

## CONTENTS

<b>Preface</b> .....	<b>xiii</b>
<b>Materials Research Society Symposium Proceedings</b> .....	<b>xv</b>

*CIGS GROWTH*

<b>The Effect of a High Temperature Reaction of Cu-In-Ga Metallic Precursors on the Formation of Cu(In,Ga)(Se,S)<sub>2</sub></b> .....	<b>3</b>
Dominik M. Berg, Christopher P. Thompson, and William N. Shafarman	
<b>Analysis of NaF Precursor Layers During the Different Stages of the Cu(In,Ga)Se<sub>2</sub> Co-evaporation Process</b> .....	<b>9</b>
M. Edoff, P.M.P. Salomé, A. Hultqvist, and V. Fjällström	
<b>Incorporation of Sb, Bi, and Te Interlayers at the Mo/Cu-In-Ga Interface for the Reaction of Cu(In,Ga)(Se,S)<sub>2</sub></b> .....	<b>15</b>
Kihwan Kim, Jaesung Han, and William N. Shafarman	
<b>First-principles Study on Diffusion of Cd in CuInSe<sub>2</sub></b> .....	<b>21</b>
Tsuyoshi Maeda and Takahiro Wada	
<b>Characterization of Electron-induced Defects in Cu (In, Ga) Se<sub>2</sub> Thin-film Solar Cells using Electroluminescence</b> .....	<b>27</b>
Shirou Kawakita, Mitsuru Imaizumi, Shogo Ishizuka, Hajime Shibata, Shigeru Niki, Shuichi Okuda, and Hiroaki Kusawake	
<b>Impact of Maximum Copper Content During the 3-stage Process on CdS Thickness Tolerance in Cu(In,Ga)Se<sub>2</sub>-based Solar Cell</b> .....	<b>33</b>
Thomas Lepetit, Ludovic Arzel, and Nicolas Barreau	

<b>Effects of Additives on the Improved Growth Rate and Morphology of Chemical Bath Deposited Zn(S,O,OH) Buffer Layer for Cu(In,Ga)Se<sub>2</sub>- based Solar Cells</b> . . . . .	<b>39</b>
Thibaud Hildebrandt, Nicolas Loones, Nathanaelle Schneider, Muriel Bouttemy, Jackie Vigneron, Arnaud Etcheberry, Daniel Lincot, and Negar Naghavi	
<b>A Low Temperature, Single Step, Pulsed d.c Magnetron Sputtering Technique for Copper Indium Gallium Diselenide Photovoltaic Absorber Layers</b> . . . . .	<b>45</b>
Sreejith Karthikeyan, Kushagra Nagaich, Arthur E. Hill, Richard D. Pilkington, and Stephen A. Campbell	
<b>Effect of Location of Sodium Precursor on the Morphological and Device Properties of CIGS Solar Cells</b> . . . . .	<b>51</b>
Neelkanth G. Dhere, Ashwani Kaul, and Helio Moutinho	
<b>Observation of Sodium Diffusion in CIGS Solar Cells with Mo/TCO/Mo Hybrid Back Contacts.</b> . . . . .	<b>61</b>
Yukiko Kamikawa, Hironori Komaki, Shigenori Furue, Akimasa Yamada, Shogo Ishizuka, Koji Matsubara, Hajime Shibata, and Shigeru Niki	
<b>Formation of Ga<sub>2</sub>O<sub>3</sub> Barrier Layer in Cu(InGa)Se<sub>2</sub> Superstrate Devices with ZnO Buffer Layer</b> . . . . .	<b>67</b>
Jes K. Larsen, Peipei Xin, and William N. Shafarman	

*KESTERITE*

<b>Effects of Growth Conditions on Secondary Phases in CZTSe Thin Films Deposited by Co-evaporation.</b> . . . . .	<b>75</b>
Douglas M. Bishop, Brian E. McCandless, Thomas C. Mangan, Kevin Dobson, and Robert Birkmire	
<b>* Is it Possible to Grow Thin Films of Phase Pure Kesterite Semiconductor? A ZnSe Case Study</b> . . . . .	<b>83</b>
Phillip J. Dale, Monika Arasimowicz, Diego Colombara, Alexandre Crossay, Erika Robert, and Aidan A. Taylor	
<b>Polarization Dependent Raman Spectroscopy Characterization of Kesterite Cu<sub>2</sub>ZnSnS<sub>4</sub> Single Crystals.</b> . . . . .	<b>95</b>
D.O. Dumcenco, Y.P. Wang, S. Levcenco, K.K. Tiong, and Y.S. Huang	

