

# SYMPOSIUM ES14

Thin-Film Chalcogenide Semiconductor Photovoltaics  
April 18 - April 21, 2017

## Symposium Organizers

Shubhra Bansal, University of Nevada-Las Vegas  
Ingrid Repins, National Renewable Energy Laboratory  
Sascha Sadewasser, International Iberian Nanotechnology  
Laboratory  
Edgardo Saucedo Silva, Catalanian Institute for Energy  
Research (IREC)

## Symposium Support

Dr. Eberl MBE-Komponenten GmbH  
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National Renewable Energy Laboratory

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\* Invited Paper

## TUTORIAL

### Young Scientist Tutorial on Characterization Techniques for Thin-Film Solar Cells

Monday Morning, April 17, 2017  
8:30 AM – 5:00 PM  
PCC North, 200 Level, Room 229 B

**8:30 AM - 8:35 AM**  
Welcome

**8:35 AM - 9:50 AM**  
Part I: **Thomas Paul Weiss**  
*Device Characterization and Modeling*

Basic concepts of electrical characterization using IV, QE, EBIC, C-V and C-f. Discussion of characteristic features of QE and I-V curves and how to extract the diode parameters using a 1-diode model. EBIC as a tool to access the carrier collection function and its connection to the device QE. Various contributions of a solar cell to its capacitance and how C-V and C-f measurements can be employed to extract doping densities, charge-carrier barriers and deep defect levels.

**9:50 AM BREAK**

**10:20 AM - 11:35 AM**  
Part II: **Matthias Maiberg**  
*Characterization of Thin-Film Semiconductors by Time-Resolved Luminescence*

Introduction to measurement and analysis of time-resolved luminescence (TRL) in photovoltaic thin-film semiconductors. Discussion of various techniques for measurement of TRL as well as of advantages and disadvantages. Examples for luminescence decay curves from measurements on Cu(In,Ga)Se<sub>2</sub> and Cu<sub>2</sub>ZnSnSe<sub>4</sub>. Classification of these luminescence transients and determination of material parameters using simulations.

**11:35 AM LUNCH**

**12:45 PM - 2:00 PM**  
Part III: **Michelle Mezher**  
*Soft X-Ray and Electron Spectroscopy*

Introduction to several soft x-ray characterization techniques, including x-ray and UV photoelectron spectroscopy, inverse photoemission spectroscopy and x-ray emission spectroscopy. Discussion includes how they can be used to determine the electronic and chemical structure of surfaces and interfaces in photovoltaic devices.

**2:00 PM BREAK**

**2:30 PM - 3:45 PM**  
Part IV: **Jacob Gruber and Jose J. Chavez**  
*Introduction to Atomistic Modeling for Materials Characterization*

Introduction to atomistic modeling in general. Several example applications for the study of mechanical behaviors of materials while avoiding potential pitfalls. Along with post processing tools, application for the study of structure and behavior of defects, analysis of bulk properties from models of atomic interactions, as well as of synthesis processes for numerous materials systems.

**3:45 PM - 5:00 PM**  
Part V: **Tao Song**  
*Device Design and Modeling of Thin-Film Photovoltaic Devices*

Basic design principles of thin-film solar cells and techniques. Numerical simulation to support interpretation of experimental results. Examples to illustrate the importance of device modeling, including the impact of material parameters on cell performance, the energy band alignment and interface recombination, as well as the grain boundary and non-uniformity issues of thin-film solar cells.

**5:00 PM**  
Closing Remarks

Instructors  
**Thomas Paul Weiss**, Swiss Federal Laboratories for Materials Science and Technology (EMPA)  
**Matthias Maiberg**, Martin Luther University of Halle-Wittenberg  
**Michelle Mezher**, University of Nevada, Las Vegas  
**Jacob Gruber**, Drexel University  
**Jose J. Chavez**, Sandia National Laboratories  
**Tao Song**, Colorado State University

SESSION ES14.1: Passivation  
Session Chairs: Sascha Sadewasser and Edgardo Saucedo Silva  
Tuesday Morning, April 18, 2017  
PCC North, 200 Level, Room 229 B

**10:30 AM \*ES14.1.01**  
**Improving the Open-Circuit Voltage of Cu<sub>2</sub>ZnSnSe<sub>4</sub> Thin-Film Solar Cells via Interface Passivation** [Byungha Shin](#); KAIST, Korea (the Republic of).

**11:00 AM ES14.1.02**  
**Boosting the Open Circuit Voltage of Cu<sub>2</sub>ZnSnS<sub>4</sub> Solar Cells by a Lattice-Matched CeO<sub>2</sub> Layer and Theoretical Understanding of Interface Defects** [Andrea Crovetto](#)<sup>1,2</sup>; <sup>1</sup>Technical University of Denmark, Denmark; <sup>2</sup>University of New South Wales, Australia.

**11:15 AM ES14.1.03**  
**Understanding the Full Effects of Rear Contact Passivation in CIGS Solar Cells** [Pedro M. Salome](#); INL, Portugal.

**11:30 AM ES14.1.04**  
**Improved CdTe Solar-Cell Performance with An Evaporated Te Layer before the Back Contact** [Andrew Moore](#); Colorado State University, United States.

**11:45 AM ES14.1.05**  
**On the Effects of Chalcogen Excess for High Efficiency Kesterite Solar Cells** [Douglas M. Bishop](#); IBM T.J. Watson Research Center, United States.

SESSION ES14.2: Absorber Characterization  
Session Chairs: Matthias Maiberg and Byungha Shin  
Tuesday Afternoon, April 18, 2017  
PCC North, 200 Level, Room 229 B

**1:30 PM \*ES14.2.01**

**Correlative Optical Microscopy of Charge Carrier Lifetimes, Mobilities and Space Charge Fields in Thin-Film Chalcogenide Solar Cells** Darius Kuciauskas; National Renewable Energy Laboratory, United States.

**2:00 PM ES14.2.02**

**Expanding the Theory of the Diode Factor from Devices towards Semiconductor Layers Using the Example of Cu(In,Ga)Se<sub>2</sub>** Finn Babbe; University of Luxembourg, Luxembourg.

