



Exponent[®]
Engineering & Scientific Consulting

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Professional Profile

Dr. Hardigree specializes in investigating the physical and chemical properties of films and coatings made from functional materials of varying thicknesses, including those on the nanometer and micrometer scale. He has expertise applying a wide range of optical, electronic, and chemical diagnostic techniques to evaluate performance and failure of organic LEDs, solar cells, transistors, vapor sensors, and micro-optics.

Dr. Hardigree has led the development and scale-up of optical thin films for concentrated solar thermal, lighting, and display applications, and his background includes fabrication of thin film electronics using vacuum (PVD, e-Beam) and solution roll-to-roll (slot-die, gravure) methods. He has experience with numerous non-destructive techniques including grazing incidence x-ray scattering (GIWAXS/GISAXS), neutron reflectometry, surface probe microscopy (AFM, SKPM), optical spectroscopy and scattering (UV-Vis, FTIR, ellipsometry), and electronic carrier measurements (impedance, photo-CELIV, ToF).

Dr. Hardigree has developed processes for fabricating and characterizing functional materials including molecular and polymer semiconductors, ultra-thin oxides for display backplanes, solar concentrators, and large area coated optical films. He has expertise probing surface properties such as material morphology and texture, microstructure, and chemical composition. He is also skilled in techniques that enable discrimination between bulk and surface defects. He has evaluated manufacturing processes and chemical degradation pathways in materials used for additive manufacturing (3D printing), optical adhesives, and solar cells. Among Dr. Hardigree's key areas of expertise is imaging and simulation of complex multilayers using visible light, x-rays, and neutrons to determine failures due to layer de-adhesion, film intermixing, and material breakdown. He has developed surface modification techniques to improve material compatibility in optical multilayers and in organic, organohalide perovskite, and hybrid electronic devices. Dr. Hardigree also has significant experience commissioning complex multi-material physical vapor deposition (PVD) systems and associated metrology instruments, ranging from laboratory-scale units to a synchrotron endstation.

Prior to joining Exponent, Dr. Hardigree was co-founder and director of technology at a photonics startup, developing micro-optical thin films for high efficiency solar thermal, LED lighting, and display applications. There he oversaw manufacturing scale-up and quality operations. Before that, Dr. Hardigree developed and commissioned an experimental endstation at a national synchrotron that established new in-situ techniques for accelerating the scalable manufacture of advanced photovoltaics.

Academic Credentials & Professional Honors

Ph.D., Materials Science and Engineering, Johns Hopkins University, 2015

S.B., Materials Science and Engineering, Massachusetts Institute of Technology (MIT), 2007

Junior Research Fellow, Wolfson College, Univ. of Oxford, 2016-17

NSF Nordic Research Opportunities Program Fellow, 2012

NSF Graduate Research Fellow, 2010

Jay D. Samstag Engineering Fellow, 2009

Licenses and Certifications

ASQ Certified Reliability Engineer (CRE)

Certified Quality Engineer (CQE)

Prior Experience

Independent Consultant, 2019

Co-Founder & Director of Technology, Agira Inc, 2018-19

Postdoctoral Research Associate, Dept. of Physics, University of Oxford, 2015-17

Investment Analyst, MIT Investment Management Company, 2007-09

Professional Affiliations

Materials Research Society (MRS)

American Society for Quality (ASQ)

Languages

Spanish

Patents

Patent Application US2018/032740: Light guide apparatus and fabrication method thereof, May 2018 (Dhar BM, Venkatesan S, Hardigree JFM).

Publications

Moore G, Causa' M, Hardigree JFM, Karuthedath S, Ramirez I, Jungbluth A, Laquai F, Riede M, Banerji N. Ultrafast Charge Dynamics in Dilute-Donor versus Highly Intermixed TAPC:C60 Organic Solar Cell Blends. Journal of Physical Chemistry Letters 2020 11:5610-5617.

Derrien TL, Lauritzen AE, Kaienburg P, Hardigree JFM, Nicklin C, Riede M. In-Situ Observations of the Growth Mode of Vacuum Deposited α -Sexithiophene. Journal of Physical Chemistry C 2020: 124:11863-11869.

Ye H, Kesava SV, Hardigree JFM, Brown RE, Mazzotta G, Warren R, Skabara PJ, Riede M. Efficiency enhancement of small molecule organic solar cells using hexapropyltruxene as an interface layer. Journal of Materials Chemistry C 2020; 8:4909-4918.

Warren PR, Hardigree JFM, Lauritzen AE, Nelson J, Riede M. Tuning the ambipolar behavior of organic field effect transistors via band engineering. *AIP Advances* 2019; 9:035202.

