

MENG TAO

Professor, School of Electrical, Computer and Energy Engineering
Chair, Physical Electronics and Photonics
Arizona State University, Tempe, AZ 85287-5706



EMPLOYMENT HISTORY

2011-Present: Professor, School of Electrical, Computer and Energy Engineering and Chair, Physical Electronics and Photonics, Arizona State University, USA

2001-2011: Full/Associate/Assistant Professor, Department of Electrical Engineering and Associate Director, Center for Renewable Energy Science and Technology, University of Texas at Arlington, USA

1999-2001: South Central Bell Assistant Professor of Electrical Engineering, Louisiana Tech University, USA

1998-1999: Research Scientist, Department of Electrical and Computer Engineering, University of South Carolina, USA

1993-1998: Research Assistant, Department of Materials Science and Engineering, Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, USA

1992-1993: Research Assistant, Department of Materials Science and Engineering, University of Utah, USA

1986-1992: Assistant Professor/Lecturer, Department of Materials Science and Engineering and Research Coordinator, State Key Laboratory for Silicon Materials, Zhejiang University, China

1983-1986: Research Assistant, Department of Materials Science and Engineering, Zhejiang University, China

1982-1983: Assistant Engineer/Engineer, Hangzhou Iron and Steel Plant, China

VISITING POSITIONS

August 2017-May 2018: Fulbright Distinguished Chair in Alternative Energy Technology, Chalmers University of Technology, Sweden

June-August 2009: Visiting Professor, Department of Electrical and Computer Engineering, Hong Kong University of Science and Technology, Hong Kong

EDUCATION

- PhD 1998, Materials Science and Engineering (Electronic Materials), University of Illinois at Urbana-Champaign, USA (Advisor: Joseph Lyding)
- MS 1986, Semiconductor Materials, Zhejiang University, China (Advisor: Duanlin Que)
- BS 1982, Ferrous Metallurgy, Jiangxi Institute of Metallurgy, China

AWARDS AND HONORS

- Invited to the Nobel Prize Award Ceremony in Stockholm, Sweden on December 10, 2017
- Fulbright Distinguished Chair in Alternative Energy Technology, “one of the most respected Fulbright awards globally”, U.S. Department of State (2017)
- Featured in cover story “Keeping Renewables out of the Trash” by M. Bomgardner and A. Scott (Chemical & Engineering News, vol. 96, no. 15, pp. 34–41, 2018)
- Finalist for the Katerva Award in Energy & Power, “the Nobel Prize for Sustainability” (2019)

- Scientific Panelist, Joint Scientific and Financial Summit, 10th International Photovoltaic Power Generation Conference & Exhibition (Shanghai, China, 2016)
- IEEE Electron Device Society Webinar on “Showstoppers and Bottlenecks to Terawatt Solar Photovoltaics”, one of the most popular webinars in Electron Device Society history (2015)
- University Outstanding Research Achievement Award, University of Texas at Arlington (2011)
- Keynote Speaker, U.S. Photovoltaic Manufacturing Consortium Strategy Workshop (Washington, DC, 2010)
- Xizhi Distinguished Lecture Series, Zhejiang University (2008)
- Outstanding Young Faculty Award, College of Engineering, UTA (2004)
- South Central Bell Professorship, Louisiana Tech (2001)

CURRENT RESEARCH

The goal of my current research is to push solar energy into a mainstream energy source by 2050. We focus on scalable and sustainable solar technologies. Here are a few examples of the research projects in my group:

- Earth-abundant materials for terawatt solar photovoltaics, including solution-based deposition and doping techniques in metal oxides for antireflection, light trapping, surface passivation and in metal oxysulfides for p-n junction
- Terawatt-ready, low-cost and energy-efficient silicon solar photovoltaics, including alternative metallization to replace the silver electrode in silicon solar cells with aluminum; energy-efficient electrorefining for solar-grade silicon directly from metallurgical-grade silicon; and technologies to improve the profitability of waste silicon solar cell and module recycling
- Technologies for sustainable solar energy storage, delivery and application, including a closed storage loop based on the zinc↔zinc oxide cycle; a new system topology for solar electrolysis based on load management; applications of the load-managing solar systems in electric vehicle charging, solar energy storage and industrial electrolysis