\*Invited Paper

<b>Influence of Sodium-containing Substrates on Kesterite CZTSSe Thin Films Based Solar Cells</b> . . . . .	<b>103</b>
Giovanni Altamura, Charles Roger, Louis Grenet, Joël Bleuse, H�el�ene Fournier, Simon Perraud, and Henri Mariette	
<b>Air-stable Solution Processed <math>\text{Cu}_2\text{ZnSn}(\text{S}_x\text{Se}_{1-x})_4</math> Thin Film Solar Cells: Influence of Ink Precursors and Preparation Process</b> . . . . .	<b>107</b>
Xianzhong Lin, Jaison Kavalakkatt, Martha Ch. Lux-Steiner, and Ahmed Ennaoui	
<b>Fabrication and Characterization of Low-cost, Large-area Spray Deposited <math>\text{Cu}_2\text{ZnSnS}_4</math> Thin Films for Heterojunction Solar Cells</b> . . . . .	<b>115</b>
Sandip Das, Kelvin J. Zavalla, M.A. Mannan, and Krishna C Mandal	
<b>The Effect of Soft Pre-annealing of Differently Stacked Cu-Sn-Zn Precursors on the Quality of <math>\text{Cu}_2\text{ZnSnSe}_4</math> Absorbers</b> . . . . .	<b>123</b>
Monika Arasimowicz, Maxime Thevenin, and Phillip J. Dale	

### *THIN FILM SOLAR CELLS*

<b>* Electroluminescence of <math>\text{Cu}(\text{In,Ga})\text{Se}_2</math> Solar Cells and Modules</b> . . . . .	<b>133</b>
U. Rau, T.C.M. M�uller, T.M.H. Tran, B.E. Pieters, and A. Gerber	
<b>Impact of the Deposition Conditions of Window Layers on Lowering the Metastability Effects in <math>\text{Cu}(\text{In,Ga})\text{Se}_2/\text{CBD ZnS}</math>-based Solar Cell</b> . . . . .	<b>145</b>
N. Naghavi, T. Hildebrandt, G. Renou, S. Temgoua, J.F. Guillemoles, and D. Lincot	
<b>The Research and Development of the Third Generation of Photovoltaic Modules</b> . . . . .	<b>151</b>
Tingkai Li	

\*Invited Paper

<b>Using Dilute Nitrides to Achieve Record Solar Cell Efficiencies . . . . .</b>	<b>161</b>
Rebecca Jones-Albertus, Emily Becker, Robert Bergner, Taner Bilir, Daniel Derkacs, Onur Fidaner, David Jory, Ting Liu, Ewelina Lucow, Pranob Misra, Evan Pickett, Ferran Suarez, Arsen Sukiasyan, Ted Sun, Lan Zhang, Vijit Sabnis, Mike Wiemer, and Homan Yuen	
<b>Over 20% Efficiency Mechanically Stacked Multi-junction Solar Cells Fabricated by Advanced Bonding Using Conductive Nanoparticle Alignments . . . . .</b>	<b>167</b>
Kikuo Makita, Hidenori Mizuno, Hironori Komaki, Takeyoshi Sugaya, Ryuji Oshima, Hajime Shibata, Koji Matsubara, and Shigeru Niki	
<b>MoO<sub>3</sub> Back Contact for CuInSe<sub>2</sub>-based Thin Film Solar Cells . . . . .</b>	<b>173</b>
Hamed Simchi, Brian E. McCandless, T. Meng, Jonathan H. Boyle, and William N. Shafarman	
<b>Fabrication of Cu<sub>2</sub>ZnSn(S,Se)<sub>4</sub> Solar Cells by Printing and High-pressure Sintering Process. . . . .</b>	<b>179</b>
Feng Gao, Tsuyoshi Maeda, and Takahiro Wada	
<b>Cupric Oxide Thin Films for Photovoltaic Applications . . . . .</b>	<b>185</b>
Patrick J.M. Isherwood, Biancamaria Maniscalco, Fabiana Lisco, Piotr M. Kaminski, Jake W. Bowers, and John M. Walls	
<b>Spectral Calibrated and Confocal Photoluminescence of Cu<sub>2</sub>S Thin-film Absorber. . . . .</b>	<b>191</b>
Hendrik Sträter, Rudolf Brüggemann, Sebastian Siol, Andreas Klein, Wolfram Jaegermann, and Gottfried H. Bauer	
<b>CuO and Cu<sub>2</sub>O Nanoparticles for Thin Film Photovoltaics. . . . .</b>	<b>197</b>
Jan Flohre, Maurice Nuys, Christine Leidinger, Florian Köhler, and Reinhard Carius	
<b>Optimising The Parameters For The Synthesis of CuIn-nanoparticles By Chemical Reduction Method For Chalcopyrite Thin Film Precursors. . . . .</b>	<b>203</b>
Matthias Schuster, Stefan A. Möckel, Rachmat Adhi Wibowo, Rainer Hock, and Peter J. Wellmann	

