UNIVERSITY OF WEST BOHEMIA
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF MATERIAL SCIENCE AND TECHNOLOGY

Ph.D. Thesis

To acquire academical degree Doctor of Philosophy
in Material Science and Technology

Lucie Prušáková

DEVELOPMENT OF TRANSPARENT CONDUCTIVE OXIDES FOR PHOTOVOLTAIC APPLICATIONS

Supervisor: doc. RNDr. Pavol Šutta, Ph.D.
Date of state doctoral exam: 23.9.2011
Date of submission: 30.8.2012

Declaration

The author hereby declares that her Ph.D. thesis is entirely her own work and has not been submitted in any other form for another degree or diploma at any university or other institution. The information obtained from the published or unpublished work of other authors has been acknowledged in the text and in the list of references.

Acknowledgement

There are many of those, to whom belongs my deep thanks. At the very first place I need to thank to my parents Ilona and Josef Prušákovi, to whom I need to express my deepest gratitude for all they have taught me and done for me.

Great thanks belong to Doc. RNDr. Pavol Šutta, Ph.D., the head of our department and my mentor. Without him I could not find and feel the atmosphere and enthusiasm of the work in the labs. There is no doubt in my mind that no less acknowledgement belongs also to Prof. RNDr. Vladimír Tvarožek, Ph.D. for sharing his ideas and knowledge with me. I would like to express my thanks to members of our department – concretely Ing. Veronika Vavruňková, Ph.D.; Ing. Marie Netrvalová; Ing. Jan Říha, Ph.D. and Ing. Petr Novák and Ing. Erik Vavrinský, Ph.D.; Ing. Soňa Flickyngerová and Ing. Ivan Novotný, Ph.D from Department of Microelectronics, STU Bratislava – for inspiring and enriching discussions. Special thanks, of course, belong to my close friends, who make my life bright and joyful. Thank you.

Plzeň, 2012 ……

The result was developed within the CENTEM project, reg. no. CZ.1.05/2.1.00/03.0088 that is cofunded from the ERDF within the OP RDI programme of the Ministry of Education, Youth and Sports

Contents

Aim and outline of this work

This work is motivated by applications of ZnO thin films as a top electrode and back reflector in thin-film solar cells and the need of the light scattering improvement to increase the thin-film solar cells performance. The research presented in this thesis has been particularly focused to investigate in detail the behaviour of doped zinc oxide films in dependence on conditions of both, deposition by magnetron sputtering and post-deposition treatment.

Aims of the thesis are addressed to:

- Obtaining new knowledge and deeper understanding of the influence of chosen technological process parameters on the structure, electrical and optical properties of doped ZnO thin films.
- Estimation of difference among various doping of ZnO (Al, Ga, Sc).
- Comparison between static rf diode sputtering and dynamic rf magnetron sputtering.
- Development of post-deposition treatment to achieve effective light trapping and electrical conductivity
- Verification the application of developed ZnO films with different dopants in the pilot thin-film solar cells.

In chapter 1 you just went through the brief introduction to the problematics. In chapter 2 resent knowledge about transparent conductive oxides, specially zinc oxide is described. The chapter is focused on description of electrical and optical behaviour of ZnO important for solar cells applications. There are also some information about structure and doping of ZnO. Chapter 3 describes the brief overview of deposition techniques used for the TCO fabrication. The attention is mostly paid to sputtering process and description of phase of thin films formation. The detailed description of analytical method used for evaluation of structure, optical and electrical properties of fabricated films can be found in chapter 4. Chapter 5 introduces into the experimental details. The deposition system, substrate preparation, deposition process steps, postdeposition treatment and procedures used for thin film characterization are described here. Chapter 6 contains results and discussion of performed experiments. Each section of this chapter is divided into introduction, experimental, results and conclusions parts for easier orientation in the concrete studied problem. In final chapter 7 the contribution of the thesis is concluded.

References

[1] www.iea.org, International energy outlook 2010.doc, International Energy Agency

[2] Shafiee, S; Topal, E: When will fossil fuel reserves be diminished?, *in* Energy Policy 37 (2009) 181-189.

[3] Noyes, P.D. at al.: The toxicology of climate change: Environmental contaminants in a warming world, *in* Environmental International 35/6 (2009) 971-986.

[4] Fthenakis, V: Sustainability of photovoltaics: The case for thin-film solar cells, *in* Renewable and Sustainable Energz Reviews 13/9 (2009) 2746-2750.

[5] Poortmans, J; Arkhipov, V; Zeman, M.: Thin film solar cells: fabrication, characterization and applications, John Wiley & Sons Ltd., West Sussex, England 2006.

[6] Shah, A.V. at al.: Material and solar cell research in microcrystalline silicon, *in* Solar Energy Materials & Solar Cells 78 (2003) 469-491.

[7] Muller, J.; Rech, B.; Springer, J.; Vaněček, M.: TCO and light trapping in silicon thin film solar cells, *in* Solar Energy 77 (2004) 917-930.