**2:15 PM ES14.2.03**

**Structural Defects and Lateral Composition Inhomogeneities in Cu(In,Ga)Se<sub>2</sub> Layers Grown by Multistage Co-Evaporation** Enrico Avancini; Empa, Switzerland.

**2:30 PM ES14.2.04**

**Interpreting Time-Resolved Photoluminescence for Chalcopyrite and Kesterite Absorbers and Devices** Charles Hages; Helmholtz Zentrum Berlin, Germany.

**2:45 PM ES14.2.05**

**Origin of Band-Tails in Kesterite** Germain Rey; University of Luxembourg, Luxembourg.

**3:00 PM BREAK**

SESSION ES14.3: Interfaces and Contacts  
Session Chairs: Sergio Giraldo and Clemens Heske  
Tuesday Afternoon, April 18, 2017  
PCC North, 200 Level, Room 229 B

**3:30 PM \*ES14.3.01**

**(Zn,Mg)O Transparent Electrode and Buffer Layer for Junction Control in Cu(In,Ga)(Se,S)<sub>2</sub> Solar Cells** Takashi Minemoto; Ritsumeikan University, Japan.

**4:00 PM ES14.3.02**

**Benefit of Textured CIGS Cells for Low Reflecting Nanogrid Application** Joop van Deelen; TNO, Netherlands.

**4:15 PM ES14.3.03**

**Well-Controlled Dielectric Nanomeshes by Colloidal Nanosphere Lithography for Opto-Electronic Enhancement of Ultrathin Cu(In,Ga)Se<sub>2</sub> Solar Cells** Guanchao Yin; Helmholtz Zentrum Berlin, Germany.

**4:30 PM \*ES14.3.04**

**Alternative Buffer and Front Contact Layers for Thin-Film Chalcogenide Cells** Yaroslav E. Romanyuk; EMPA, Switzerland.

SESSION ES14.4: Poster Session I: Passivation, Absorber and Advanced Characterization, Interfaces and Contacts  
Session Chairs: Ingrid Repins and Edgardo Saucedo Silva  
Tuesday Afternoon, April 18, 2017  
8:00 PM - 10:00 PM  
Sheraton, Third Level, Phoenix Ballroom

**ES14.4.01**

**Mapping Disordered Nanodomains in Cu<sub>2</sub>(Zn,Sn)S<sub>4</sub> and Cu<sub>2</sub>(Zn,Sn)Se<sub>4</sub>S<sub>4</sub>** Dennis S. Pruzan; University of Utah, United States.

**ES14.4.02**

**Nondestructive High-Power-High-Temperature Raman Spectroscopy for Probing Microscopic Structural Variations in CZTSe Alloys** Qiong Chen; University of North Carolina at Charlotte, United States.

**ES14.4.03**

**Effects of CdCl<sub>2</sub> Treatment and Br<sub>2</sub>/MeOH Etching on the Absorption of CdTe Thin Films as Measured by Photothermal Deflection Spectroscopy** Jordan J. Andrews<sup>1,2</sup>; <sup>1</sup>University of British Columbia Okanagan, Canada; <sup>2</sup>University of British Columbia, Canada.

**ES14.4.04**

**Simulation Study of Photoluminescence Lifetime and Device Efficiency of Cu(In,Ga)Se<sub>2</sub> Thin Film Solar Cells** Jose Fabio Lopez Salas; University of Oldenburg, Germany.

**ES14.4.05**

**High Fidelity Polycrystalline CdTe/CdS Heterostructures via Molecular Dynamics** Rodolfo Aguirre; The University of Texas at El Paso, United States.

**ES14.4.06**

**Charged Grain Boundaries Reduce the Open Circuit Voltage of Polycrystalline Solar Cells—An Analytic Description** Benoit Gaury<sup>1,2</sup>; <sup>1</sup>National Institute of Standards and Technology, United States; <sup>2</sup>University of Maryland, United States.

**ES14.4.07**

**Admittance-Spectroscopy Model of CIGS-Based Solar Cells** Kazimierz J. Plucinski; Military University of Technology, Poland.

**ES14.4.08**

**XESCA—X-Ray Emission Spectroscopy for Chemical Analysis** Sang Jun Lee<sup>1,2</sup>; <sup>1</sup>SLAC, United States; <sup>2</sup>Stanford University, United States.

**ES14.4.09**

**Surface Phases in (Ag,Cu)(In,Ga)Se<sub>2</sub> Semiconductors Determined by Ultraviolet and X-Ray Photoemission Spectroscopy** Kevin Jones; University of Delaware, United States.

**ES14.4.10**

**Evaluation of Electrical Characteristics of Cu(In,Ga)(S,Se)<sub>2</sub> Thin Films Prepared by a Two-Step Sputtering/Annealing Large-Scale Fabrication Process** Juran Kim; Ewha Womans University, Korea (the Republic of).

**ES14.4.11**

**Surface and Local Electronic Properties of (Ag,Cu)<sub>2</sub>ZnSn(S,Se)<sub>4</sub> Photovoltaic Absorbers Grown by 2-Step Processes** Juran Kim; Ewha Womans University, Korea (the Republic of).

**ES14.4.12**

**Revisiting Thin-Film Absorption Coefficient Measurement from Photoluminescence** Germain Rey; University of Luxembourg, Luxembourg.

**ES14.4.13**

**Role of Defects in Cu(In,Ga)Se<sub>2</sub> Solar Cells with CdS and Zn(1-x)Sn(x)O(y) Buffer Layers—Microscopy and Photoluminescence Study** Jennifer P. Teixeira; Univ de Aveiro, Portugal.

**ES14.4.14**

**Effect of Varying the Cu Content on Cu(In,Ga)Se<sub>2</sub> Solar Cells** Jennifer P. Teixeira; Univ de Aveiro, Portugal.

**ES14.4.15**

**Characterization of CIGS Solar Cells through Glow Discharge Optical Emission Spectrometry and Differential Interferometry Profiling** Mathieu Chausseau; HORIBA Scientific, United States.

**ES14.4.16**

**Luminescence Detection of the 0.8eV Defect** Conrad Spindler; University of Luxembourg, Luxembourg.

**ES14.4.17**

**Role of Pre-Layer Mo Films in Microstructural and Morphological Properties of Over-Layer CIGS Films** Hamda Al-Thani; National Energy & Water Research Center (NEWRC), United Arab Emirates.