<b>Moisture Resistant Ga-doped ZnO Films with Highly Transparent Conductivity for Use in Window Layers of Thin-film Solar Cells</b> . . . . .	<b>.209</b>
H.-P. Song, H. Makino, S. Kishimoto, and T. Yamamoto	
<b>Effective Electrochemical n-type Doping of ZnO Thin Films for Photovoltaic Window Applications</b> . . . . .	<b>.215</b>
B. Mari-Soucase, P. Cembrero-Coca, M. Mollar, and M.E. Calixto	
<b>Study of Optical Losses in Mechanically Stacked Dye-sensitized/CdTe Tandem Solar Cells</b> . . . . .	<b>.221</b>
Vincent Barrioz, Simon Hodgson, Peter Holliman, Arthur Connell, Giray Kartopu, Andrew J. Clayton, Stuart J.C. Irvine, Shafiul Monir, and Matthew L. Davies	
<b>Point Contact Admittance Spectroscopy of Thin Film Solar Cells</b> . . . . .	<b>.227</b>
Anthony Vasko, Kristopher Wieland, and Victor Karpov	
<b>Ternary Cu<sub>3</sub>BiY<sub>3</sub> (Y = S, Se, and Te) for Thin-film Solar Cells</b> . . . . .	<b>.235</b>
Mukesh Kumar and Clas Persson	

### *CdTe SOLAR CELL AND ELECTRONIC STRUCTURE*

<b>Development of CdTe on Si Heteroepilayers for Controlled PV Material and Device Studies</b> . . . . .	<b>.243</b>
T.A. Gessert, R. Dhere, D. Kuciauskas, J. Moseley, H. Moutinho, M.J. Romero, M. Al-Jassim, E. Colegrove, R. Kodama, and S. Sivananthan	
<b>CdTe Solar Cells: Processing Limits and Defect Chemistry Effects on Open Circuit Voltage</b> . . . . .	<b>.249</b>
Brian E. McCandless	
<b>Low-temperature Photoluminescence Studies of CdTe Thin Films Deposited on CdS/ZnO/Glass Substrates</b> . . . . .	<b>.261</b>
Corneliu Rotaru, Sergiu Vatavu, Christoph Merschjann, Chris Ferekides, Vladimir Fedorov, Tobias Tyborski, Mihail Caraman, Petru Gaşin, Martha Ch. Lux-Steiner, and Marin Rusu	

<b>Metal Chloride Passivation Treatments for CdTe Solar Cells . . . . .</b>	<b>.269</b>
Jennifer Drayton, Russell Geisthardt, John Raguse, and James R. Sites	

<b>Developing Monolithically Integrated CdTe Devices Deposited by AP-MOCVD . . . . .</b>	<b>.275</b>
S.L. Rugen-Hankey, V. Barrioz, A.J. Clayton, G. Kartopu, S.J.C. Irvine, C. White, G. Rutterford, and G. Foster-Turner	

### *COMPOUND SEMICONDUCTORS*

<b>Integration of GaAs on Ge/Si Towers by MOVPE. . . . .</b>	<b>.283</b>
A.G. Taboada, T. Kreiliger, C.V. Falub, M. Richter, F. Isa, E. Müller, E. Uccelli, P. Niedermann, A. Neels, G. Isella, J. Fompeyrine, A. Dommann, and H. von Känel	

<b>* Development of High k/III-V (InGaAs, InAs, InSb) Structures for Future Low Power, High Speed Device Applications. . . . .</b>	<b>.291</b>
Edward Yi Chang, Hai-Dang Trinh, Yueh-Chin Lin, Hiroshi Iwai, and Yen-Ku Lin	

<b>Growth and Characteristics of a-Plane GaN/ZnO/GaN Heterostructure . . . . .</b>	<b>.303</b>
Chiao-Yun Chang, Huei-Min Huang, Yu-Pin Lan, Tien-Chang Lu, Hao-Chung Kuo, Shing-Chung Wang, Li-Wei Tu, and Wen-Feng Hsieh	

