WILLIAM N. SHAFARMAN

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EDUCATION

Ph.D. Physics, University of Rochester, New York, May 1986
Thesis: "Magnetic Tuning of the Metal-Insulator Transition in Arsenic-doped Silicon", advisor Theodore Castner.
M.A. Physics, University of Rochester, 1982.
B.S. Physics, University of Delaware, 1980.

ACADEMIC HONORS: Rush Rhees Fellowship, University of Rochester, 1980-83.

EXPERIENCE

2018-Present *Professor*
2011-2018 *Associate Professor*
2006-2011 *Assistant Professor*
Materials Science and Engineering, University of Delaware

2018-Present *Director*
2017-2018 *Interim Director*
Institute of Energy Conversion, University of Delaware

2013-Present *Affiliated Professor*
Physics and Astronomy, University of Delaware

2013-2018 *Sr. Scientist*
1998-2012 *Scientist*
1996-1998 *Manager, Electronic Materials Laboratory*
1986-1995 *Research Associate III*
Institute of Energy Conversion, University of Delaware

1982-1986 *Adjunct Faculty*
Learning Development Center, Rochester Institute of Technology, Rochester, New York

1982-1986 *Research Assistant*
Condensed Matter Lab, University of Rochester

PROFESSIONAL SERVICE

Team Leader, DOE Thin Film Partnership Program: National CIS R&D Team, 1997-1999.

Program Committee, 28th IEEE Photovoltaic Specialists Conference, Anchorage AK, 2000.

Program Committee, 29th IEEE Photovoltaic Specialists Conference, New Orleans LA, 2002.

Symposium Co-organizer, "Compound Semiconductor Photovoltaics" at Materials Research Society 2003 Spring Meeting, San Francisco, 2003. Co-editor of Symposium Proceedings.

Symposium Lead-organizer, "Thin-Film Compound Semiconductor Photovoltaics" at Materials Research Society 2005 Spring Meeting, San Francisco, 2005. Co-editor of Symposium Proceedings.

International Advisory Committee for the International Photovoltaic Science and Engineering Conference, ongoing since 2005 – present.

Program Area Co-Chair, 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, HI, 2006.

Program Area Chair, 33rd IEEE Photovoltaics Specialists Conference, San Diego, May 2008.

Tutorials Chair, Organizing Committee, 34th IEEE Photovoltaics Specialists Conference, Philadelphia, 2009.

Symposium Co-organizer, "Thin Film Chalcogenide Photovoltaic Materials" at European Materials Research Society 2012 Spring Meeting, Strasbourg, FR, 2012.

Member, Electronic Media Subcommittee, Materials Research Society, 2012 – 2014.

Symposium Lead-organizer, "Thin-Film Compound Semiconductor Photovoltaics" at Materials Research Society 2013 Spring Meeting, San Francisco, 2013.

Guest Editor, "Thin film photovoltaic materials and device physics", with Eric Schiff and Baojie Yan, *Solar Energy Materials and Solar Cells*, **129**, 2014.

Organizer, DOE SunShot Thin-Film PV Workshop, University of Delaware, 2014

Associate Editor, IEEE Journal of Photovoltaics, 2014 – 2023.

National Science Foundation Panel Reviewer, 2016, 2017.

Organizing Committee, CIGSTech 8: 8th International Workshop on CIGS Solar Cell Technology, Stuttgart, Germany, 2017.

International Advisory Committee – Grand Renewable Energy 2018 International Conference, Yokohama, Japan.

International Advisory Board, 21st International Conference on Ternary and Multinary Compounds, Denver, 2018.

Treasurer, Organizing Committee, 46th IEEE Photovoltaics Specialists Conference, Chicago, 2019.

Organizing Committee – CIGSTech 10: 10th International Workshop on CIGS Solar Cell Technology, Paris, France, 2019.

Organizing Committee, 47th IEEE Photovoltaics Specialists Conference, Calgary, 2020.

International Advisory Committee 22nd International Conference on Ternary and Multinary Compounds, Beijing, 2020.

Trustee and Chair of the Karl W. Böer Trust at the University of Delaware, 2020 –.

Deputy Conference Chair & Secretary, 48th IEEE Photovoltaics Specialists Conference, 2021.

Conference Chair, 49th IEEE Photovoltaics Specialists Conference, Philadelphia, 2022.