**ES14.4.18**

**Compositional Influence of the Cationic Solution in CZTS Thin Films Deposited by SILAR for Solar Cells Applications** Shadai Lugo Loredó; Centro de Investigación en Materiales Avanzados S. C. Unidad Monterrey, Mexico.

- ES14.4.19**  
**Photoconductive Properties of Nano-Flakes Assembled Porous Microspheres CuInS<sub>2</sub>: Cd<sup>2+</sup>, V<sup>3+</sup> Thin Films via Hydrothermal Method on Spray Seed Coated Substrates** K. Sethuraman<sup>1,2</sup>; <sup>1</sup>University of Alabama, United States; <sup>2</sup>Madurai Kamaraj University, India.
- ES14.4.20**  
**Evaporated CdIn<sub>2</sub>S<sub>4</sub> Buffer Layer for Kesterite Solar Cells** Leo Choubrac; Institut des Matériaux Jean Rouxel (IMN), Université de Nantes, France.
- ES14.4.21**  
**Back Contact Functionalization by Transition Metal Oxides for Kesterite Solar Cells** Sergio Giraldo; Catalonia Institute for Energy Research (IREC), Spain.
- ES14.4.22**  
**Electronic Structure of Cu(In,Ga)(S,Se)<sub>2</sub> Surface and CdS/Cu(In,Ga)(S,Se)<sub>2</sub> Interface** Suehiro Kawamura; Kagoshima University, Japan.
- ES14.4.23**  
**Band Alignment of CdS/Cu<sub>2</sub>ZnSnSe<sub>4</sub> Heterointerface and Solar Cell Performances** Takehiko Nagai; National Institute of Advanced Industrial Science and Technology (AIST), Japan.
- ES14.4.24**  
**Cu<sub>2</sub>ZnSn(S,Se)<sub>2</sub> Surface Modification by Epitaxial Growth of Al(OH)<sub>3</sub> Nanolayers—Impact on the Devices Efficiency** Edgardo Saucedo Silva; IREC, Spain.
- ES14.4.25**  
**Zn<sub>1-x</sub>Sn<sub>x</sub>O<sub>y</sub>/Cu<sub>2</sub>ZnSnS<sub>4</sub> Interface and Its Chemical Structure Studied by Soft X-Ray Spectroscopies** Bridget Elizan; University of Nevada, Las Vegas, United States.
- ES14.4.26**  
**Bi-Facial CdTe Thin Film Solar Cells Using Nanowire Back Contact for Flexible Applications** Yongbeom Kwon; Korea University, Korea (the Republic of).
- ES14.4.27**  
**From Bandstructure to Bandalignment—A Study on Chalcopyrite Surfaces** Christian Pettenkofer; Helmholtz-Zentrum Berlin, Germany.
- ES14.4.28**  
**Cadmium Tin Oxide and Zinc Magnesium Oxide Prepared by Hollow Cathode Sputtering for CdTe Photovoltaics** Alan E. Delahoy; CNBM New Energy Materials Research Center, Department of Physics, New Jersey Institute of Technology, United States.
- ES14.4.29**  
**ALD of ZnO<sub>1-x</sub>S<sub>x</sub> Buffer Layer Films** Samual Wilson; University of Florida, United States.
- ES14.4.30**  
**DFT Calculations and XPS Analysis of the Adsorption of Transition Metal-Citrate Complexes on a CdS Surface for the Deposition of Cu<sub>2</sub>ZnSnS<sub>4</sub> Thin Films** Raquel Garza Hernandez; Centro de Investigación en Materiales Avanzados S. C. Unidad Monterrey, Mexico.
- ES14.4.31**  
**A Comparative Study of CdTe/CdS Junction Activation Using MgCl<sub>2</sub> and CdCl<sub>2</sub>** Xavier Mathew; Instituto de Energías Renovables, Universidad Nacional Autónoma de México, Mexico.
- ES14.4.32**  
**Structural and Optical Properties of CdS<sub>x</sub>Se<sub>1-x</sub> Thin-Film Chalcogenide Glass** Pawan Kumar<sup>1,3</sup>; <sup>1</sup>University of Puerto Rico San Juan, United States; <sup>3</sup>Gurukula Kangri University Haridwar, India.
- ES14.4.33**  
**Deposition Kinetics of Zinc Oxide Thin Films by Magnetron Sputtering** Yifei Sun; Macalester College, United States.
- ES14.4.34**  
**Effects of Gas Flow Rate on the Properties of SnO<sub>2</sub> Thin Films Deposited by RF Sputtering** Muntaser Al-Mansoori; Masdar Institute of Science and Technology, United Arab Emirates.
- ES14.4.35**  
**Micropatterned Oxide Layers for Front Contact Passivation in CdTe-Based Thin-Film Photovoltaics** Jason M. Kephart; Colorado State University, United States.
- ES14.4.36**  
**CIGS Performance Enhancement by Texturisation** Joop van Deelen; TNO, Netherlands.
- ES14.4.37**  
**Investigation of Crystal Growth Mechanisms of the CuGaSe<sub>2</sub> - CuAlSe<sub>2</sub> Single Crystals Grown by Chemical Vapor Transport** B.V. Korzun; The City University of New York, Borough of Manhattan Community College, United States.
- ES14.4.38**  
**Mössbauer Studies of the CuFeS<sub>2-6</sub> - CuInS<sub>2</sub> System** B.V. Korzun; The City University of New York, Borough of Manhattan Community College, United States.
- SESSION ES14.5/ES11.5: Joint Session: Tandem Devices  
 Session Chairs: Richard King and Yaroslav Romanyuk  
 Wednesday Morning, April 19, 2017  
 PCC North, 200 Level, Room 221 ABC
- 8:00 AM \*ES14.5.01/ES11.5.01**  
**Efficiency Potential and Recent Activities of High Efficiency and Si Tandem Solar Cells** Masafumi Yamaguchi; Toyota Technological Institute, Japan.
- 8:30 AM \*ES14.5.02/ES11.5.02**  
**Development of High Gap Ge- and Si-Based Kesterite-Like Solar Cells for Tandem Applications** Guy Brammertz; imec - Division of IMOMECE, Belgium.
- 9:00 AM ES14.5.03/ES11.5.03**  
**NIR-Transparent Perovskite Solar Cell for Flexible All-Thin-Film Tandem Devices** Stefano Pisoni; EMPA, Switzerland.
- 9:15 AM ES14.5.04/ES11.5.04**  
**Infrared-Tuned Silicon Bottom Cell for 23.6%-Efficient Perovskite/Silicon Tandem** Zhengshan J. Yu; Arizona State University, United States.
- 9:30 AM ES14.5.05/ES11.5.05**  
**Large-Area Scalable Perovskite/Silicon Multi-Junction Solar Modules** Manoj Jaysankar; imec, Belgium.
- 9:45 AM ES14.5.06/ES11.5.06**  
**Study of Polycrystalline Mg<sub>x</sub>Cd<sub>1-x</sub>Te/Mg<sub>x</sub>Cd<sub>1-x</sub>Te Double Heterostructures for Tandem Solar Cell Applications** Calli M. Campbell<sup>1,2</sup>; <sup>1</sup>Arizona State University, United States; <sup>2</sup>Arizona State University, United States.
- 10:00 AM BREAK**
- SESSION ES14.6: Buffer Layer and Alkali Treatments  
 Session Chairs: Michelle Mezher and Pedro Salome  
 Wednesday Morning, April 19, 2017  
 PCC North, 200 Level, Room 229 B
- 10:30 AM \*ES14.6.01**  
**Design of Optimal Buffer Layers for CIGS Thin-Film Solar Cells** Vincenzo Lordi; Lawrence Livermore National Laboratory, United States.
- 11:00 AM \*ES14.6.02**  
**Highly Efficient Solar Cells Based on Full PVD Processed CIGSe/CdIn<sub>2</sub>S<sub>4</sub> Heterojunction** Nicolas Barreau; Université de Nantes, France.
- 11:30 AM ES14.6.03**  
**Impact of the Heavy Alkali Fluoride Post-Deposition Treatment on the Electronic Structure of the CdS/Cu(In,Ga)Se<sub>2</sub> Interface in High-Efficiency Thin-Film Solar Cells** Dirk Hauschild<sup>1,2,3</sup>; <sup>1</sup>Karlsruhe Institute of Technology (KIT), Germany; <sup>2</sup>Karlsruhe Institute of Technology (KIT), Germany; <sup>3</sup>University of Würzburg, Germany.