KEY ACCOMPLISHMENTS

- Publication of a book “Terawatt Solar Photovoltaics: Roadblocks and Opportunities” by Springer in 2014. It provides a more comprehensive picture about solar energy and identifies major roadblocks to sustainable solar technologies
- Proposition of a sustainable, closed loop of zinc↔zinc oxide to complement the hydrogen↔water loop for long-term storage and global trade of solar energy
- Formulation of a theory for impurity segregation in electrolysis. It provides the theoretical foundation for ultrapure materials by electrolysis such as energy-efficient electrorefining of metallurgical-grade silicon to solar-grade silicon
- Demonstration of technologies to maximize the revenue from waste silicon solar cells and modules, improving the profitability of silicon cell and module recycling (with W.-H. Huang)
- Invention of a new solar system topology based on load management to achieve 30% lower levelized cost of electricity. Applications of the system include electric vehicle charging, solar energy storage and industrial electrolysis (with J.A. Azzolini)
- Demonstration of a semiconductor surface free of surface states, leading to 1) demonstration of the Mott-Schottky theory, 2) a negative Schottky barrier and 3) a larger-than-bandgap Schottky barrier on the silicon (100) surface (with W.P. Kirk)
- Development of consistent, predictive and quantitative models for growth kinetics of various chemical vapor deposition (CVD) processes: thermal CVD of silicon, photo-CVD of silicon and

germanium, metalorganic CVD of III-V semiconductors, ultrahigh vacuum CVD of silicon-germanium alloys and doping in silicon CVD

- Initiation of and technical support to the U.S. Photovoltaic Manufacturing Consortium under SEMATECH, which won a \$62.5M grant from the U.S. Department of Energy and \$150M state funds from New York and Florida (with D. Holladay)

FUNDED RESEARCH

Total funding: \$9.2M; as PI: \$5.6M

Sample Projects:

- Sustainable Recycling of Silicon Solar Modules (NSF, \$309,036, July 2019 – June 2022: Single PI)
- Profitable Recycling of Silicon Solar Cells and Modules (NSF SBIR Phase II, \$732,880, Sept. 2018 – Aug. 2020; Lead PI: C. S. Tao (TG Companies), Co-PI: M. Tao)
- Aluminum Plating – An Alternative to Copper or Silver Electrode in Silicon Solar Cells (DOE, \$250,000, July 2017 – Sept. 2019; single PI)
- Upgrading a Sulfur-Dedicated UHV CVD System for 2D Monolayer Growth (Air Force Office of Scientific Research, \$61,940, Sept. 2017 – Aug. 2018; single PI)
- SusChEM Collaborative Research: Theoretical and Experimental Investigation of Iron Oxysulfide for Terawatt Photovoltaics (NSF, \$503,547, July 2013 – June 2018; Lead PI: M. Tao, Co-PI: Q. Zhang)
- Fulbright Distinguished Chair in Alternative Energy Technology at Chalmers University of Technology (Department of State, SEK1,100,000 (\$135,000), Aug. 2017 – May 2018; single PI)
- High Efficiency Schottky Barrier Silicon Solar Cells (NSF, \$388,359, Sept. 2013 – Aug. 2016; Lead PI: M. Tao, Co-PI: C. J. Tracy)
- CVD-Based Valence-Mending Passivation for Crystalline-Si Solar Cells (DOE Solar Energy Technologies Office, \$1,700,000, Jan, 2012 – Dec. 2014; Lead PI: M. Tao, Co-PI's: S. Bowden, W. Zhang and D. Holladay)
- Doping Cuprous Oxide in Electrolyte Solution: Dopant Incorporation, Atomic Structures and Electrical Properties (DOE, \$501,000, Aug. 2009 – Dec. 2013; Lead PI: M. Tao, Co-PI: Q. Zhang)
- Doping-Free p-n Junction Formation (NSF, \$270,000, Aug. 2006 – July 2011; Single PI)
- Electrodeposited TCOs for Thin-Film and Future Solar Cells (DOE, \$149,457, Aug. 2009 – July 2010; Single PI)
- Semiconductor Surfaces Free of Surface States for Nanoelectronic Applications (NSF, \$270,000, Aug. 2003 – July 2006; Single PI)
- CVD and ALD Hafnium Dioxide on Selenium and Tellurium-Passivated Silicon (100) (SEMATECH, \$310,000, Oct. 2004 – Mar. 2006; Lead PI: M. Tao, Co-PI's: W. P. Kirk, D. L. Kwong and Y. J. Chabal)
- Understanding Intra-Band Absorption in Semiconductors for Photovoltaics (Petroleum Research Fund, \$80,000, July 2002 – Aug. 2005; Single PI)
- High-k Dielectrics on Valence-Mended Silicon (100) Surface (Semiconductor Research Corporation, \$50,000, Nov. 2003 – Oct. 2004; Single PI)
- Atomic-Scale Modification of Silicon (100) Surface: Removing Dangling Bonds and Surface States (Semiconductor Research Corporation, \$40,000, Dec. 2002 – Nov. 2003; Lead PI: M. Tao, Co-PI: W. P. Kirk)
- An Omni-Directional Antireflection Coating from Solutions (NSF SBIR Phase II, \$500,000, Nov. 2009 – Oct. 2011; Lead PI: E. Cline (ZT Solar, Inc.), Co-PI's: W. Zhou and M. Tao)
- Low Resistivity Zinc Oxide by Solution Deposition as a Transparent Conducting Oxide for Solar

