett., 363 (2002) 134.
[56]S. Y. Li, C. Y. Lee and T. Y. Tseng, Copper-catalyzed ZnO nanowires on silicon (100) grown by vapor-liquid-solid process, J. Cryst. Growth, 247 (2003) 357.
[57]M. J. Zheng, L. D. Zhang, G. H. Li and W. Z. Shen, Fabrication and optical properties of large-scale uniform zinc oxide nanowire arrays by one-step electrochemical deposition technique, Chem. Phys. Lett., 363 (2002) 123.
[58]L. Vayssieres, K. Keis, A. Hagfeldt and S. E. Lindquist, Three-dimensional array of highly oriented crystalline ZnO microtubes, Chem. Mater., 13 (2001) 4395.
[59]J. Q. Hu, Synthesis of uniform hexagonal prismatic ZnO whiskers, 14 (2002) 1216.
[60]Y. C. Wang, I. C. Leu and M. H. Hon, Preparation of nanosized ZnO arrays by electrophoretic deposition, Electrochem. Solid State Lett., 5 (2002) 4.

[61]R. F. Service, Will UV lasers beat the blues? Sci., 895 (1997) 276.
[62]R. A. Laudise and A. A. Ballman, Hydrothermal synthesis of zinc oxide and zinc sulfide, J. Phys. Chem., 64 (1960) 688.
[63]H. Ohta, M. Orita and M. Hirano, Fabrication and characterization of ultraviolet-emitting diodes composed of transparent p-n heterojunction, p-SrCu2O2 and n-ZnO, J. Appl. Phys., 89 (2001) 5720.
[64]H. Kawazoe, M. Tasukawa, H. Hyodo, M. Kurita, H. Yanagi and H. Hosono, p-type electron conduction in transparent thin films of CuAlO2, Nature (London), 389 (1997) 939.
[65]A. Kudo, H. Yanagi, H. Hosono and H. Kawazoe, SrCu2O2: A p-type conductive oxide with wide band gap, Appl. Phys. Lett., 73 (1998) 220.
[66]Y. R. Ryu, W. J. Kim and H. W. White, Fabrication of homostructural ZnO p-n junctions, J. Cryst. Growth, 219 (2000) 419.
[67]H. Nagayama, H. Honda and H. Kawahera, A new process for sili coating, J. Electrochem., 135 (1998) 2013.
[68]Wen-Jun Li, Growth mechanism and growth habit of oxide crystals, J. Cryst. Growth, 203 (1999) 186.
[69]Woong Lee, Catalyst-free growth of ZnO nanowires bymetal-organic chemical vapour deposition (MOCVD) and thermal evaporation, Acta Mater., 52 (2004) 3949.
[70]Zuowan Zhou, A new method for preparation of zinc oxide whiskers, Mater. Resea. Bull., 34 (1999) 1563.
[71]Zuowan Zhou, Tetrapod-shaped ZnO whisker and its composites, J. Mater. Process. Technol., 89 (1999) 415.
[72]Y. C. Wang, Preparation and characterization of nanosized ZnO arrays byelectrophoretic deposition, J. Cryst. Growth, 237 (2002) 564.
[73]Edwin Hall, On a new action of the magnet on electric currents, Amer. J. Math., 2 (1879) 00.
[74]Donald A. Neamen 著，楊賜麟譯，「半導體物理與元件」，2009年8月出版三刷，麥格羅．希爾國際股份有限公司台灣分公司。