Conference Co-Chair, 8th World Conference on Photovoltaic Energy Conversion, Daejeon, S. Korea 2026.

INVITED and PLENARY PRESENTATIONS

1. 25th IEEE Photovoltaic Specialists Conference; Washington DC, 1996.
2. Uppsala University, Ångström Solar Center; Uppsala SW, 1999.
3. National Center for Photovoltaics Program Review Meeting; Denver CO, 2001.
4. National Center for Photovoltaics and Solar Program Review Meeting; Denver CO, 2003.
5. 3rd World Conference on Photovoltaic Energy Conversion; Osaka Japan, 2003.
6. Korean Conference on Innovative Science and Technology; Gyeongju S Korea, 2004.

7. NREL/SNL Photovoltaics Program Review; Lakewood CO, 2006.
8. 3rd Workshop on the Future Direction of Photovoltaics; Aogaku Kaikan in Tokyo, 2007.
9. Materials Research Society Spring Meeting; San Francisco, 2007.
10. General Electric Global Research Center; Niskayuna NY, 2008.
11. 18th International Photovoltaic Science and Engineering Conference; Kolkata India, 2009.
12. US-Korea Conference on Science, Technology, and Entrepreneurship; Raleigh NC, 2009
13. University of Delaware; Department of Materials Science and Engineering, 2009.
14. 19th International Photovoltaic Science and Engineering Conference; Jeju S Korea, 2009.
15. DuPont Experimental Station; Wilmington DE, 2010.
16. Korean Institute of Chemical Engineers 2010 Spring Meeting; Daegu S Korea.
17. IBM Thomas J Watson Research Center; Yorktown Heights NY, 2010.
18. American Vacuum Society 59th International Symposium; Tampa FL, 2012.
19. Japan Society for the Promotion of Science, 9th Workshop on the Future Direction of Photovoltaics; Tokyo, 2013.
20. 39th IEEE Photovoltaic Specialists Conference; Tampa FL, 2013.
21. University of Toledo, Department of Physics Colloquium; Toledo OH, 2013.
22. University of Delaware Energy Institute (UDEI) Annual Symposium; 2013.
23. Solar and Photovoltaics Engineering Research Center Inauguration, King Abdullah University of Science and Technology; Saudi Arabia, 2014.
24. Materials Research Society Spring Meeting; San Francisco, 2015.
25. 25th International Photovoltaic Science and Engineering Conference; Pusan, South Korea, 2015.
26. International Semiconductor Device Research Symposium 2016; Bethesda MD, 2016.
27. CIGSTech 10: 10th International Workshop on CIGS Solar Cell Technology; Paris, France, 2019.
28. 29th International Photovoltaic Science and Engineering Conference; Xi'an, China, 2019.
29. Xi'an Technical University, Xi'an, China, 2019.
30. University of Delaware, Department of Chemistry and Biochemistry, 2021.

TUTORIALS

"Cu(InGa)Se_2 Thin Film Solar Cells" Dow Chemical Company, 2006.

"Polycrystalline Thin Film Photovoltaics" 33rd IEEE Photovoltaic Specialists Conference, San Diego, 2008.

"Thin Film Solar Cells" 19th Photovoltaic Science and Engineering Conference, Jeju, S. Korea, 2009.

"Polycrystalline Thin Film Photovoltaics" 34th IEEE Photovoltaic Specialists Conference, Philadelphia, 2010.

"Cu(InGa)Se_2 Thin Film Solar Cells: Fundamentals, Fabrication and Characterization" Corning Glass Company, 2010.

"Cu(InGa)Se_2 Thin Film Solar Cells: Materials and Processes" Korean Institute of Chemical Engineering Annual Meeting, Daegu, S. Korea, 2010.

PROFESSIONAL SOCIETY MEMBERSHIPS

Materials Research Society
Institute of Electrical and Electronics Engineers
American Solar Energy Society

PATENTS

1. “Chemical Surface Deposition of Ultra-Thin Semiconductors,” B. E. McCandless and W. N. Shafarman, United States Patent 6,537,845, Mar. 25, 2003.
2. “I-III-VI2 Photovoltaic Absorber Layers,” G. M. Hanket and W.N. Shafarman, International Patent WO 2009/046178, Apr. 9, 2009, US Patent Application US20200/303571A1, Sept. 24, 2020.