[8] Baedeker, K., Ann.Phys (Leipzig), 22 (1907) 749.

[9] Zhang, H. at al.: The effects of substrate bias and reactive gas partial pressure on the resistivity of sputtered ITO films, *in* Vacuum 45 (1994) 145-148.

[10] Selvan, J.A. at al. : A new light trapping TCO for nc-Si:H solar cells, *in* Solar Energy Materials & Solar Cells 90 (2006) 3371-3376.

[11] Ü. Özgür, Ya. I. Alivov, C. Liu, A. Teke, M. A. Reshchikov, S. Doğan, V. Avrutin, S.-J. Cho, and H. Morkoç: A comprehensive review of ZnO materials and devices. J. Appl. Phys 98 (2005) 041301(103).

[12] Z.L. Wang: Towards Self-Powered Nanosystems: From Nanogenerators to Nanopiezotronics. Adv. Funct. Mater. 18 (2008) 3553-67.

[13] H. Pan, J. B. Yi, L. Shen, R. Q. Wu, J. H. Yang, J. Y. Lin, Y. P. Feng, J. Ding, L. H. Van, and J. H. Yin: Room-Temperature Ferromagnetism in Carbon-Doped ZnO. Phys. Rev. Lett. 99 (2007), 127201(4)

[14] Heiland, G; Mollwo, E.; Stockmann, F.: Electronic Processes in Zinc Oxide, *in* Solid State Physics 8 (1959) 191-323.

[15] Kroger, F.A.; Meyer, H.J.G.: The edge emission of ZnS, CdS and ZnO and its relation to the lattice vibrations of these solids, *in* Physica 20 (1954) 1149-1155.

[16] Honerlage, B.; Rossler, U.: Inelastic scattering of electrons with bound excitons, *in* Journal of Luminiscence, 12-13 (1976) 593-597.

[17] Butkhuzi, T.V. at al, J. Cryst. Growth 117 (1992) 366.

[18] Shtereva, K; Tvarožek, V. at al., Modification of sputtered zinc oxide thin films by introducting of gallium and nitrogen, *in* Proceedings of the 17th International Conference on Applied Physics of Condensed Matter, Univerzity of Žilina, Slovak Republic 2011, ISBN 978-80-554-0386-1.

[19] Klingshirn, C.F. at al: Zinc Oxide: From Fundamental Properties Towards Novel Applications, Springer-Verlag, Berlin Heidlberg 2010, ISBN 978-3-642-10576-0.

[20] L. Schmidt-Mende and J. L. MacManus-Driscoll: ZnO – nanostructures, defects, and devices. Materials Today 10(5) (2007) 40-48

[21] A.K.Chawla, D.Kaur, and R.Chandra: Structural and optical characterization of ZnO nanocrystalline films deposited by sputtering. Opt. Mater. 29(2007)995-998.

[22] A.B.Djurišić, A.M.C.Ng, and X.Y.Chen: ZnO nanostructures for optoelectronics: Material properties and device applications. Prog. Quant. Electron. 34(2010) 191-259.

[23] A. Wei, L. Pan, and W. Huang, Recent progress in the ZnO nanostructure-based sensors. Mater. Sci. Eng. B 176 (2011) 1409–1421

[24] D.Wei: Dye Sensitized Solar Cells. Int. J. Mol. Sci. 11(2010) 1103-1113.

[25] D. C. Look: Progress in ZnO Materials and Devices. J. Electron. Mater., 35 (2006), 1299-1305

[26] D.C.Look: Unusual electrical properties of hydrothermally grown ZnO. Superlattice Microstr. 42(2007) 284-289.

[27] M.D.McCluskey and S.J.Jokela: Defects in ZnO. J. Appl. Phys. 106(2009) 071101(13).

[28] D. C Look: Electrical and optical properties of p-type ZnO. Semicond. Sci. Technol. 20 (2005) S55–S61

[29] J. H. Lee, J. S. Lee, S. N. Cha, J. M. Kim, D. S. Seo, W. B. Im, and J. P. Hong: ¨

Realization of high mobility p-type co-doped ZnO: AlN film with a high density of nitrogen-radicals. Thin Solid Films 517 (2009) 3950–3953.

[30] J. A. Anta: Electron transport in nanostructured metal-oxide semiconductors. Current Opinion in Colloid & Interface Science 2012, doi:10.1016/j.cocis.2012.02.003.

[31] Q.Xu, L. Hartmann, H. Schmidt, H. Hochmuth, M. Lorez, R. Schmidt-Grund, C. Sturm, D. Spemann, and M. Grundmann: Metal-insulator transition In Co-doped ZnO: Magnetotransport properties. Phys. Rev. B (2006) 73 205342(5).

[32] M. Nadeem, A. Farooq, and T.J.Shin: Metal-insulator transition in ZnO nanopowder during thermal cycling by impedance spectroscopy. Appl. Phys. Lett. 96(2010)212104(3).

[33] J.J.Mareš, X.Feng, F. Koch, A.Kohl, and J. Krištofík: Magnetotransport in InP-based dilute single δ layers. Phys.Rev.B 50(1994) 5213-5220.