11:45 AM ES14.6.04

**Comparison of the Interface Formation of Cu(In,Ga)Se<sub>2</sub> with RbF Post-Deposition Treatment and CdS and ZnS Buffer Layers** Nicoleta Nicoara; International Iberian Nanotechnology Laboratory, Portugal.

SESSION ES14.7: Defects and Disorder  
Session Chairs: Shubhra Bansal and Stephan Lany  
Wednesday Afternoon, April 19, 2017  
PCC North, 200 Level, Room 229 B

1:30 PM ES14.7.01

**Optical Properties and Band Structures of Cu-Deficient Phases, Cu(In,Ga)<sub>3</sub>Se<sub>5</sub> and Cu(In,Ga)<sub>2</sub>Se<sub>8</sub> in Cu-Poor Cu<sub>2</sub>Se-(In,Ga)<sub>2</sub>Se<sub>3</sub> Pseudo-Binary System** Takahiro Wada; Ryukoku Univ, Japan.

1:45 PM ES14.7.02

**Investigation of Carrier Transport in CuInGaSe, by Highly Spatially, Spectrally and Time Resolved Cathodoluminescence Microscopy** Mathias Mueller; Otto-von-Guericke-University, Germany.

2:00 PM ES14.7.03

**Optoelectronic Properties of Bulk Single-Crystal (Ag,Cu)<sub>2</sub>ZnSnSe<sub>4</sub> Alloys** Michael A. Lloyd<sup>1,2</sup>; <sup>1</sup>University of Delaware, United States; <sup>2</sup>Institute of Energy Conversion, United States.

2:15 PM ES14.7.04

**Role of Nanoscale Disorder in Photovoltaics** Jeffery A. Aguilar<sup>1,2</sup>; <sup>1</sup>Idaho National Laboratory, United States; <sup>2</sup>University of Utah, United States.

2:30 PM BREAK

SESSION ES14.8: Alkali Incorporation  
Session Chairs: Nicolas Barreau and Stefan Haass  
Wednesday Afternoon, April 19, 2017  
PCC North, 200 Level, Room 229 B

3:30 PM \*ES14.8.01

**Thermodynamic Limitations for Alkali Metals in Cu(In,Ga)Se<sub>2</sub>** Dimitrios Hariskos; Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Germany.

4:00 PM ES14.8.02

**KF Post-Deposition Treatment of Industrial Cu(In,Ga)(S,Se)<sub>2</sub> Thin-Film Surfaces—Modifying the Chemical and Electronic Structure** Michelle Mezher; University of Nevada, Las Vegas, United States.

4:15 PM ES14.8.03

**Na-Diffusion Enhanced p-Type Conductivity in Cu(In,Ga)Se<sub>2</sub>: A New Mechanism for Efficient Doping in Semiconductors** Shiyong Chen; East China Normal University, China.

4:30 PM ES14.8.04

**Impact of Different Alkali Post Deposition Treatments on the Formation of the Zn(O,S)/Cu(In,Ga)Se<sub>2</sub> Interface** Thomas Kunze; Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany.

4:45 PM ES14.8.05

**Improvement of Open Circuit Voltage in Cu<sub>2</sub>ZnSnSe<sub>4</sub> Solar Cells by Surface Treatment** Hitoshi Tampo; National Institute of Advanced Industrial Science and Technology, Japan.

SESSION ES14.9: Poster Session II: Defects, Degradation and Stability, Chalcopyrite Growth, Tandem Devices and Alkali Incorporation  
Session Chairs: Shubhra Bansal and Ingrid Repins  
Wednesday Afternoon, April 19, 2017  
8:00 PM - 10:00 PM  
Sheraton, Third Level, Phoenix Ballroom

ES14.9.01

**Using Diffusion-Reaction Simulation to Study Light Soaking Effect in CdTe Solar Cells** Da Guo; Arizona State University, United States.