BOOK CHAPTERS

1. "Tuning the Metal-Insulator Transition in n-Type Silicon with a Magnetic Field," T.G. Castner and W.N. Shafarman, in Localization and Metal-Insulator Transitions, ed. H. Fritzsche and D. Adler, Plenum, New York, 9 (1985).
2. “Cu(InGa)Se_2 Solar Cells,” W.N. Shafarman and L. Stolt, Chapter 13 in Handbook of Photovoltaic Science and Engineering, ed. by A. Luque and S. Hegedus, John Wiley & Sons, Ltd., 567 (2003).
3. “Defect Studies Using Photocapacitance Spectroscopy in the Copper Indium Diselenide Alloys,” J.D. Cohen, J.T. Heath and W.N. Shafarman, in Wide Gap Chalcopyrites, ed. by U. Rau and S. Siebentritt, Springer Scientific, 69 (2005).
4. “Cu(InGa)Se_2 Solar Cells,” W.N. Shafarman, S. Siebentritt, and L. Stolt, Chapter 13 in Handbook of Photovoltaic Science and Engineering, Second Edition, ed. by A. Luque and S. Hegedus, John Wiley & Sons, Ltd., 546 (2011). doi: 1002/9780470974704.ch13.
5. “CIGS Module Design and Manufacturing” William Shafarman, Chapter 4.4 in Photovoltaic Solar Energy: From Fundamentals to Applications, ed. By A. Reinders, P. Verlinden, W. van Sark, A. Freundlich, John Wiley & Sons, Ltd., 204 (2017). doi: 10.1002/9781118927496

PUBLICATIONS

6. "The Low Temperature Magneto-resistance of Silicon near the Metal-Insulator Transition," W.N. Shafarman, T.G. Castner, J.S. Brooks, K.P. Martin and M.J. Naughton, Solid State Electronics 28, 93 (1985).
7. "The Magnetic-Field Dependence of Variable Range Hopping Conduction for Barely Insulating Arsenic Doped Silicon Samples," W.N. Shafarman and T.G. Castner, *Proc. 17th International Conference on the Physics of Semiconductors*, 1079 (1985).
8. "Critical Behavior of Mott Variable-Range Hopping in Si:As Near the Metal-Insulator Transition," W.N. Shafarman and T.G. Castner, *Physical Review B* **33**, 5:3570 (1986).
9. "Magnetic Tuning of the Metal-Insulator Transition for Uncompensated Arsenic-Doped Silicon," W.N. Shafarman, T.G. Castner, J.S. Brooks, K.P. Martin, and M.J. Naughton, *Physical Review Letters* **56**, 9:980 (1986).
10. "Low-Temperature, Low-Frequency Complex Conductance Measurements for a Barely Insulating Si:As Sample," T.G. Castner, W.N. Shafarman, R.J. Deri, and J.S. Brooks, *Journal of Physics* **C19**, L491 (1986).
11. "Tuning Correlation and Localization Lengths with High Magnetic Fields near the Metal-Insulator Transition," T.G. Castner, W.N. Shafarman and D. Koon, *Philosophical Magazine* **B56**, 6:805-820 (1987).