[34] J.J.Mareš, J.Krištofík, and P. Hubík: Low-field magnetoresistance anomaly in two-dimensional electron gas. Solid State Commun. 101(1997) 243-247.

[35] J.J.Mareš, J.Krištofík, P.Hubík: Quantum Transport in Boron-Doped Nanocrystalline Diamond. Chem. Vapor Depos. 14(2008) 161-172.

[36] C.Wöll: The chemistry and physics of zinc oxide surfaces. Progr. Surf. Sci. 82(2007) 55-120.

[37] M.Nakagawa and H.Mitsudo: Anomalous temperature dependence of the electrical conductivity of zinc oxide thin films. Surf. Sci. 175(1986) 157-176.

[38] A.Goldenblum, V.Bogatu, T.Stoica, Y.Goldstin, And A.Many: Weak localization effects in ZnO surface wells. Phys. Rev. B 60(1999) 5832-5838.

[39] Y.Goldstein, Y.Grinshpan, and A.Many: Negative magnetoresistance in quantized accumulation layers on ZnO surfaces. Phys. Rev. B 19(1979) 2256-2265.

[40] M.W.Allen, C.H.Swartz, T.H.Myers, T.D.Veal, C.F.McConville, and S.M.Durbin: Bulk transport measurements in ZnO: The effect of surface electron layers. Phys. Rev. B 81 (2010) 075211(6).

[41] S. Flickyngerova, J. Skriniarova, M. Netrvalova, J. Kovac Jr., I. Novotny, P. Sutta, and V. Tvarozek: Surface modification of doped ZnO thin films. Appl. Surf. Sci. 256 (2010) 5606–5609

[42] M. Netrvalova, I. Novotny, L. Prusakova, V. Tvarozek, and P. Sutta: Influence of deposition regime on physical properties of gallium doped zinc oxide films, Vacuum 86 (2012) 707–710

[43] J.J.Mareš, J.Krištofík, P.Hubík, X.Feng, J.Novák, and S.Hasenöhrl: Highly disordered two-dimensional electron system in a weak magnetic field. Europhys. Lett. (1999) 374-380.

[44] M.Nakano, A.Tsukazaki, A.Ohtomo, K.Ueno, S.Akasaka, H.Yuji, K..Nakahara, T.Fukumura, and M.Kawasaki. Electronic-Field Control of Two-Dimensional Electrons in Polymer-Gated-Oxide Semiconductor Heterostructures. Adv.Mater. 22(2010) 876-879.

[45] A.Tsukazaki, A.Ohtomo, T.Kita, Y.Ohno, H.Ohno, M.Kawasaki: Quantum Hall Effect in Polar Oxide Heterostructures. Science 315(2007) 1388-1391.

[46] J.Hüpkes, J.Müller, and B.Rech: Texture Etched ZnO:Al for Silicon Thin Film Solar Cells. In: K.Ellmer, A.Klein, and B.Rech (eds.)Transparent Conductive Zinc Oxide, Springer, Berlin (2008) pp. 359-413.

[47] V.Quemener, M.Alnes, L.Vines, O.Nilsen, H.Fjellvag, E.Monakhov, B.G.Svensson: Electronic Properties of ZnO/Si Heterojunction Prepared by ALD. Solid State Phenomena 178-179 (2011) 130-135.

[48] K.Park, J.Xi, Q.Zhang, and G.Cao: Charge Transport Properties of ZnO Nanorod Aggregate Photoelectrodes for DSCs, J.Phys.Chem.C 115(2011) 20992-20999.

[49] C.-H.Ku and J.-J.Wu: Electron transport properties in ZnO nanowire array/nanoparticle composite dye-sensitized solar cells. Appl. Phys.Lett. 91(2007) 093117(3).

[50] Y.Lin, M.Shatkhin, E.Flitsiyan, L.Chernyak, Z.Dahevsky, S.Chu, and J.L.Liu: Minority carrier transport in p-ZnO nanowires. J.Appl. Phys. 109 (2011) 0161107(3).

[51] Y.J:Zeng, L.M.C.Pereira, M.Menghini, K.Temst, A.Vantomme, J.-P.Locquet, and C.Van Haesendonck: Tuning Quantum Corrections and Magnetoresistance in ZnO Nanowires by Ion Implantation. Nano Lett. 12(2012)666-672.

[52] Özgür, Ü. at al: A comprehensive review of ZnO materials and devices, *in* Journal of Applied Physics 98 (2005) 413.

[53] Morkoc, H.; Özgür, Ü.: Zinc Oxide: Fundamentals, Materials adn Device Technology, WILEY-VCH Verlag GmbH, Germany 2009, ISBN 978-3-527-40813-9.

[54] Sze, S.M.: Physics of Semiconductor Devices: Chapter 5, WILEY-VCH Verlag GmbH, New York 1981.