ES14.9.02

**Alkali Doping in Solution Processed Kesterite Solar Cells** Stefan G. Haass; Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Thin Films and Photovoltaics, Switzerland.

ES14.9.03

**Analysis of Waiting Times between CIGS and CdS and In-Diffusion of Na on the Properties of Cu(In,Ga)Se<sub>2</sub> Materials and Solar Cells** Pedro M. Salome; INL, Portugal.

ES14.9.04

**Na-Assisted Grain Growth in Cu<sub>2</sub>ZnSnS<sub>4</sub> Nanoparticle Thin Films for Solar Cell Applications** Sara Engberg; Technical University of Denmark, Denmark.

ES14.9.05

**In-Ga Interdiffusion in CIGS—The Roles of Potassium and Selenium** Diego Colombara; Université du Luxembourg, Luxembourg.

ES14.9.06

**Enhanced Performance of Cu<sub>2</sub>ZnSn(S,Se)<sub>4</sub> Solar Cells with Introducing Interfacial Alkali Fluoride Layers** Cheng-Ying Chen<sup>1,2</sup>; <sup>1</sup>National Taiwan University, Taiwan; <sup>2</sup>Institute of Atomic and Molecular Science, Academia Sinica, Taiwan.

ES14.9.07

**Composition Dependent Cation Ordering Characteristics of Thin-Film CZTS** Katharina Rudisch; Uppsala University, Sweden.

ES14.9.08

**Antisite Defects in Cu<sub>2</sub>ZnSn(S,Se)<sub>4</sub>—Local and Long Range Order** Michael F. Toney; SLAC National Laboratory, United States.

ES14.9.09

**Can Deep Defects Limit the Open Circuit Voltage of Cu(In,Ga)Se<sub>2</sub> Solar Cells?** Conrad Spindler; University of Luxembourg, Luxembourg.

ES14.9.10

**Atomic-Scale Study of Grain Boundaries in CdTe** Fatih G. Sen; Argonne National Laboratory, United States.

ES14.9.11

**Molecular Dynamics Study of Grain Boundaries within CdTe Thin Films Grown on CdS Substrates** Jose J. Chavez; Sandia National Laboratories, United States.

ES14.9.12

**Structural Trends in Chalcopyrite Based Intermediate Band Absorber Materials** Julien Marquardt<sup>1,2</sup>; <sup>1</sup>Helmholtz-Zentrum Berlin für Materialien und Energie, Germany; <sup>2</sup>Freie Universität Berlin, Germany.

ES14.9.13

**Defects in Copper Indium Gallium Aluminum Diselenide (CIAGS) Films and Their Impact on Photovoltaic Device Performance** Stephen Campbell; University of Minnesota, United States.

ES14.9.14

**Electronic Transitions in Highly Doped and Compensated Chalcopyrites and Kesterites** Jennifer P. Teixeira; Univ de Aveiro, Portugal.

ES14.9.15

**The Defects Generated in Magnetron Sputtered Thin-Film CdTe Solar Cells that Limit Performance and Cause Delamination** John M. Walls; Loughborough University, United Kingdom.

**ES14.9.16**  
**A Review—Metastability, Potential Induced and Damp Heat Degradation and Recovery in CIGS Solar Cells** Shubhra Bansal; University of Nevada, Las Vegas, United States.

**ES14.9.17**  
**Anomalous Reverse Breakdown of CIGS Devices—Theory and Simulation** Marco Nardone; Bowling Green State University, United States.

**ES14.9.18**  
**Clarification of Proton- and Electron-Irradiated Degradation Mechanism of  $\text{Cu}_2\text{ZnSnS}_4$  Solar Cells** Mutsumi Sugiyama; Tokyo University of Science, Japan.

**ES14.9.19**  
**Compare Corrosion Resistance of Aluminum-Doped Zinc Oxide (AZO) and Gallium-Doped Zinc Oxide (GZO) Films Depending on the Hydrogen Content** Soo Ho S. Cho; Koreatech, Korea (the Republic of).

**ES14.9.20**  
**Low Band Gap  $\text{Cu}(\text{In,Ga})\text{Se}_2$  Absorber Layers for Current Matched Perovskite/CIGS Tandem Solar Cells** Thomas Feurer; Empa, Switzerland.

**ES14.9.21**  
**Comparison of Low Bandgap  $\text{CuInSe}_2$  Alloys for Tandem Solar Cells** Nicholas H. Valdes<sup>1,2</sup>; <sup>1</sup>Institute of Energy Conversion, United States; <sup>2</sup>University of Delaware, United States.

**ES14.9.22**  
 **$\text{Cu}(\text{In,Ga})\text{Se}_2$ -Based Monolithic Tandem Solar Cell with Open-Circuit Voltage over 1 V** Jae-Hyung Wi; Electronics and Telecommunications Research Institute (ETRI), Korea (the Republic of).

**ES14.9.23**  
**Textured CIGS/Perovskite Tandem Cells** Joop van Deelen; TNO, Netherlands.

**ES14.9.24**  
**Understanding the Effect of Stainless Steel Substrates on Flexible CIGS Solar Cell Performance** Tara Nietzold; Arizona State University, United States.

**ES14.9.25**  
**Predicting Ga and Cu Profiles in Co-Evaporated  $\text{Cu}(\text{In,Ga})\text{Se}_2$  Using Modified Diffusion Equations and a Spreadsheet** Ingrid Repins; National Renewable Energy Laboratory, United States.

**ES14.9.26**  
**CIGS and CIS Solar Cells Processed from Environmental Benign and Stable Molecular Inks** Hao Xin; Nanjing University of Posts & Telecommunications, China.

**ES14.9.27**  
**Photovoltaic Assessment of Single Solution Derived  $\text{CuIn}(\text{S,Se})_2$  Films and Devices** Devendra Tiwari; University of Bristol, United Kingdom.

**ES14.9.28**  
**Pulsed Laser Deposition (PLD) of the CZTS Absorber Material for Solar Cells with up to 5.2% Efficiency** Jorgen Schou; TU Denmark, Denmark.

**ES14.9.29**  
**Pulsed Laser Deposition of Thin Films of Chalcogenides** Stela Canulescu; Technical University of Denmark, Denmark.

**ES14.9.30**  
 **$\text{Cu}(\text{In,Ga})\text{Se}_2$  Solar Cell Fabrication and Characterization** Yasir I. Alrikabi; University of Arkansas at Little Rock, United States.

