

Hydrogenated ZnO thin film with p-type surface conductivity from plasma treatment

Gurylev V., Useinov A., Hsieh P., Su C., Perng T.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2017 IOP Publishing Ltd. Fabrication of a ZnO p-n homojunction within a single structure by a simple process is a challenging task. In this work, an intrinsic p-type surface conductive layer of ZnO with a controlled concentration of holes over n-type conductive bulk was obtained by a one-step room-temperature process via hydrogen plasma treatment. Non-contact surface sensitive techniques, such as Kelvin probe force microscopy and conductive force atomic microscopy, confirmed the existence of surface p-type conductivity through analyzing the distribution and concentration of charge carriers on the topmost surface of hydrogenated ZnO. A theoretical framework was constructed to provide a rationale of the p-type surface conductivity and justify its relation to the treatment time. It is believed that this finding will open a new possibility for the fabrication of ZnO based p-n junction devices.

<http://dx.doi.org/10.1088/1361-6463/aa6e91>

Keywords

hydrogen plasma, p-type, thin film, ZnO

References

- [1] Wang Z L 2009 ZnO nanowire and nanobelt platform for nanotechnology Mater. Sci. Eng. R 64 33-71
- [2] Chang Y T et al 2014 Excellent piezoelectric and electrical properties of lithium-doped ZnO nanowires for nanogenerator applications Nano Energy 8 291-6
- [3] Liu Y et al 2010 Conversion of p-type to n-type conductivity in undoped ZnO films by increasing operating temperature Appl. Surf. Sci. 257 1236-8
- [4] Van de Walle C G 2000 Hydrogen as a cause of doping in zinc oxide Phys. Rev. Lett. 85 1012
- [5] Janotti A and Van de Walle C G 2009 Fundamentals of zinc oxide as a semiconductor Rep. Prog. Phys. 7 126501
- [6] Lin C C, Chen S Y, Cheng S Y and Lee H Y 2004 Properties of nitrogen-implanted p-type ZnO films grown on Si₃N₄/Si by radio-frequency magnetron sputtering Appl. Phys. Lett. 84 5040-2
- [7] Ma Y et al 2013 Growth and conduction mechanism of as-doped p-type ZnO thin films deposited by MOCVD Mater. Res. Bull. 48 1239-43
- [8] Joseph M et al 2001 Fabrication of the low-resistive p-type ZnO by codoping method Physica B 302-3 140-8
- [9] Ma Y et al 2004 Control of conductivity type in undoped ZnO thin films grown by metalorganic vapor phase epitaxy J. Appl. Phys. 95 6268-72
- [10] Zeng Y J et al 2006 p-type behavior in nominally undoped ZnO thin films by oxygen plasma growth Appl. Phys. Lett. 88 262103
- [11] Li G et al 2013 Synthesis and characterization of p-n homojunction containing zinc oxide nanowires Nanoscale 5 2259-63

- [12] Shi L et al 2014 A highly efficient UV photodetector based on a ZnO microwire p-n homojunction *J. Mater. Chem. C* 2 5005-10
- [13] Wei Z P et al 2007 Room temperature p-n ZnO blue-violet light-emitting diodes *Appl. Phys. Lett.* 90 042113
- [14] Kusumori T, Nakao S and Yoshimura K 2013 Light emission from planar-type ZnO p-n junction fabricated by PLD *Phys. Status Solidi C* 10 1261-4
- [15] Xiang B et al 2007 Rational synthesis of p-type zinc oxide nanowire arrays using simple chemical vapor deposition *Nano Lett.* 7 323-8
- [16] Sharma A et al 2016 Nanoscale heterogeneity and workfunction variations in ZnO thin films *Appl. Surf. Sci.* 363 516-21
- [17] Ben C V et al 2012 Doping transition of doped ZnO nanorods measured by Kelvin probe force microscopy *Thin Solid Films* 520 4622-5
- [18] Wang Z et al 2015 Size dependence and UV irradiation tuning of the surface potential in single conical ZnO nanowires *RSC Adv.* 5 42075-80
- [19] Bandopadhyay K and Mitra J 2016 Spatially resolved photoresponse on individual ZnO nanorods: correlating morphology, defects and conductivity *Sci. Rep.* 6 28468
- [20] Beinik I et al 2011 Electrical properties of ZnO nanorods studied by conductive atomic force microscopy *J. Appl. Phys.* 110 052005
- [21] Su T and Zhang H F 2012 Influence of oxygen partial pressure on the fermi level of ZnO films investigated by Kelvin probe force microscopy *Chin. Phys. Lett.* 29 127102
- [22] Thimsen E et al 2014 High electron mobility in thin films formed via supersonic impact deposition of nanocrystals synthesized in nonthermal plasmas *Nat. Commun.* 5 5822
- [23] Chang M et al 2012 Fabrication and optoelectronic properties of core-shell biomimetic ZnO/Si nanoball arrays *RSC Adv.* 2 11089-94
- [24] Scholes G D and Rumbles G 2006 Excitons in nanoscale systems *Nat. Mater.* 5 683-96
- [25] Lawrie B J, Mu R and Haglund R F 2013 Plasmonic control of near-interface exciton dynamics in defect-rich ZnO thin films *Plasmonics* 8 693-7
- [26] Johnson J C et al 2003 Optical cavity effects in ZnO nanowire lasers and waveguides *J. Phys. Chem. B* 107 8816-28
- [27] Heo Y W, Norton D P and Pearton S J 2005 Origin of green luminescence in ZnO thin film grown by molecular-beam epitaxy *J. Appl. Phys.* 98 073502
- [28] Gurylev V, Su C Y and Perng T P 2016 Distribution pattern and allocation of defects in hydrogenated ZnO thin films *Phys. Chem. Chem. Phys.* 18 16033
- [29] Kim W et al 2012 Surface and internal reactions of ZnO nanowires: etching and bulk defect passivation by H atoms *J. Phys. Chem. C* 116 16093
- [30] Kim H R, Lee G H and Kim D H 2011 Effects of hydrogen plasma treatment on the structural and electrical properties of sputter-deposited SnO₂ thin films *J. Phys. D: Appl. Phys.* 44 185203
- [31] Feng Z C 2013 *Handbook of Zinc Oxide and Related Materials* vol 1 (Boca Raton, FL: CRC Press) p 28
- [32] Bonnel D 2001 *Scanning Probe Microscopy and Spectroscopy: Theory, Techniques, and Applications* 2nd edn (New York: Wiley) p 211
- [33] Trasatti S 1986 The absolute electrode potential: an explanatory note *Pure Appl. Chem.* 58 955-66
- [34] Datta S 2012 *Lessons from Nanoelectronics A New Perspective on Transport* (Singapore: World Scientific) pp 47-64
- [35] Sarma S D, Adam S, Hwang E H and Rossi E 2011 Electronic transport in two-dimensional graphene *Rev. Mod. Phys.* 83 407
- [36] Wang X J, Vlasenko L S, Pearton S J, Chen W M and Buyanova I A 2009 Oxygen and zinc vacancies in as-grown ZnO single crystals *J. Phys. D: Appl. Phys.* 42 175411