[55] Edwards, P.P.; Porch, A.; Jones, M.O.; Morgan, D.V.; Perks, R.M.: Dalton Transactions 19 (2004) 2995.

[56] Look, D.C. at al. : Progress in Compound Semiconductor Materials IV-Electronic and Optoelectronic Applications, *in* Material Research Society Symposium Proceedings, vol. 829, p. B8.6.1, Boston, U.S.A. 2004

[57] Thangaraju, B.: Structural and electrical studies on highly conducting spray deposited fluorine and antimony doped SnO_2 thin films from $SnCl_2$ precursor, *in* Thin Solid Films 402 (2002) 71-78.
[58] Ellmer, K.: Resistivity of polycrystalline zinc oxide films: current status and physical limit, *in* Journal of Physics D: Applied physics 34 (2001) 3097-3108.
[59] Kostlin, H.; Frank, G.: Optimization of transparent heat mirrors based on a thin silver film between antireflection films, *in* Thin Solid Films 89 (1982) 287-293.
[60] Ellmer, K.; Wendt, R.: D.c. and r.f. magnetron sputtering of ZnO:Al films from metallic and ceramic targets: a comparative study, *in* Surface and Coatings Technology 93 (1997) 21-26.
[61] Musil, J.; Baroch, P.; Vlček, J.; Nam, K.H.; Han, J.G.: Reactive magnetron sputtering of thin films: present status and trends, *in* Thin Solid Films 475 (2005) 208-218.
[62] Ginley D. at al: Non-vacuum and PLD growth of next generation TCO materials, *in* Thin Solid Films 445 (2003) 193-198.
[63] Minami, T.; Ida, S.; Miyata, T.: High rate deposition of transparent conducting oxide thin films by vacuum arc plasma evaporation, *in* Thin Solid Films 416 (2002) 92-96.
[64] Graaf, A. at al: Development of atmospheric pressure CVD processes for high-qualiti transparent conductive oxides, *in* Energy Procedia 2 (2010) 41-48.
[65] Lin, K.; Tsai, P.: Parametric study on preparation and characterization of ZnO:Al films by sol-gel method for solar cells, *in* Material Science and Engineering B 139 (2007) 81-87.
[66] Musil, J.; Vlček, J., Baroch, P.: Materials Surface Processing by Directed Energy Techniques – chapter 3, Elsevier, Amsterdam, The Netherlands 2005.
[67] Tvarožek, V. at al: Semiconductor Technologies, In Tech, India 2010, ISBN 978-953-307-080-3.
[68] Ohring, M.: Material science of thin films, Academic Press 2001, ISBN 978-0-12-524975-1.
[69] Thorton, J. A. & Hoffman, D. W. (1989). Stress-related effects in thin films, *Thin Solid Films*, Vol., 171, pp. 5-31
[70] Yasonuri at al: Role of kinetic energy of sputtered particles in thin film formation, *in* Surface Science 386 (1997) 231-240.
[71] ranenburg at al: Tailoring growth and local composition by oblique-incidence deposition: a review and new experimental data, *in* Material Science Engineering R 11 (1994) 295-354.
[72] Valvoda, V.: X-ray diffraction structure analysis of thin films, *in* Diagnostics and applications of thin films, Proceeding of the International Summer School 27th May – 5th June 1991, Chlum u Třeboně, Czechoslovakia, Edited by Eckertová L. Růžička T.
[73] Zeman M. at al: Structural properties of amorphous silicon prepared from hydrogen-diluted silane, *in* Philosophical Magazine 89 (2009) 2435-2448.
[74] Langford, J.I.; Boultif, A.; Auffredic, J.P. and Louer, D.: J. Appl. Crystalography 26 (1993) 22.
[75] Delhez, R.; Keijser, T.H. and Mittemeijer, E.J.: Surf.Eng. 3 (1987) 331.
[76] Šutta, P.; Jackuliak, Q.: Macro-stress formation in thin films and its determination by X-ray diffraction, *in* Proceedings of the 2nd International Conference on Advanced Semiconductor Device and Microsystems 1998, 227-230.
[77] Smit, J.: The spontaneous hall effect in ferromagnetics I, *in* Physica 21 (1955) 877-887.
[78] Keithley Instruments, Inc., Measuring the Resistivity and Determining the Conductivity Type of Semiconductor Materials Using a Four-Point Collinear Probe and the Model 6221 DC and AC Current Source, Cleveland, USA, 2005.