12. "Analysis of a Transparent Cu/ITO Contact and Heat Treatments on CdTe/CdS Solar Cells," R.W. Birkmire, S.S. Hegedus, B.E. McCandless, J.E. Phillips, and W.N. Shafarman, *Proc. 19th IEEE Photovoltaic Specialists Conference*, 967 (1987).
13. "The Metal-Insulator Transition in n-type Silicon in High Magnetic Fields," T.G. Castner and W.N. Shafarman, In High Magnetic Fields in Semiconductors, *Proc. Intl. Conf.*, 366 (1987).
14. "CdTe/CdS Solar Cells with Transparent Contacts," R.W. Birkmire, B.E. McCandless, and W.N. Shafarman, *Solar Cells* **23**(1-2), 115 (1988).
15. "Characterization of Window Layers in $CuInSe_2$ Thin Film Solar Cells," W.N. Shafarman and R.W. Birkmire, *Proc. 20th IEEE Photovoltaic Specialists Conference* **2**, 1515 (1988).
16. "The DC Conductivity of Arsenic-Doped Silicon Near the Metal Insulator Transition," W.N. Shafarman, D.W. Koon, and T.G. Castner, *Physical Review B* **40**, 1216 (1989).
17. "Approaches for High Efficiency $CuInSe_2$ Solar Cells," R.W. Birkmire, B.E. McCandless, W.N. Shafarman and R.D. Varrin, Jr., *Proc. 9th Euro. Comm. PV Solar Energy Conf.*, 134 (1989).
18. "Advances in $CuInSe_2$ and CdTe Thin Film Solar Cells," W.N. Shafarman, R.W. Birkmire, D.A. Fardig, B.E. McCandless, A. Mondal, J.E. Phillips and R.D. Varrin, Jr., *Solar Cells* **30**, 61 (1991).
19. "Options for Fabrication and Design of $CuInSe_2$ Based Solar Cells," R.W. Birkmire, W.N. Shafarman and R.D. Varrin, Jr., *Proc. 21st IEEE Photovoltaic Specialists Conference*, 550 (1990).
20. "Diode Analysis of $CuInSe_2$ Solar Cells," W.N. Shafarman and J.E. Phillips, *Proc. 22nd IEEE Photovoltaic Specialists Conference*, 934 (1991).
21. "Polycrystalline Heterojunction Solar Cells: Device Perspective," J.E. Phillips, W.N. Shafarman, R.W. Birkmire, S.S. Hegedus and B.E. McCandless, *AIP Conf. Proc*. **268**, 206 (1992).
22. "Polycrystalline Heterojunction Solar Cells: Processing Perspective," R.W. Birkmire, S.S. Hegedus, B.E. McCandless, J.E. Phillips, TWF Russell, W.N. Shafarman, S. Verma and S. Yamanaka, *AIP Conf. Proc*. **268**, 212 (1992).
23. "Current-Voltage Characterization of $CuInSe_2$/CdS Solar Cells Deposited by Different Methods," W.N. Shafarman and J.E. Phillips, *Proc. 23rd IEEE Photovoltaic Specialists Conference*, 453 (1993).
24. "Chemical Process Device Analysis of $CuInSe_2$-Based Solar Cell Materials," TWF Russell, R.W. Birkmire, J.E. Phillips, S. Verma and W.N. Shafarman, *AIP Conf. Proc*. **306**, 390 (1994).
25. "Lessons Learned from a Hydrogen Explosion at a Photovoltaic Research Facility," P.D. Moskowitz, W.A. Buchanan and W.N. Shafarman, *Proc. 1994 IEEE First World Conf. on PVEC*, 504 (1994).
26. "Polycrystalline $CuIn_{1-x}Ga_xSe_2$ Thin Film PV Solar Cells Prepared by Two-Stage Selenization Process Using Se Vapor," N.G. Dhere, S. Kuttath, K.W. Lynn, R.W. Birkmire and W.N. Shafarman, Proc. *1994 IEEE First World Conf. on PVEC*, 190 (1994).
27. "Evidence for Amorphous Like Behavior in Small Grain Thin Film Polycrystalline Solar Cells," J.E. Phillips, W.N. Shafarman and E. Shan, Proc. *1994 IEEE First World Conf. on PVEC*, 303 (1994).
28. "Characterization and Modeling of Cu(In,Ga)$(S,Se)_2$-Based Photovoltaic Devices: A Laboratory and Industrial Perspective," J.R. Tuttle, J.R. Sites, A. Delahoy, W.N. Shafarman, B. Basol, S. Fonash, J. Gray, R. Menner, J.E. Phillips, A. Rockett, J. Scofield, F.R. Shapiro, P. Singh, V. Suntharalingam, D. Tarrant, T. Walter, S. Wiedeman and T.M. Peterson, *Progress in Photovoltaics **3***, 89 (1995).
29. "The Growth by the Hybrid Sputtering Evaporation Method Microstructural Studies of $CuInSe_2$ Films," L.-C. Yang, H.Z. Xaio, A. Rockett, W.N. Shafarman and R.W. Birkmire, *Solar Energy Mat. & Solar Cells* **36**, 445 (1995).