### *DEVICES AND LEDs*

<b>Nickel Foam as a Substrate for III-nitride Nanowire Growth. . . . .</b>	<b>.311</b>
Michael A. Mastro, Neeraj Nepal, Fritz Kub, Jennifer K. Hite, Jihyun Kim, and Charles R. Eddy	

<b>Non Radiative Recombination Centers in ZnO Nanorods . . . . .</b>	<b>.317</b>
D. Montenegro, V. Hortelano, O. Martínez, M.C. Martínez-Tomas, V. Sallet, V. Muñoz, and J. Jiménez	

<b>Assessment of Homogeneity of Extruded Alumina-SiC Composite Rods Used in Microwave Heating Applications by Impedance Spectroscopy . . . . .</b>	<b>.323</b>
Justin R. Brandt and Rosario A. Gerhardt	

\*Invited Paper

**Improvement of Minority Carrier Lifetime in Thick 4H-SiC Epi-layers by Multiple Thermal Oxidations and Anneals . . . . . 329**

Lin Cheng, Michael J. O'Loughlin, Alexander V. Suvorov, Edward R. Van Brunt, Albert A. Burk, Anant K. Agarwal, and John W. Palmour

**Impact of Gate Metal on Surface States Distribution and Effective Surface Barrier Height in AlGaIn/GaN Heterostructures . . . . . 335**

Nitin Goyal and Tor A. Fjeldly

**\* Effect of Growth Pressure and Gas-phase Chemistry on the Optical Quality of InGaIn/GaN Multi-quantum Wells . . . . . 341**

E.A. Armour, D. Byrnes, R.A. Arif, S.M. Lee, E.A. Berkman, G.D. Papasouliotis, C. Li, E.B. Stokes, R. Hefti, and P. Moyer

**Hexagonal Pyramids Shaped GaN Light Emitting Diodes Array by N-polar Wet Etching . . . . . 353**

Jun Ma, Liancheng Wang, Zhiqiang Liu, Guodong Yuan, Xiaoli Ji, Ping Ma, Junxi Wang, Xiaoyan Yi, Guohong Wang, and Jinmin Li

*OPTOELECTRONICS***\* Hybrid III-V-on-silicon Microring Lasers . . . . . 363**

Di Liang, Géza Kurczveil, Marco Fiorentino, Sudharsanan Srinivasan, David A. Fattal, Zhihong Huang, John E. Bowers, and Raymond G. Beausoleil

**Improved Yellow Light Emission in the Achievement of Dichromatic White Light Emitting Diodes . . . . . 371**

Zhao Si, Tongbo Wei, Jun Ma, Ning Zhang, Zhe Liu, Xuecheng Wei, Xiaodong Wang, Hongxi Lu, Junxi Wang, Jinmin Li

**Modification of the Optical and Electrical Properties CdS Films by Annealing in Neutral and Reducing Atmospheres . . . . . 377**

J. Pantoja Enriquez, G. Pérez Hernandez, X. Mathew, G. Ibáñez Duharte, J. Moreira, J.A. Reyes Nava, J.J. Barrionuevo, L.A. Hernandez, R. Castillo, and P.J. Sebastian

\*Invited Paper

<b>Carrier Density in p-type ZnTe with Nitrogen and Copper Doping</b> .....	<b>383</b>
Maryam Abazari, Faisal R. Ahmad, Kamala C. Raghavan, James R. Cournoyer, Jae-Hyuk Her, Robert Davis, John Chera, Vince Smentkowski, and Bas A. Korevaar	

<b>Electrical Properties of Photoconductor Using Ga<sub>2</sub>O<sub>3</sub>/CuGaSe<sub>2</sub> Heterojunction</b> .....	<b>391</b>
Kenji Kikuchi, Shigeyuki Imura, Kazunori Miyakawa, Misao Kubota, and Eiji Ohta	

### *WIDE BANDGAP MATERIALS*

<b>The Wide Band p-type Material Formed by the Thin Film with ZnO-NiO Mixed Crystal System</b> .....	<b>399</b>
Mikihiko Nishitani, Masahiro Sakai, and Yukihiro Morita	

<b>A Novel Technique for Growth of Lithium-free ZnO Single Crystals.</b> .....	<b>405</b>
Shaoping Wang, Aneta Kopec, and Andrew G. Timmerman	

<b>Author Index</b> .....	<b>411</b>
---------------------------	------------

<b>Subject Index</b> .....	<b>415</b>
----------------------------	------------