[79] Flir Systems, Inc. Thermacam PM 595 – High Performance Handheld Infrared Camera, http://www.flir.com, Boston, USA
[80] Agilent Technologies, Inc., Agilent VEE Pro 9.2, www.agilent.com, 2010.
[81] Vavrinský, E.; Prušáková, L.; Tesař, J.; Šutta, P.; Tvarožek, V.; Benko, P.: Resistivity measurement and conductivity type determination for semiconducting materials using a four-point probe, *in* Proceedings of the 17th International Conference on Applied Physics of Condensed Matter, June 22-24 2011, ISBN 978-80-554-0386-1.
[82] Goldstein, J. at al: Scanning Electron Microscopy and X-ray Microanalysis, Springer, USA 2003, ISBN 978-0-306-47292-3.
[83] Reimer, L.: Transmission electron microscopy, *in* Diagnostics and applications of thin films, Proceeding of the International Summer School 27th May – 5th June 1991, Chlum u Třeboně, Czechoslovakia, Edited by Eckertová L. Růžička T.
[84] J.Müllerová, V.Vavruňková, P.Šutta, R.Srnánek, Proc. SPIE 7141(2008) 714103.
[85] P. Ballo, L. Harmatha, D. Donoval, *Computational Materials Science* **42**, 380, 2008
[86] K.H.Kim, K.C.Park, D-Y.Ma. in J.Appl.Phys. 81(12)(1997) 7764.
[87] E. Burstein, Phys.Rev.93 (3) (1954) 632.
[88] T. Minami, T. Yamamoto, T. Miyata, Thin Solid Films 366 (2000) 63-68
[89] H. Sato, T. Minami, S. Takata, T. Mouri, N. Ogawa, Thin solid Films, 220 (1992) 327-332
[90] Y. Cai, W. Liu, Q. He, Y. Zhang, T. Yu. Y Sun, Applied Surface Science 256 (2010) 1694–1697
[91] D. Hermann Surface and Coatings Technology 174 –175 (2003) 229–234
[92] N. Tsukamoto, D. Watanabe Journal Vacuum Science and technology A 28 (2010), 846-850
[93] S. Mráz, J. M. Schneider, Journal of Applied Physics 100 (2006), 023503
[94] L. W. Rieth, P. H. Holloway, Journal of Vacuum Science & Technology A 22 (2004) 10
[95] MÜLLEROVÁ, J. Spektrofotometria tenkých vrstiev. Liptovský Mikuláš: Slovenská elektrotechnická spoločnosť, Pobočka pri Vojenskej akadémii v Liptovskom Mikuláši, 2004. 82 s. ISBN 80-968711-7-X.
[96] T. Welzel, K. Ellmer, Surface and Coatings technology 205 (2011) 294-298
[97] D. Severin, O. Kappertz, T. Nyberg, S. Berg, M. Wuttig, Thin Solid Films 515 (2007), 3554-3558
[98] O. Kappertz, R. Drese, M. Wuttig, Journal of vacuum science and technology A 20 (2002), 2084
[99] R. G. Singh, F. Singh, V. Kumar, R. M. Mehra, Current Applied Physics 11 (2011) 624-630
[100] R. Sharma, K. Sehrawat, A. Wakahara, R. M. Mehra, Applied Surface Science 255 (2009) 5781-5788
[101] V. Tvarozek et al, Thin Solid Films 515 (2007), 8756–8760
[102] V. Tvarozek, R. Harman, V. Jesenakova, Fine Mechanics and Optics XXVII 4 (1982) 89
[103] T. Smid: Theoretical Principles of Plasma Physics and Atomic Physics, GB, <http://www.plasmaphysics.org.uk>
[104] S.Flickyngerová, M.Netrvalová, L.Prušáková, I.Novotný, P.Šutta, V.Tvarožek: Modification of AZO thin-film properties by annealing and ion etching, Vacuum (2009) Volume 84, Issue 1, p. 215-217, ISSN 0042-207X.
[105] Staebler L, Wronski R. Reversible conductivity changes in discharge produced amorphous Si. Appl. Phys. Lett 1977;31(4):292

[106] van Elzaker G, Sutta P, Tichelaar FD, Zeman M. Phase control and stability of thin silicon films deposited from silane diluted with hydrogen. Materials Research Society Proceedings 2007;989:A.8.1
[107] Marie Netrvalová, Ivan Novotný, Lucie Prušáková, Vladimír Tvarožek, Pavol Šutta: Influence of deposition regime on physical properties of gallium doped zinc oxide films. In Vacuum 86 (2012) 707-710.
[108] Miro Mikolášek, Lucie Prušáková, L. Matay, V. Řeháček, J. Jakabovič, G. Vanko, M. Kotlár, L. Harmatha: Determination of the conduction band offset in the a-Si:H/c-Si heterojunction structures from coplanar temperature current-voltage measurements. In Proceedings of the 17th International Conference on Applied Physics of Condensed Matter 2011.
[109] Lucie Prušáková, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Optical and structural characterization of inhomogeneities in a-Si:H to uc-Si transition. In Vacuum 85 (2010) 502-505.
[110] Lucie Prušáková, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Quantum size effects in a-Si:H films prepared by PECVD with different hydrogen-diluted silane. In Advances in Science and Technology 74 (2010) 137-142.
[111] Jarmila Mullerová, Lucie Prušáková, Marie Netrvalová, Veronika Vavruňková, Pavol Šutta: A study of optical absorption in amorphous hydrogenated silicon thin films of varied thickness. In Applied Surface Science 256 (2010) 5667-5671.