Causa' M, Ramirez R, Hardigree JFM, Riede M, Banerji N. Femtosecond Dynamics of Photoexcited C60 Films. *Journal of Physical Chemistry Letters* 2018; 9:1885-1892.

Hardigree JFM, Ramirez IR, Mazzotta G, Nicklin C, Riede M. In-situ observation of stacking fault evolution in vacuum-deposited C60. *Applied Physics Letters* 2017; 111:233305.

Nicklin C, Hardigree JFM, Warne A, Green S, Burt M, Naylor J, Dorman A, Wicks D, Din S, Riede M. MINERVA: A facility to study Microstructure and Interface Evolution in Realtime under Vacuum. *Review of Scientific Instruments* 2017; 88:103901.

Milot RL, Sutton RJ, Eperon GE, Haghighirad AA, Hardigree JFM, Miranda L, Snaith HJ, Johnston MB, Herz LM. Charge-Carrier Dynamics in 2D Hybrid Metal-Halide Perovskites. *Nano Letters* 2016; 16:7001-7007.

Wojciechowski K, Ramirez IR, Gorisse T, Dautel O, Dasari R, Sakai N, Hardigree JFM, Song S, Marder S, Riede M, Wantz G, Snaith HJ. Cross-Linkable Fullerene Derivatives for Solution-Processed n-i-p Perovskite Solar Cells. *ACS Energy Letters* 2016; 1:648-653.

Alley O, Wu MY, Hardigree JFM, Arnold MS, Katz HE. Substrate-correlated interface polarity reversal at a carbon nanotube/fullerene junction. *Proc. 42nd IEEE Photovoltaics Specialist Conference* 2015; 1-5.

Alley O, Wu MY, Johns GL, Dawidczyk TJ, Hardigree JFM, Marković N, Arnold M, Katz HE. Negative polarity of phenyl-C61 butyric acid methyl ester adjacent to donor macromolecule domains. *Applied Physics Letters* 2015; 106:033301.

Yeh ML, Wang SY, Hardigree JFM, Podzorov V, Katz HE. Effect of side chain length on film structure and electron mobility of core-unsubstituted pyromellitic diimides and enhanced mobility of the dibrominated core using the optimized side chain. *Journal of Materials Chemistry C* 2015; 3:3029-3037.

Surampudi S, Yeh ML, Siegler M, Hardigree JFM, Kasl T, Katz HE, Klausen RS. Increased carrier mobility in end-functionalized oligosilanes. *Chemical Science* 2015; 6:1905-1909.

Streifel BC, Hardigree JFM, Katz HE, Tovar JD. Heteroaromatic variation in amorphous 1,6-methano[10]annulene-based charge-transporting organic semiconductors. *Journal of Materials Chemistry C*, 2014; 2:7851-7858.

Hardigree JFM and Katz HE. Through Thick and Thin: Tuning the Threshold Voltage in Organic Field-Effect Transistors. *Accounts of Chemical Research* 2014; 47:1369-1377.

Dawidczyk TJ, Hardigree JFM, Johns GL, Ozgun R, Alley O, Andreou AG, Marković N, Katz HE, "Visualizing and Quantifying Charge Distributions Correlated to Threshold Voltage Shifts in Lateral Organic Transistors," *ACS Nano* 2014; 8:2714-2724.

Huang W, Besar K, LeCover R, Dulloor P, Sinha J, Hardigree JFM, Pick C, Swavola J, Everett AD, Frechette J, Bevan M, Katz HE. Label-free brain injury biomarker detection based on highly sensitive large area organic thin film transistor with hybrid coupling layer. *Chemical Science* 2014; 5:416-426.

Hardigree JFM, Dawidczyk TJ, Ireland RM, Johns GL, Jung BJ, Nyman M, Österbacka R, Marković N, Katz HE. Reducing Leakage Currents in n-Channel Organic Field-Effect Transistors using Molecular Dipole Monolayers on Nanoscale Oxides. *ACS Applied Materials and Interfaces* 2013; 5:7025-7032.

Huang W, Sinha J, Yeh ML, Hardigree JFM, LeCover R, Besar K, Rule AM, Breyse PN, Katz HE. Diverse Organic Field-Effect Transistor Sensor Responses from Two Functionalized

Naphthalenetetracarboxylic Diimides and Copper Phthalocyanine Semiconductors Distinguishable Over a Wide Analyte Range. *Advanced Functional Materials* 2013; 23:4094-4104.