Cells (NSF SBIR, \$150,000, June – Nov. 2010; Lead PI: L. Q. Guo (Tao Companies LLC), Co-PI's: N. Shepherd and M. Tao)

MEMBERSHIPS

- Institute of Electrical and Electronic Engineers
- The Electrochemical Society

STUDENTS GRADUATED

PhD:

- Woo Jung Shin (ASU), PhD in Materials Science & Engineering, Spray-Deposited Oxides for Applications in Solar Cells, May 2019, employed with ASML
- Wen-Hsi Huang (ASU), PhD in Materials Science & Engineering, Recovery of Valuable Materials from Crystalline-Si Solar Modules, Feb. 2018, employed with Intel
- Laidong Wang (ASU), PhD in Electrical Engineering, Development of New Front Side Metallization Method of Aluminum Electroplating for Silicon Solar Cell, November 2017, employed with SanDisk
- Wen-Cheng Sun (ASU), PhD in Electrical Engineering, Development of Silver-Free Silicon Photovoltaic Solar Cells, May 2016, employed with KLA-Tencor
- Longcheng Wang (UTA), PhD in Materials Science & Engineering, Fabrication and Characterization of First p-n Homojunction of Cuprous Oxides by Electrochemical Deposition, Dec. 2006, employed with Zhejiang Sci-Tech University (China)
- Xiaolong Yang (UTA), PhD in Electrical Engineering, Issues in Front-End Engineering of CMOS Nanoelectronics, Feb. 2007, employed with PerkinElmer
- Guanghua Song (UTA), PhD in Materials Science & Engineering, Diffusion-Free Back Contact Solar Cells on Sulfur-Passivated Si(100) Substrates, Nov. 2007, employed with Sunprime
- Yusuf Ali (UTA), PhD in Electrical Engineering, Passivation of Si(100) Surface and Fabrication of Doping-Free MOSFET, May 2008, employed with Texas Instruments
- Kunhee Han (UTA), PhD in Electrical Engineering, Electrodeposited Cuprous Oxide Solar Cells, Dec. 2009, employed with Samsung Semiconductor (South Korea)
- Xiaofei Han (UTA), PhD in Materials Science & Engineering, Electrochemical n-Type Doping in Metal Oxides and Its Application in Photovoltaics, May 2011, employed with ASU
- Bin Zhou (ASU), PhD in Electrical Engineering, Codoped Zinc Oxide by a Novel Co-Spray Deposition Technique for Solar Cell Applications, Nov. 2013, employed with UT Dallas