About the author

Lucie Prušáková was born in Pilsen on 25th of Februarry 1982. In 2001 she finished her pre-university education at Gymnasium L.Pika in Pilsen. She studied the material science at the University of West Bohemia in Pilsen, Department of Material science and Technology. As a part of her study she did an internship at Namakkal University in India, during which she studied the operation research. In June 2007 she obtained the Master degree, with a graduation project on the topic of tribological properties of TiCN thin films. Subsequently she joined the New Technology Research Centre – Department of Materials & Technology, where she is carrying out her doctoral research in the group of Doc.RNDr. Pavol Šutta, Ph.D. Her research on materials for thin film silicon based solar cells, with a main focus on the development of transparent conductive oxides, is described in this work.

List of publications

2012

- **Lucie Prušáková**, Petr Novák, Pavel Kulha, Adam Bouřa: Mikrogenerátor napětí s piezoelektrickou ZnO vrstvou.
  PROTOTYP / FUNKČNÍ VZOREK 2012.
- **Lucie Prušáková**, Soňa Flickyngerová, Marinus Fischer, Ivan Novotný, Martijn Tijssen, Marie Netrvalová, Miro Zeman, Vladimír Tvarožek, Pavol Šutta: Analysis of single junction a-Si:H solar cells grown on different TCO´s. In **Vacuum** 86 (2012) 765-768.
- Marie Netrvalová, Ivan Novotný, **Lucie Prušáková**, Vladimír Tvarožek, Pavol Šutta: Influence of deposition regime on physical properties of gallium doped zinc oxide films. In **Vacuum** 86 (2012) 707-710.

2011

- **Lucie Prušáková**, Erik Vavrinský: Software pro stanovení typu vodivosti polovodičů. **SOFTWARE** 2011.
- Jiří J. Mareš, Pavel Hubík, Jozef Kryštofík, **Lucie Prušáková**, Štěpán Uxa, Tanya Paskova, Keith Evans: Radial space-charge-limited electron flow in semi-insulating GaN:Fe. In **Journal of Applied Physics** 110 (2011) 013723.
- Miro Mikolášek, **Lucie Prušáková**, L. Matay, V. Řeháček, J. Jakabovič, G. Vanko, M. Kotlár, L. Harmatha: Determination of the conduction band offset in the a-Si:H/c-Si heterojunction structures from coplanar temperature current-voltage measurements. In Proceedings of the 17th International Conference on Applied Physics of Condensed Matter 2011.
- Erik Vavrinský, **Lucie Prušáková**, Jiří Tesař, Pavol Šutta, Vladimír Tvarožek, Peter Benko: Resistivity measurement and conductivity type determination for semiconducting materials using a four-point probe. In Proceedings of the 17th International Conference on Applied Physics of Condensed Matter 2011.
- Marie Netrvalová, **Lucie Prušáková**, Petr Novák, Pavol Šutta: Optical properties of amorphous hydrogenated and microcrystalline silicon films prepared by plasma enhanced chemical vapour deposition and re-crystallized at moderate temperatures. In Physica Status Solidi C 8 (2011) 2680-2683.
- Marie Netrvalová, **Lucie Prušáková**, Petr Novák, Pavol Šutta: Influence of deposition conditions of ZnO thin films on their photonic properties. In Proceedings of SPIE 2011.

2010

- **Lucie Prušáková**, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Optical and structural characterization of inhomogeneities in a-Si:H to uc-Si transition. In **Vacuum** 85 (2010) 502-505.
- **Lucie Prušáková**, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Quantum size effects in a-Si:H films prepared by PECVD with different hydrogen-diluted silane. In **Advances in Science and Technology** 74 (2010) 137-142.

- Jarmila Mullerová, **Lucie Prušáková**, Marie Netrvalová, Veronika Vavruňková, Pavol Šutta: A study of optical absorption in amorphous hydrogenated silicon thin films of varied thickness. In **Applied Surface Science** 256 (2010) 5667-5671.
- **Lucie Prušáková**, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Change of optical properties of a-Si:H films in dependence on different material structure. Sborník 5. České fotovoltaické conference 2010.
- **Lucie Prušáková**, Marie Netrvalová, Pavol Šutta: Study of ZnO films grown with different dopants – physical properties and their comparison. In Proceedings of 8th International Conference on Advanced Semiconductor Devices & Microsystems 2010.
- Veronika Vavruňková, Marie Netrvalová, **Lucie Prušáková**, Jarmila Mullerová, Pavol Šutta: Study of re-crystallization processes in amorphous silicon films. In Proceedings of 27th International Conference on Microelectronics 2010.
- Marie Netrvalová, Soňa Flickingerová, **Lucie Prušáková**, Ivan Novotný, Vladimír Tvarožek, Pavol Šutta : Studium fyzikálních vlastností dopovaných tenkých vrstev ZnO pro fotovoltaické aplikace. *In* 5. Česká fotovoltaická konference, Brno : Czech RE Agency, 2010, s. 18-22.
- Marie Netrvalová, **Lucie Prušáková**, Jarmila Müllerová, Pavol Šutta : Optical properties of amorphous hydrogenated and microcrystalline silicon films prepared by plasma enhanced chemical vapor deposition and re-crystallized at high temperature. *In* Fourth International Conference on Optical, Optoelectronic and Photonic Materials and Applications, 2010 A-0177.