**ES14.9.31**  
**Photoluminescence Study of Pentanary Ag-Containing Chalcopyrite Solar Cells** Abhinav Chikhalkar; Arizona State University, United States.

**ES14.9.32**  
**Monolithic Tandem Devices Demonstrating over 1.2 V Voc Using a Wide-Bandgap Chalcopyrite Absorber** Kim Horsley; Hawaii Natural Energy Institute, United States.

SESSION ES14.10: Advanced Characterization  
 Session Chairs: Daniel Abou-Ras and Thomas Kunze  
 Thursday Morning, April 20, 2017  
 PCC North, 200 Level, Room 229 B

**8:30 AM \*ES14.10.01**  
**Alternative Buffer Materials and Their Electronic and Chemical Properties in  $\text{Cu}(\text{In,Ga})(\text{S,Se})_2$  and  $\text{CdTe}$  Thin-Film Solar Cells** Clemens Heske<sup>1,2</sup>; <sup>1</sup>University of Nevada Las Vegas (UNLV), United States; <sup>2</sup>Karlsruhe Institute of Technology (KIT), Germany.

**9:00 AM ES14.10.02**  
**Synchrotron-Based *In Situ* Characterization of  $\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$  Solar Cells—Nanoscale Performance under Operating Conditions** Michael Stuckelberger; Arizona State University, United States.

**9:15 AM ES14.10.03**  
***In Situ* Nano Elemental Mapping to Visualize the Growth of  $\text{Cu}(\text{In,Ga})\text{Se}_2$  Thin Films** Bradley West; Arizona State University, United States.

**9:30 AM ES14.10.04**  
**Nanoscale Photovoltaic Performance throughout 3-Dimensions in  $\text{CdTe}$  Solar Cells via Tomographic AFM** Bryan D. Huey; University of Connecticut, United States.

**9:45 AM ES14.10.05**  
**Studies of Atom Disorder in  $\text{Cu}_2\text{ZnSnSSe}_4$  and  $\text{Ag}_2\text{ZnSnSSe}_4$  Alloys** David Cherns; University of Bristol, United Kingdom.

**10:00 AM BREAK**

SESSION ES14.11: Defects  
 Session Chairs: Igor Sankin and Dragica Vasileska  
 Thursday Morning, April 20, 2017  
 PCC North, 200 Level, Room 229 B

**10:30 AM ES14.11.01**  
**Three-Dimensional Lifetime Tomography Reveals How  $\text{CdCl}_2$  Improves Recombination throughout  $\text{CdTe}$  Solar Cells** Edward S. Barnard; Lawrence Berkeley National Lab, United States.

**10:45 AM ES14.11.02**  
**Correlations of Grain-Boundary Character with Electrical and Optoelectronic Properties of  $\text{CuInSe}_2$  Thin Films** Daniel Abou-Ras; Helmholtz-Zentrum Berlin, Germany.

**11:00 AM ES14.11.03**  
**Phosphorus, Arsenic and Antimony Diffusion and Doping in Polycrystalline  $\text{CdTe}$**  Eric Colegrove; National Renewable Energy Laboratory (NREL), United States.

**11:15 AM ES14.11.04**  
**Influence of Defects Interactions on the Properties of  $\text{CdTe}:\text{Cl,Cu}$  Solar Cell Absorber** Dmitry Krasikov; First Solar Inc, United States.

**11:30 AM ES14.11.05**  
**Voltage Dependent Admittance Spectroscopy for the Detection of near Interface Defect States and the Extraction of the Doping Density** Thomas P. Weiss; Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland.

**11:45 AM ES14.11.06**  
**Structural and Compositional Dependence of the  $\text{CdTe}_{1-x}\text{Se}_x$  Alloy Layer Photoactivity in  $\text{CdTe}$ -Based Solar Cells** Jonathan Poplawsky; Oak Ridge National Laboratory, United States.

SESSION ES14.12: Degradation, Stability and Modules

Session Chairs: Da Guo and Lars Stolt

Thursday Afternoon, April 20, 2017

PCC North, 200 Level, Room 229 B

1:30 PM \*ES14.12.01

**Scaling Up Solar** Becca Jones-Albertus; U.S. Department of Energy, United States.

2:00 PM \*ES14.12.02

**Metastability and Reliability of CdTe Solar Cells** Dragica Vasileska; Arizona State University, United States.

2:30 PM ES14.12.03

**Reduced Degradation of Cu(In,Ga)Se<sub>2</sub> Devices through Modification of ZnO:Al Surfaces** Lorelle M. Mansfield; National Renewable Energy Lab, United States.

2:45 PM ES14.12.04

**Study of Time-Resolved Photoluminescence on Cu(In,Ga)Se<sub>2</sub> Absorbers with Varying Cu-Content** Matthias Maiberg; Martin Luther University Halle-Wittenberg, Germany.

3:00 PM BREAK

SESSION ES14.13: Industry

Session Chairs: Dmitry Krasikov and Lorelle Mansfield

Thursday Afternoon, April 20, 2017

PCC North, 200 Level, Room 229 B

3:30 PM \*ES14.13.01

**Comprehensive Solution for Defect Chemistry in II-VI Photovoltaics** Igor Sankin; First Solar, Inc, United States.

4:00 PM \*ES14.13.02

**CIGS Solar Cell Research in Solar Frontier—Progress and Current Status** Takuya Kato; Solar Frontier, Japan.

4:30 PM ES14.13.03

**In-Line Alkali Post-Deposition Treatment for Flexible CIGS Solar Cell Manufacturing** JinWoo Lee; Global Solar Energy, United States.

4:45 PM ES14.13.04

**Alkali Element Interdependence in CIGS Relating to Depth Distribution of Na/K and Ga/(Ga+In)** Lars F. Stolt<sup>1,2</sup>; <sup>1</sup>Solibro Research AB, Sweden; <sup>2</sup>Uppsala University, Sweden.