MS:

- Lewis Ricci (ASU), MS in Chemical Engineering, Spray Deposition of Co_3O_4 for a $\text{Co}_3\text{O}_4/\text{Si}$ Tandem Cell, May 2017, pursuing PhD at ASU
- Arunodoy Saha (ASU), MS in Electrical Engineering, Grain Boundary Passivation of Multicrystalline Silicon Using Hydrogen Sulfide as a Sulfur Source, Dec. 2014, employed with Intel
- Qazi Aied Iqbal (ASU), MS in Materials Science & Engineering, Electrodeposition of Fe_2O_3 Films for Thin-Film Photovoltaics, May 2013
- Shraddha Agarwal (UTA), MS in Electrical Engineering, Reexamination of Schottky Barrier Heights between Metals and Selenium-Passivated n-Type Silicon (100) Surfaces, Dec. 2003, employed with Micron Technology
- Darshak Udeshi (UTA), MS in Electrical Engineering, Electrical Characterization of Interface Stability between Metals and Selenium Passivated n-Type Silicon (100), May 2004, employed with Intel
- Bhavesh Mehta (UTA), MS in Electrical Engineering, Kinetics of n- and p-Type Doping in

- Silicon Epitaxy, Aug. 2004, employed with Intel
- Janadass Shanmugam (UTA), MS in Electrical Engineering, Suppression of High Resistance Nickel Silicide Phases by Selenium Passivation on Si(100), Aug. 2005, employed with United Nations Educational, Scientific and Cultural Organization
- Kunhee Han (UTA), MS in Electrical Engineering, Electrical and Optical Characterization of Electrochemically Deposited Cupric Oxide, Dec. 2005, continued to pursue PhD at UTA
- Amit Banik (UTA), MS in Electrical Engineering, Preparation of Pyramidal Zinc Oxide Particles as an Antireflective Coating in Solar Cells, Dec. 2009, employed with IBM
- Munteha Pac (UTA), MS in Materials Science & Engineering, Electrodeposition of Nickel Sulfide for Photovoltaic Applications and Its Thermal Oxidation, Dec. 2011
- Feng Gao (Louisiana Tech), MS in Electrical Engineering, Misalignment Tolerance in a 100 nm T-Gate Recessed-Channel Si nMOSFET, Nov. 2000, employed with Silicon Storage Technology
- Changyuan Chen (Louisiana Tech), MS in Electrical Engineering, Manufacturability in a 100 nm T-Gate SOI Recessed-Channel MOSFET, Jan. 2002, employed with Silicon Storage Technology
- Mosiur Rahman (Louisiana Tech), MS in Electrical Engineering, Design of a Novel Windowless 126 nm Excimer Lamp, May 2002, employed with Atmel Corporation

CURRENT STUDENTS

PhD:

- William Parquette (ASU), pursuing PhD in Electrical Engineering, A Load-Managing Solar Photovoltaic System for Energy Storage, Aug. 2019-present
- Mao-Feng Tseng (ASU), pursuing PhD in Electrical Engineering, Electrochemical Refining of Metallurgical-Grade Silicon for Solar-Grade Silicon, Aug. 2018-present
- Lewis Ricci (ASU), pursuing PhD in Electrical Engineering, Light-Induced Aluminum Plating to Replace Screen-Printed Silver in Silicon Solar Cells, Jan. 2018-present
- Joseph Azzolini (ASU), pursuing PhD in Electrical Engineering, A Loading-Managing Controller for Solar Photovoltaic Systems, Aug. 2015-present

OTHER GROUP MEMBERS

Postdoctoral Fellows:

- Dr. Xiaofei Han (ASU), Electrorefining of Metallurgical-Grade Silicon for Solar-Grade Silicon, Aug. 2011 to Nov. 2013
- Dr. Haifeng Zhang (ASU), CVD-Based Valence-Mending Passivation for Solar Cells and High-Temperature Electronics, June 2012 to Dec. 2014, employed with Samsung
- Dr. Jingtang Zhu (UTA), Low Resistance Ohmic Contacts to Silicon (100) Surface for CMOS Source/Drain Engineering, April 2004 to Nov. 2005, employed with KLA Tencor
- Dr. Guilhem Larrieu (UTA), CVD and ALD High-k Dielectrics on Selenium and Tellurium Passivated Silicon (100) Surface, Jan. 2005 to Sept. 2005, employed with IEMN, France
- Dr. Yuehui Wang (UTA), Solution-Prepared Surface Textures for Antireflection in Solar Cells, Nov. 2007 to Feb. 2009, employed with University of Electronic Science and Technology of China
- Dr. Feng Kang (UTA), Electrochemical Deposition of Transition-Metal Sulfides for Next-Generation Solar Cells, Nov. 2009 to July 2010

Exchange Scholars:

- Araceli H. Granados (ASU, from de Energias Renovables, Universidad Nacional Autonoma de Mexico, Mexico), Doping in Spray-Deposited Fe₂O₃, Jan. to Dec. 2016
- Tomoyuki Inoue (ASU, from University of Tokyo), An All-Aluminum Si Solar Cell, June to Aug. 2013

- Prof. Ying Yang (UTA, from Xi'an University of Technology, China), Valence-Mending Passivation for Grain Boundary Defects in Polycrystalline Silicon, Sept. 2008 to Sept. 2009
- Prof. Withana P. Siripala (UTA, from University of Kelaniya, Sri Lanka), Electrochemical Methods for Energy-Efficient Production of Silicon Wafers, Feb. to Aug. 2009

PATENTS

- **M. Tao** and W. P. Kirk, Monatomic Layer Passivation of Semiconductor Surfaces, US Patent No. 6,784,114 (2004) (Licensed to SEMATECH)
- **M. Tao** and W. P. Kirk, Suppression of Chemical Reactivity on Semiconductor Surfaces, US Patent No. 7,504,155 (2009) (Licensed to SEMATECH)
- **M. Tao** and M. Y. Ali, Modification of Semiconductor Surfaces in a Liquid, US Patent No. 7,534,729 (2009)
- **M. Tao** and L. Wang, Formation of p-n Homogeneous Junctions, US Patent No. 7,768,003 (2010)
- **M. Tao** and X. Han, N-Type Doping in Metal Oxides and Chalcogenides by Electrochemical Methods, US Patent No. 8,212,246 (2012)
- **M. Tao**, System and Method for Electrorefining of Silicon, US patent No. 10,072,345 (2018)
- **M. Tao** and X. Han, System and Method for Purification of Electrolytic Salt, US Patent No. 9,783,898 (D2017)
- **M. Tao**, W.-C. Sun and X. Han, Aluminum Electroplating of Solar Cells, PCT patent application filed
- **M. Tao**, Solar Cells Formed via Aluminum Electroplating, PCT patent application filed
- **M. Tao**, Digital Load Management for Variable Output Energy Systems, US patent application filed
- **M. Tao** and Wen-Hsi Huang, Recovery of Valuable or Toxic Metals from Silicon Solar Cells, US patent application filed
- **M. Tao** and L. Wang, Light-Induced Aluminum Plating on Silicon for Solar Cell Metallization, US patent application filed

SERVICES

Conference Organization:

- Involved in organization of many conferences including leading the Electrochemical Society symposium series on Photovoltaics for the 21st Century for over a decade (2005-2018)
- Member of the Executive Team for U.S. Photovoltaic Manufacturing Consortium (2011-2014)
- Initiation of U.S. Photovoltaic Manufacturing Consortium, led by SEMATECH and supported by a \$62.5M DOE grant and \$150M state funds from New York and Florida
- Reviewer for many federal, state and foreign funding agencies including NSF, DOD, DOE, State Department, The Netherlands, Romania, Canada, Egypt, Singapore and Hong Kong
- Reviewer for 20+ top-ranked scientific journals in semiconductor materials, semiconductor processing, semiconductor surface, electronic devices, solar photovoltaic materials and photovoltaic devices
- Editor of ECS Journal of Solid State Science and Technology (2019-present) and Advances in Energy Research (2012-2016)
- Editor of several conference proceedings on solar photovoltaics and semiconductor processing