30. "Preparation of Homogeneous Cu(InGa)Se_2 Films by Selenization of Metal Precursors in H_2Se Atmosphere," M. Marudachalam, H. Hichri, R.Klenk, R.W. Birkmire, W.N. Shafarman and J.M. Schultz, *Applied Physics Letters* **67**, 3978 (1995).
31. "Polycrystalline Heterojunction Solar Cells: A Device Perspective," J.E. Phillips, R.W. Birkmire, B.E. McCandless, P.V. Meyers and W.N. Shafarman, *phys. stat. sol. (b)* **194**, 31 (1996).
32. "Device and Material Characterization of Cu(In,Ga)Se_2 Solar Cells with Increasing Bandgap," W.N. Shafarman, R. Klenk and B.E. McCandless, *Journal of Applied Physics* **79**, 7324 (1996).
33. "Transparent Conducting Oxide Contacts for n-i-p and p-i-n Amorphous Silicon Solar Cells," S.S. Hegedus, W.A. Buchanan, E. Eser, J.E. Phillips and W.N. Shafarman, *AIP Conf. Proc*. **394**, 547 (1996).
34. "Characterization of Cu(InGa)Se_2 Solar Cells with High Ga Content," W.N. Shafarman, R. Klenk, and B.E. McCandless, *Proc. 25th IEEE Photovoltaic Specialists Conference*, 763 (1996).
35. "Direct Current-Voltage Measurements of the Mo/$CuInSe_2$ Contact on Operating Solar Cells," W.N. Shafarman and J.E. Phillips, *Proc. 25th IEEE Photovoltaic Specialists Conference*, 917 (1996).
36. "Processing and Analysis of Polycrystalline Thin-Film Solar Cells Made from Uniform Single Phase Materials," R.W. Birkmire, H. Hichri, R. Klenk, M. Marudachalam, B.E. McCandless, J.E. Phillips, J.M. Schultz and W.N. Shafarman, *AIP Conf. Proc*. **353**, 420 (1996).
37. "Semiconductor Processing Manufacturing," W.N. Shafarman, B.M. Basol, J.S. Britt, R.B. Hall and R.E. Rocheleau, *Progress in Photovoltaics* **5**, 359 (1997).
38. "Fabrication and Characterization of Cu(InGa)Se_2 Solar Cells with Absorber Bandgap from 1.0 to 1.5 eV," W.N. Shafarman, R.W. Birkmire, M. Marudachalam, B.E. McCandless and J.M. Schultz, *AIP Conf. Proc*. **394**, 123 (1997).
39. "Effect of Reduced Deposition Temperature, Time and Thickness on Cu(InGa)Se_2 Films and Devices", W.N. Shafarman, R.W. Birkmire, S. Marsillac, M. Marudachalam, N. Orbey and T.W.F. Russell, *Proc. 26th IEEE Photovoltaic Specialists Conference*, 331 (1997).
40. "High Efficiency and CIGS CIS Cells with CVD ZnO Buffer Layers," L.C. Olsen, W. Lei, F.W. Addis, W.N. Shafarman, M.A. Contreras and K. Ramanathan, *Proc. 26th IEEE Photovoltaic Specialists Conference*, 363 (1997).
41. "Deconvolution of Activated and Variable-range-hopping Conduction for Barely Insulating Arsenic-doped Silicon," by T. G. Castner and W. N. Shafarman, *Physical Review B* **60**, 14182 (1999).
42. "Analysis of Cu(In,Ga)Se_2 Solar Cells: Why Performance Decreases with Increasing Ga Content," J.E. Phillips and W.N. Shafarman, *AIP Conf. Proc*. **462**, 120 (1999).
43. "Manufacturable Large Area CdS Thin Films for Solar Cell Applications Monitored with Optical Emission Spectroscopy," L. Wang, I. Eisgruber, R. Hollingsworth, C. DeHart, T. Wangensteen, R.E. Treece, P. Bhat, W.N. Shafarman, R.W. Birkmire and T.J. Gillespie, *Materials Research Society Symp. Proc*. **569**, 127 (1999). 10.1557/PROC-569-127
44. "Advanced Flexible Solar Array Program," P.V. Meyers, L. Fabick, K.C. Reinhardt and W.N. Shafarman, *Proc. 16th Space PV Res. and Tech. Conf.*, (1999).
45. "Study of Cd-Free Buffer Layers Using $In_x(OH,S)_y$ on CIGS Solar Cells," C.H. Huang, S.S. Li, W.N. Shafarman, C-H Chang, E.S. Lambers, L. Rieth, J.W. Johnson, S. Kim, B.J. Stanbery, T.J. Anderson and P.H. Holloway, *Proc. 11th Int. PVSEC*, 855 (1999).
46. "Effect of Substrate Temperature Deposition Profile on Evaporated Cu(InGa)Se_2 Films Devices," W.N. Shafarman and J. Zhu, *Thin Solid Films* **361-362**, 473 (2000).