SESSION ES14.14: Poster Session III: Novel Chalcogenide Absorber Materials and Kesterite Absorber Growth and Devices

Session Chairs: Sascha Sadewasser and Edgardo Saucedo Silva

Thursday Afternoon, April 20, 2017

8:00 PM - 10:00 PM

Sheraton, Third Level, Phoenix Ballroom

ES14.14.01

**Effect of Mg Incorporation on Solution-Processed Kesterite Solar Cells** Raquel Caballero; Univ Autonoma-Madrid, Spain.

ES14.14.02

**Kesterite Solar Cells Grown by Sulfurization of Co-Evaporated Cu<sub>2</sub>ZnSnSe<sub>4</sub> Thin Films** Raquel Caballero; Univ Autonoma-Madrid, Spain.

ES14.14.03

**Exploring the Role of Ge in the Synthesis of Cu<sub>2</sub>ZnSnSe<sub>4</sub>:Ge Kesterite Absorbers** Sergio Giraldo; Catalonia Institute for Energy Research (IREC), Spain.

ES14.14.04

**Ge Incorporated CZTSe Thin-Film Solar Cell with a Conversion Efficiency of 12.3%** Hitoshi Tampo; National Institute of Advanced Industrial Science and Technology, Japan.

ES14.14.05

**Reaction Kinetics of Cu<sub>2</sub>ZnSnS<sub>4</sub> and Cu<sub>2</sub>SnS<sub>3</sub> Formation from Cu<sub>2</sub>S, ZnS and SnS<sub>2</sub> Precursors Studied Using Differential Scanning Calorimetry** Elizabeth A. Pogue; University of Illinois, United States.

ES14.14.06

**Tuning of Stoichiometry and Band Gap of Solution-Processed Cu<sub>2</sub>ZnGeS<sub>4</sub>Se<sub>4-x</sub> Absorbers for Thin-Film Solar Cells** Thomas Schnabel; Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Germany.

ES14.14.07

**The Influence of Synthesis Conditions upon the Single-Phase Region in Cu<sub>2</sub>ZnSnS<sub>4</sub> Thin Films** Alexandra Davydova; Uppsala University, Sweden.

ES14.14.08

**Insights into the Chemistry of Amine-Thiol Solution Processing and Implications for Solution Processing of Chalcogenide Optoelectronic Devices** Caleb K. Miskin; Purdue University, United States.

ES14.14.09

**Atmospheric Variations on Close Spaced Vapor Transport Deposited SnS Thin Films—Air vs Argon** Jacob A. Andrade-Arvizu; Escuela Superior de Física y Matemáticas - Instituto Politécnico Nacional (ESFM-IPN), Mexico.

ES14.14.10

**Engineering the Crystal Phase and Morphology of Chalcogenide Nanomaterials for the Next Generation Thin-Film Solar Cells** Xiaoyan Zhang; Nanjing Tech University, China.

ES14.14.11

**Efficient Planar Antimony Sulfide Thin-Film Photovoltaics** Haisheng Song; Huazhong University of Science and Technology, China.

ES14.14.12

**Chemically Deposited Solar Cells of Orthorhombic and Cubic Tin Sulfide—An Overview** Ana Rosa Garcia Angelmo; Universidad Nacional Autonoma de Mexico, Mexico.

ES14.14.13

**Cubic Phase Tin Sulfide Thin Film Obtained by Atomic Layer Deposition and Its Application to Solar Cells** Xizhu Zhao; Harvard University, United States.

ES14.14.14

**Emitter/Absorber Interface Formation in SnS-Based Thin-Film Solar Cells** Leonard Koehler; Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany.

ES14.14.15

**Ultrasonic Spray Pyrolysis Deposition of Sb<sub>2</sub>S<sub>3</sub> for Extremely Thin Absorber Solar Cells** Erki Karber<sup>3,1</sup>; <sup>1</sup>Tallinn University of Technology, Estonia; <sup>3</sup>University of Nevada, Las Vegas (UNLV), United States.

ES14.14.16

**Perspectives on Antimony Sulfide-Selenide Thin-Film Solar Cells** Fabiola De Bray Sanchez; Universidad Nacional Autonoma de Mexico, Mexico.

ES14.14.17

**Aqueous Spray Pyrolyzed ZnO as Orientation Induced Buffer Layer for Sb<sub>2</sub>Se<sub>3</sub> Photovoltaics of Improved Stability** Liang Wang; Huazhong University of Science and Technology, China.

ES14.14.18

**Synthesis and Characterization of Sn(S<sub>x</sub>Se<sub>1-x</sub>)<sub>2</sub> Ternary Alloy Thin Films for Photovoltaic Applications** Joshua J. Fox<sup>1,2</sup>; <sup>1</sup>The Pennsylvania State University, United States; <sup>2</sup>Materials Research Institute, United States.

ES14.14.19

**Towards the Improvement of the Antimony Sulfide-Selenide Sensitized Solar Cells—Effect of Mesoporous TiO<sub>2</sub> Annealing and CdS Interlayer** Araceli Hernandez-Granados; UAEM, Mexico.

**ES14.14.20**  
**Band Gap Grading in  $\text{Cu}_2\text{ZnSnSe}_4$  Thin Films Prepared by the Annealing Process of S and Se from Metal Precursor-Based Deposits** [Juran Kim](#); Ewha Womans University, Korea (the Republic of).

**ES14.14.21**  
**Surface and Depth Profile of Phase Identification of Tin Sulfide Thin Films for Earth-Abundant Solar Cell Applications** [Juran Kim](#); Ewha Womans University, Korea (the Republic of).

**ES14.14.22**  
**Detection of Competing Parasitic Phases in Pyrite Photovoltaic Thin Films and Their Influence to Solar Cell Device Performance** [Juran Kim](#); Ewha Womans University, Korea (the Republic of).

**ES14.14.23**  
**Structural and Electronic Characterization of Tin Calcium Sulfide Alloy Thin Films Made by Atomic Layer Deposition** [Chuanxi Yang](#); Harvard University, United States.

**ES14.14.24**  
**Optoelectrical Properties of The Schottky Junction Devices Based on  $\text{Mo}_{1-x}\text{W}_x\text{Se}_2$**  [Sum-Gyun Yi](#); Yonsei University, Korea (the Republic of).

**ES14.14.25**  
**Preparation and Characterization of  $\text{In}_2\text{S}_3$ :V Solar Cells** [Matthias Maiberg](#); Martin Luther University Halle-Wittenberg, Germany.