REPRESENTATIVE PUBLICATIONS

In addition to a published book, I have authored 73 publications in top-ranked scientific journals and 75 publications in referred conference proceedings. Here is a list of my representative publications in different areas of my research:

Book

- **M. Tao**, Terawatt Solar Photovoltaics: Roadblocks and Opportunities, ISBN 978-1-4471-5642-0 (Springer, 2014), translated into Chinese, ISBN 978-7-111-52014-6 (China Machine Press, 2016)

Sustainable Solar Photovoltaics

- **M. Tao**, Terawatt Solar Photovoltaics: Roadblocks and Opportunities (Springer, London, 2014)
- W.-H. Huang, W. J. Shin, L. Wang, W.-C. Sun, and **M. Tao**, Strategy and Technology to Recycle Wafer-Silicon Solar Modules, *Solar Energy*, 144, 22 (2017)
- L. Wang, W.-H. Huang, W. J. Shin, **M. Tao**, B. Deng, and D. Wang, Light-Induced Plating of Aluminum on Silicon in a Lewis Acidic Chronoaluminate Ionic Liquid, *Journal of the Electrochemical Society*, 165, D381 (2018)
- **M. Tao**, Impurity Segregation in Electrochemical Processes and Its Application to Electrorefining of Ultrapure Silicon, *Electrochimica Acta*, 89, 688 (2013)

New Solar Photovoltaic System Topologies

- J. A. Azzolini and **M. Tao**, A Control Strategy for Improved Efficiency in Direct-Coupled Photovoltaic Systems through Load Management, *Applied Energy*, 231, 926 (2018)

Semiconductor Surfaces and Interfaces

- **M. Tao**, Removal of Surface States on Si(100) by Valence-Mending Passivation, *Applied Surface Science*, 462, 8 (2018)

Chemical Vapor Deposition of Thin Films

- **M. Tao**, Growth Kinetics and Reaction Mechanism in Si-CVD from SiH₄, *Thin Solid Films*, 223, 201 (1993)
- **M. Tao**, A Kinetic Model for Photo-CVD from GeH₄ and SiH₄, *Thin Solid Films*, 307, 71 (1997)
- **M. Tao**, A Kinetic Model for Metalorganic Chemical Vapor Deposition from Ga(CH₃)₃ and AsH₃, *Journal of Applied Physics*, 87, 3554 (2000)
- B. Mehta and **M. Tao**, A Kinetic Model for Boron and Phosphorous Doping in Si Epitaxy by CVD, *Journal of the Electrochemical Society*, 152, G309 (2005)
- X. Yang and **M. Tao**, A Kinetic Model for Si_{1-x}Ge_x Growth from SiH₄ and GeH₄ by CVD, *Journal of the Electrochemical Society*, 154, H53 (2007)

Solution Fabrication of Earth-Abundant Inorganic Solar Cells

- X. Han, K. Han, and **M. Tao**, n-Type Cu₂O by Electrochemical Doping with Cl, *Electrochemical and Solid-State Letters*, 12, H89 (2009)
- X. Han, K. Han, and **M. Tao**, Low-Resistivity Yttrium-Doped ZnO by Electrochemical Deposition, *Journal of the Electrochemical Society*, 157, H593 (2010)
- K. Han and **M. Tao**, Electrochemically-Deposited p-n Homojunction Cuprous Oxide Solar Cells, *Solar Energy Materials and Solar Cells*, 93, 153 (2009)
- **M. Tao**, W. Zhou, H. Yang, and L. Chen, Surface Texturing by Solution Deposition for Omnidirectional Antireflection, *Applied Physics Letters*, 91, 81118 (2007)