47. "Deposition of Cu(InGa)Se_2 by Inline Evaporation," G.M. Hanket, P.D. Paulson, W.N. Shafarman and R.W. Birkmire, Proc. *2000 NCPV Progress Review Mtg*, Denver, CO, 241 (2000).
48. "Cu(InAl)Se_2 Thin Films Devices Deposited by Multisource Evaporation," M.W. Haimbodi, E. Gourmelon, P.D. Paulson, R.W. Birkmire and W.N. Shafarman, *Proc. 28th IEEE Photovoltaic Specialists Conference*, 454 (2000).
49. "CIGSS Solar Cells Based on CVD ZnO Buffer Layers," L.C. Olsen, F.W. Addis, L. Huang, W.N. Shafarman, P. Eschbach and G.J. Exarhos, *Proc. 28th IEEE Photovoltaic Specialists Conference*, 458 (2000).
50. "Fabrication of Graded Cu(InGa)Se_2 Films by Inline Evaporation," G.M. Hanket, P.D. Paulson, U. Singh, S.T. Junker, R.W. Birkmire, F.J. Doyle III, E. Eser and W.N. Shafarman, *Proc. 28th IEEE Photovoltaic Specialists Conference*, 499 (2000).
51. "Reaction Temperature Dependence of $CuInSe_2$ Based Solar Cells Performance Using CuIn Precursors Selenized Using H_2Se Gas," J.M. Mwabora, W.N. Shafarman and R.W. Birkmire, *Proc. 5th Kenya Phys. Soc*. (KPS) Regional Workshop, **27** (2000).
52. "Absorber Thickness Dependence on $CuInSe_2$ Based Solar Cell Performance Using CuIn Precursors Selenized Using H_2Se Gas," J.M. Mwabora, W.N. Shafarman and R.W. Birkmire, *Proc. World Renewable Energy Congress-VI*, Brighton, UK, **2049** (2000).
53. "Study of Cd-free Buffer Layers Using $In_x(OH,S)_y$ on CIGS Solar Cells," C.H. Huang, Sheng S. Li, W.N. Shafarman, C.-H. Chang, E.S. Lambers, L. Rieth, J.W. Johnson, S. Kim, B.J. Stanbery, T.J.Anderson and P.H. Holloway, *Solar Energy Mat. & Solar Cells* **69**, 131 (2001).
54. "Post-Deposition Sulfur Incorporation into $CuInSe_2$ Thin Films," J. Titus, H.W. Schock, R.W. Birkmire, W.N. Shafarman and U.P. Singh, *Materials Research Society Symp. Proc.*, **668**, H151 (2001). doi: 10.1557/PROC-668-H1.5
55. "Effect of Grain Size, Morphology and Deposition Temperature on Cu(InGa)Se_2 Solar Cells," W.N. Shafarman and J. Zhu, *Materials Research Society Symp. Proc.* **668**, H231 (2001). doi: 10.1557/PROC-668-H2.3
56. "Characterization of Deep Defects in $CuIn_{1-x}Ga_xSe_2$ (CIGS) Working Photovoltaic Devices," J.T. Heath, J.D. Cohen, W.N. Shafarman and D.C. Johnson, *Photovoltaics for the 21st Century II*, R.D. McConnell and V.K. Kapur, eds, Electrochem. Soc., Inc., *Proc. 199th Electrochemical Soc. Mtg*. **2001-13**, 324 (2001).
57. "Chalcogenide Solar Cells Grown by Physical Vapor Deposition Technique," N. Barreau, S. Marsillac, J.D. Bernede and W.N. Shafarman, *Proc. 17th Euro. PVSEC*, (2001).
58. "Cu($In_{1-x}Al_x$)Se_2 Thin Films and Solar Cells," P.D. Paulson, M.W. Haimbodi, S. Marsillac, R.W. Birkmire and W.N. Shafarman, *Journal of Applied Physics* **91**, 10153 (2002).
59. "High Efficiency Solar Cells Based on Cu(InAl)Se_2 Thin Films," S. Marsillac, P.D. Paulson, M.W. Haimbodi, R.W. Birkmire and W.N. Shafarman, *Applied Physics Letters* **81**, 1350 (2002).
60. "Ionizing Radiation Effects in Copper Indium Gallium Diselenide Thin-Film Solar Cells," J. Tringe, J. Nocerino, R. Tallon, W. Kemp, W.N. Shafarman and D. Marvin, *Journal of Applied Physics* **91**, 516 (2002).
61. "Effect of Ga Content on Defect States in $CuIn_{1-x}Ga_xSe_2$ Photovoltaic Devices," J.T. Heath, J.D. Cohen, W.N. Shafarman, D.X. Liao and A.A. Rockett, *Applied Physics Letters* **80**, 4540 (2002).
62. "Material and Device Characterization of Thin Film Cu(InAl)Se_2 Solar Cells," W.N. Shafarman, S. Marsillac, P.D. Paulson, M.W. Haimbodi, T. Minemoto and R.W. Birkmire, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 519 (2002).