Nyman M, Sandberg O, Hardigree JFM, Kola S, Katz HE, Österbacka R. Voltage dependent displacement current as a tool to measure the vacuum level shift caused by self-assembled monolayers on aluminum oxide. *Applied Physics Letters* 2013; 103:243502.

Streifel BC, Peart PA, Hardigree JFM, Katz HE, Tovar JD. Torsional Influences within Disordered Organic Electronic Materials Based upon Non-Benzenoid 1,6-Methano[10]annulene Rings. *Macromolecules* 2012; 45:7339-7349.

Jung BJ, Hardigree JFM, Dawidczyk TJ, Sun J, Dhar BM, See KC, Katz HE. Naphthalenetetracarboxylic Diimide Layer-Based Transistors with Nanometer Oxide and Side Chain Dielectrics Operating below One Volt. *ACS Nano* 2011; 5:2723-2734.

Presentations

Hardigree JFM, Ramirez IR, Mazzotta G, Nicklin C, Riede M. In-situ x-ray characterization of molecular semiconductors for organic photovoltaics. Talk, Annual Showcase, Centre for Doctoral Training in New and Sustainable Photovoltaics, Liverpool GB, 2017.

Hardigree JFM, Mazzotta G, Ramirez IR, Naylor J, Nicklin C, Riede M. Grazing incidence x-ray diffraction of molecular thin films for organic electronics. Talk, XMaS@20 Conference, ESRF – The European Synchrotron, Grenoble FR, 2017.

Hardigree JFM, Ramirez IR, Mazzotta G, Nicklin C, Riede M. In-situ characterization of vacuum deposited materials. Talk, Telluride Science Research Conference - Workshop on Regulating the Interfacial Physicochemical Processes of Organic Semiconductors by Design, Telluride CO, 2017.

Hardigree JFM, Riede M, Ramirez IR, Mazzotta G, Morel A, Gutfreund P, Wermeille D. Assessing microstructure and interfacial diffusion of MoO₃ in organic solar cells using x-ray and neutron scattering. Talk, Intl. Conference on Advanced Ceramics and Composites – Advanced Ceramic Materials and Processing for Photonics and Energy, Daytona FL, 2017.

Hardigree JFM, Kesava SV, Riede M. In-situ X-ray and Optical Characterisation of Vacuum-Deposited Organic Semiconductors. Talk, JSPS London Research Promotion Conference, London GB, 2016.

Hardigree JFM, Warne A, Mazzotta G, Ramirez IR, Green S, Burt M, Dorman A, Din S, Wicks D, Naylor J, Riede M, Nicklin C. In-situ GIWAXS of Vacuum-deposited Organic Photovoltaic Thin Films at Diamond Light Source. Poster, BeSSyII Energy Materials Research Workshop, Helmholtz-Zentrum Berlin DE, 2016.

Hardigree JFM, Morse GE, Tiwana P, Mazzotta G, Ramirez IR, Nicklin C, Lozman OR, Riede M. Managing BHJ microstructural evolution for long-term photoconversion efficiency. Talk, SPIE Optics+Photonics, San Diego CA, 2016.

Hardigree JFM. X-ray and Neutron Scattering for Revealing Microstructure and Interfaces in OPVs. Talk, Polymer-Carbon Nanotubes Active Systems for Photovoltaics Winter School, Imperial College, London GB, 2016.

Hardigree JFM, Dawidczyk TJ, Nyman M, Österbacka R, Katz HE. Charge Extraction Analysis of Inorganic and Organic Dielectrics for Organic Field-Effect Transistors. Talk, American Physical Society Meeting, Denver CO, 2014.

Hardigree JFM, Dawidczyk TJ, Ireland RM, Johns GL, Jung BJ, Marković N, and Katz HE. Controlling Leakage Currents in Organic Field Effect Transistors using Molecular Dipole Monolayers on Nanoscale

Oxides. Talk, American Physical Society Meeting, Baltimore MD, 2013.

Hardigree JFM, Dawidczyk TJ, Ireland RM, Johns GL, Jung BJ, Marković N, and Katz HE. Gate Leakage Current Reduction from a Silane Monolayer Dipole in a Naphthalenetetracarboxylic Diimide Transistor Enabling Use of a Minimal 10-nm Silicon Oxide Dielectric. Poster, Materials Research Society Fall Meeting, Boston MA, 2012.

Research Grants

GCRF-START: Synchrotron Techniques for African Research and Technology, Science and Technology Facilities Council (UK), ST/R002754/1.

Peer Reviews

ACS Applied Materials & Interfaces

Journal of Alloys and Compounds

Journal of Materials Research

MRS Communications

Sensors