2009

- **Lucie Prušáková**, Pavol Šutta: Tenkovrstvý solární článek na bázi amorfního křemíku. . **PROTOTYP / FUNKČNÍ VZOREK** 2009.
- **Lucie Prušáková**, Pavol Šutta: Tenkovrstvý solární článek na bázi hydrogenizovaného amorfního křemíku s vysoce zředěnou absorpční vrstvou. **PROTOTYP / FUNKČNÍ VZOREK** 2009.
- Soňa Flickyngerová, Marie Netrvalová, **Lucie Prušáková**, Ivan Novotný, Pavol Šutta, Vladimír Tvarožek: Modification of AZO thin-film properties by annealing and ion etching. In **Vacuum** 84 (2009) 215-217.
- Ondřej Hegr, **Lucie Prušáková**, Veronika Vavruňková: Yttrium oxide layers for antireflection coating in silicon solar cells, *In* Electronic Devices and Systems EDS´09 IMAPS CS International Conference, Novpres s.r.o., Brno 2009, p. 139-142, ISBN 978-80-214-3933-7.

2008

- **Lucie Prušáková**, Marie Netrvalová, Pavol Šutta: Tle influence of the deposition process onto tle strurcural and electrical properties of ZnO:Al thin films. *In* Applied physics of condensed matter. Bratislava : Slovenská technická univerzita v Bratislavě, 2008. s.179-182. ISBN 978-80-227-2902-4.

- **Lucie Prušáková**, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Quantum size effects in a-Si:H films prepared by PECVD with different hydrogen-diluted silane. In **Advances in Science and Technology** 74 (2010) 137-142.
- Jarmila Mullerová, **Lucie Prušáková**, Marie Netrvalová, Veronika Vavruňková, Pavol Šutta: A study of optical absorption in amorphous hydrogenated silicon thin films of varied thickness. In **Applied Surface Science** 256 (2010) 5667-5671.
- **Lucie Prušáková**, Veronika Vavruňková, Marie Netrvalová, Jarmila Mullerová, Pavol Šutta: Change of optical properties of a-Si:H films in dependence on different material structure. Sborník 5. České fotovoltaické conference 2010.
- **Lucie Prušáková**, Marie Netrvalová, Pavol Šutta: Study of ZnO films grown with different dopants – physical properties and their comparison. In Proceedings of 8th International Conference on Advanced Semiconductor Devices & Microsystems 2010.
- Veronika Vavruňková, Marie Netrvalová, **Lucie Prušáková**, Jarmila Mullerová, Pavol Šutta: Study of re-crystallization processes in amorphous silicon films. In Proceedings of 27th International Conference on Microelectronics 2010.
- Marie Netrvalová, Soňa Flickingerová, **Lucie Prušáková**, Ivan Novotný, Vladimír Tvarožek, Pavol Šutta : Studium fyzikálních vlastností dopovaných tenkých vrstev ZnO pro fotovoltaické aplikace. *In* 5. Česká fotovoltaická konference, Brno : Czech RE Agency, 2010, s. 18-22.
- Marie Netrvalová, **Lucie Prušáková**, Jarmila Müllerová, Pavol Šutta : Optical properties of amorphous hydrogenated and microcrystalline silicon films prepared by plasma enhanced chemical vapor deposition and re-crystallized at high temperature. *In* Fourth International Conference on Optical, Optoelectronic and Photonic Materials and Applications, 2010 A-0177.

2009

- **Lucie Prušáková**, Pavol Šutta: Tenkovrstvý solární článek na bázi amorfního křemíku. . **PROTOTYP / FUNKČNÍ VZOREK** 2009.
- **Lucie Prušáková**, Pavol Šutta: Tenkovrstvý solární článek na bázi hydrogenizovaného amorfního křemíku s vysoce zředěnou absorpční vrstvou. **PROTOTYP / FUNKČNÍ VZOREK** 2009.
- Soňa Flickyngerová, Marie Netrvalová, **Lucie Prušáková**, Ivan Novotný, Pavol Šutta, Vladimír Tvarožek: Modification of AZO thin-film properties by annealing and ion etching. In **Vacuum** 84 (2009) 215-217.
- Ondřej Hegr, **Lucie Prušáková**, Veronika Vavruňková: Yttrium oxide layers for antireflection coating in silicon solar cells, *In* Electronic Devices and Systems EDS´09 IMAPS CS International Conference, Novpres s.r.o., Brno 2009, p. 139-142, ISBN 978-80-214-3933-7.