63. “Pilot-scale Manufacture of Cu(InGa)Se_2 Films on a Flexible Polymer Substrate,” G.M. Hanket, U.P. Singh, E. Eser, W.N. Shafarman and R.W. Birkmire, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 567 (2002).
64. “Correlation between Deep Defect States and Device Parameters in $CuIn_{1-x}Ga_xSe_2$ Photovoltaic Devices,” J.T. Heath, J.D. Cohen and W.N. Shafarman, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 596 (2002).
65. “Study of a New Indium Sulphide Derivative for Buffer Layer Application,” N. Barreau, S. Marsillac, J.C. Bernede, C. Deudon, L. Brohan, W.N. Shafarman and A. Barreau, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 628 (2002).
66. “Investigation of Chemical-Bath-Deposited ZnS Buffer Layers for Cu(InGa)Se_2 Thin Film Solar Cells,” B. Sang, W.N. Shafarman and R.W. Birkmire, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 632 (2002).
67. "Substrate and Back Contact Effects in CIGS Devices on Steel Foil," W.K. Batchelor, M.E. Beck, R. Huntington, I.L. Repins, A. Rockett, W.N. Shafarman, F.S. Hasson and J.S. Britt, *Proc. 29th IEEE Photovoltaic Specialists Conference*, 716 (2002).
68. "Near-Surface Defect Distributions in Cu(InGa)Se_2," A. Rockett, D. Liao, J.T. Heath, J.D. Cohen, Y.M. Strzhemechny, L.J. Brillson, K. Ramanathan and W.N. Shafarman, *Thin Solid Films* **431-432**, 301 (2003).
69. "New Cd-Free Buffer Layer Deposited by PVD: In_2S_3 Containing Na Compounds," N. Barreau, N. Bernede, S. Marsillac, C. Amoy and W.N. Shafarman, *Thin Solid Films* **431-432**, 326 (2003).
70. "Distinguishing Metastable Changes in Bulk CIGS Defect Densities for Interface Effects," J.T. Heath, J.D. Cohen, W.N. Shafarman, *Thin Solid Films* **431-432**, 426 (2003).
71. "Optical Characterization of $CuIn_{1-x}Ga_xSe_2$ Alloy Thin Films by Spectroscopic Ellipsometry," P.D. Paulson, R.W. Birkmire and W.N. Shafarman, *Journal of Applied Physics* **94**, 879 (2003). doi: 10.1063/1.1581345
72. Determination of Activation Barriers for the Diffusion of Sodium through CIGS Thin-Film Solar Cells," M.B. Zellner, R.W. Birkmire, E. Eser, W.N. Shafarman and J.G. Chen, *Progress in Photovoltaics* **11**, 543 (2003).
73. "Advances in $CuInSe_2$-based Solar Cells: From Fundamental to Processing," W.N. Shafarman, J. Titus, M. Haimbodi, M. Gossla, G. Hanket, S. Marsillac, T. Minemoto, P.D. Paulson, B. Sang, U. Singh, E. Eser and R.W. Birkmire, *Proc. NCPV Solar Program Review Meeting*, Denver CO, 525 (2003).
74. "New Junction Capacitance Methods for the Study of Defect Distributions Carrier Properties in the Copper Indium Diselenide Alloys," J.D. Cohen, J.T. Heath and W.N. Shafarman, *Materials Research Society Symp. Proc*. **763,** 429 (2003). doi: 10.1557/PROC-763-B9.1
75. "Defects in Copper Indium Aluminum Diselenide Films their Impact on Photovoltaic Device Performance," J.T. Heath, J.D. Cohen and W.N. Shafarman, *Materials Research Society Symp. Proc*. **763,** 441 (2003). doi: 10.1557/PROC-763-B9.2
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