**ES14.14.26**  
**Transparent Laminated Electrode for Highly Efficient Chemically Synthesized n-MoS<sub>2</sub> /p-Si Heterojunction Solar Cell** [Sungbum Kang](#); UNIST, Korea (the Republic of).

**ES14.14.27**  
**Antimony Sulfide-Selenide Thin-Film Solar Cells of 4% Efficiency from Stibnite Mineral** [Eira Anais Zamudio Medina](#); Universidad Nacional Autonoma de Mexico, Mexico.

**ES14.14.28**  
**Versatile Transition Metal Perovskite Chalcogenides as Strong Solar Absorbers** [Shanyuan Niu](#); University of Southern California, United States.

**ES14.14.29**  
 **$\text{Cu}_2\text{-II-Sn-VI}_4$  (II = Ba, Sr and VI = S, Se) Quaternary Compounds for Earth-Abundant Photovoltaics** [Weiwei Meng](#)<sup>1,2</sup>; <sup>1</sup>Department of Physics and Astronomy, The University of Toledo, United States; <sup>2</sup>School of Physics and Technology, Center for Electron Microscopy, MOE Key Laboratory of Artificial Micro- and Nano-Structures and Institute for Advanced Studies, Wuhan University, China.

**ES14.14.30**  
**Zinc Molybdenum Oxide—A New Solar Absorber** [Pramod Ravindra](#); Indian Institute of Science, India.

**ES14.14.31**  
**Antimony Chalcogenide Solar Cells Exceeding 2% Efficiency Prepared by Thermal Evaporation of Core-Shell Precipitates** [Angelica Lizbeth Espinosa Santana](#); Universidad Nacional Autonoma de Mexico, Mexico.

**ES14.14.32**  
**Antimony Sulfide Thin Films Deposited by Microwave Heating for Hybrid Solar Cells Application** [Claudia Martinez-Alonso](#); FQ-UAQ, Mexico.

**ES14.14.33**  
**Comparative Study of the Properties of SnS Thin-Film Absorbers Deposited by Both E-Beam Evaporation Followed by Sulfurization and RF Sputtering Processes** [Jeha Kim](#); Cheongju University, Korea (the Republic of).

**ES14.14.34**  
**Cus Thin Films Doped with Cus and Zns Nanoparticles for Semiconductor Devices Applications** [Adriana Garcia Gallardo](#); Universidad Autonoma de Ciudad Juarez, Mexico.

**ES14.14.35**  
**Fabrication of Thin Film Solar Devices Using Emergent Materials** [Hector Padron Perez](#); Universidad Autonoma de San Luis Potosi, Mexico.

**ES14.14.36**  
**Plasmon Enhanced Photovoltaic Effect in Graphene/ $\text{Mo}_{1-x}\text{W}_x\text{Se}_2$ /Pd Vertical Schottky Diodes** [Sung Hyun Kim](#); Yonsei University, Korea (the Republic of).

SESSION ES14.15: Novel Chalcogenide Absorber Materials  
Session Chairs: Gilles Dennler and Joop van Deelen  
Friday Morning, April 21, 2017  
PCC North, 200 Level, Room 229 B

**8:15 AM ES14.15.01**  
**Potential Resolution to the “Doping Puzzle” in Pyrite  $\text{FeS}_2$ : Carrier Type Determination by Hall Effect and Thermopower** [Chris Leighton](#); University of Minnesota, United States.

**8:30 AM ES14.15.02**  
**Binary and Ternary Sb-Based Chalcogenide Thin-Film Solar Cells** [Jiang Tang](#); Huazhong University of Science and Technology, China.

**8:45 AM ES14.15.03**  
**Should KCN Etching be Performed when  $\text{Cu}_2\text{Sn}_{1-x}\text{Ge}_x\text{S}_3$ -Based Thin Films are Processed into Solar Cells?** [Erika Robert](#); University of Luxembourg, Luxembourg.

**9:00 AM ES14.15.04**  
**Metastable Cubic SnS, SnSe and Their Alloys as Photovoltaic Materials** [Stephan Lany](#); National Renewable Energy Laboratory, United States.

**9:15 AM ES14.15.05**  
 **$\text{Cu}_2\text{BaSn(S,Se)}_4$ —Earth-Abundant Chalcogenides for Solar Energy Conversion Applications** [Donghyeop Shin](#); Duke University, United States.

**9:30 AM ES14.15.06**  
**Reduced Secondary Phase Formation and Doping in  $\text{Cu}_2\text{SnS}_3$  by Alloying with Ag to be Used for Solar Cell Applications** [Jessica de Wild](#); Luxembourg Univ, Luxembourg.

**9:45 AM BREAK**

SESSION ES14.16: Kesterite Absorber Growth and Devices  
Session Chairs: Raquel Caballero and James Clark  
Friday Morning, April 21, 2017  
PCC North, 200 Level, Room 229 B

**10:15 AM \*ES14.16.01**  
**11.5% CZTSSe Devices Spray Coated from a Water-Ethanol Ink—Current Limitations and Ways Forward** [Gilles Dennler](#); IMRA, France.

**10:45 AM ES14.16.02**  
 **$\text{Cu}_2\text{ZnSnS}_4$  Solar Cell with over 700 mV Open Circuit Voltage from High Sulfur Partial Pressure during the Annealing Process** [Yi Ren](#); Uppsala University, Sweden.

**11:00 AM ES14.16.03**  
**Thermal Annealing Effect on Layer Morphology and Performance of Kesterite Solar Cells** [Samira Khelifi](#); Gent University, Belgium.

**11:15 AM ES14.16.04**  
**High Voltage CZTS,Se Devices with High Efficiencies** [Richard Haight](#); IBM T.J. Watson Research Ctr, United States.

**11:30 AM ES14.16.05**  
 **$\text{Cu}_2\text{ZnSnSe}_4$  Solar Cell with 11.5% Efficiency Achieved by Sputtering from Quaternary Target** [Rujun Sun](#); Tsinghua University, China.

**11:45 AM ES14.16.06**  
 **$\text{Cu}_2\text{ZnSnS}_4$  Thin Films from a Single Precursor Solution—Effect of Na and Sb Doping on Device Performance** [David J. Fermín](#); University of Bristol, United Kingdom.