2008

- **Lucie Prušáková**, Marie Netrvalová, Pavol Šutta: Tle influence of the deposition process onto tle strurcural and electrical properties of ZnO:Al thin films. *In* Applied physics of condensed matter. Bratislava : Slovenská technická univerzita v Bratislavě, 2008. s.179-182. ISBN 978-80-227-2902-4.
- Soňa Flickyngerová, Marie Netrvalová, **Lucie Prušáková**, Andrea Pullmanová, Erik Vavrinský, Pavol Gašpierik, Peter Ballo, Ivan Novotný, Pavol Šutta, Vladimír Tvarožek:: Sputtered transparent conductive ZnO:Al thin films for solar cells. *In* 3.Česká fotovoltaická konference, 3.-5.listopadu 2008, Brno. s.195 – 199. ISBN 978-80-254-3528-1.
- Pavol Šutta, Miro Zeman, Vladimír Tvarožek, Ivan Novotný, Peter Ballo, L. Harmatha, Soňa Flickingerová, Veronika Vavruňková, Marie Netrvalová, **Lucie Prušáková**, Pavol Gašpierik, Andrea Pullmanová, Erik Vavrinský: Výskum materiálov pre fotovoltaické články na tenkých vrstvách amorfného kremíku. *In:* 3.Česká FV konference, 3.-5.listopadu 2008, Brno. s.90–95. ISBN 978-80-254-3528-1.
- Vladimír Tvarožek, Pavol Šutta, Peter Ballo, L. Harmatha, Soňa Flickyngerová, **Lucie Prušáková**, Marie Netrvalová, Veronika Vavruňková, Andrea Pullmanová, Erik Vavrinský, Pavol Gašpierik, Miro Mikolášek: Preparation of transparent conductive AZO thin films for solar cells. *In:* ASDAM 2008. The seventh international conference on advanced semiconductor devices and microsystems. – Piscataway : Institute of electrical and electronics engineers, 2008. ISBN 978-1-4244-2325-5.
- Vladimír Tvarožek, Soňa Flickyngerová, Ivan Novotný, Andrea Řeháková, Pavol Šutta, Marie Netrvalová, Pavol Gašpierik, **Lucie Prušáková**, Peter Ballo, Erik Vavrinský: Influence of spatial sputtering distribution on TCO thin film properties. *In:* ICTF 14 : 14th International conference on thin films and reactive sputter deposition. Ghent, Belgium, 17.-20.11.2008. ISBN 978-90-334-7347-0. s. 247
- Marie Netrvalová, **Lucie Prušáková**, Pavol Šutta: Influence of structure on optical properties of ZnO:Al thin films. *In* Proceedings of tle 14th International Conference on Applied Physics of Condensed Matter. Bratislava : Slovak University of Technology, 2008. s.167-170. ISBN 978-80-227-2902-4.

2007

- **Lucie Prušáková**, Marie Netrvalová, Pavol Zubko, Pavol Šutta: Deposition of ZnO:Al for photovoltaic aplications in TF 600 vacuum coating system. *In* Vákuové technológie – nové trendy vo výskume a aplikáciách. Bratislava : Slovenská vákuová spoločnosť, 2007. s.100-103. ISBN 978-80-969435-3-1.
- Marie Netrvalová, **Lucie Prušáková**, Pavol Šutta: Optical properties of ZnO:Al thin films deposited on TF 600 sputtering system. *In* Vákuové technológie – nové trendy vo výskume a aplikáciách. Bratislava : Slovenská vákuová spoločnosť, 2007.s.116-118. ISBN 978-80-969435-3-1.
- Olga BLáhová, **Lucie Prušáková**, Josef Sobota, Tomáš Fořt, Jan Grossman, Miroslav Fajkus: Mechanické vlastnosti tenkých vrstev TiCN. *In* Vrstvy a povlaky 2007. Trenčín : Digital graphic, 2007.s.19-24. ISBN 978-80-969310-4-0.

- Stanislav Hořejš, Miroslav Fajkus, **Lucie Prušáková**, Olga Bláhová: Výhody využití metody PACVD pro povlakování nástrojů. *In* Vrstvy a povlaky 2007. Trenčín : Digital graphic, 2007. s. 1-6. ISBN 978-80-969310-4-0.

2006

- **Lucie Prušáková**, Olga Bláhová, Pavel Carbol: Mechanické vlastnosti vrstev TiCN deponovaných metodou CVD. *In* Vrstvy a povlaky 2006. Trenčín : Digital graphic. s. 114-119. ISBN 80-969310-2-4.
- Olga Bláhová, **Lucie Prušáková**, Jarmila Savková, Miroslav Fajkus, Stanislav Hořejš: Mechanické vlastnosti tenkých vrstev TiCN. *In* Vrstvy a povlaky 2006. Trenčín : Digital graphic, 2006. s.102-107. ISBN 80-969310-2-4.
- Olga Bláhová, **Lucie Pručáková**, Jarmila Savková, Miroslav Fajkus, Stanislav Hořejš: Nanoindentační měření tenkých vrstev TiCN připravených různými metodami. *In* Lokální mechanické vlastnosti 2006. Plzeň : Západočeská univerzita, 2006. s. 32-35. ISBN 80-7043-512-7.