**Curriculum Vitae**
Stephen A. Campbell

Educational History

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| PhD | Physics | Northwestern University | 1981 |
| MS | Physics | Northwestern University | 1978 |
| BA | Physics | College of St. Thomas | 1975 |

Employment History

1986 – 2023 University of Minnesota
- Emeritus Professor
- Director, Minnesota Nano Center (1999 – 2021)
- Penrose Professorship in Science and Engineering (2015 – 2021)
- Bordeau Chair in Electrical and Computer Engineering (2007 - 2015)
- Professor of Electrical and Computer Engineering (1998 - Present)
- Associate Professor of Electrical Engineering (1992 - 1998)
- Assistant Professor of Electrical Engineering (1986 - 1992)
- Presidential Young Investigator

Professor Campbell is very active in education, research, and service to the university. In the first, he leads the University's participation in Nano-Link, an NSF sponsored regional center for nanotechnology education at the AAS level. He has designed and implemented a one-semester capstone experience that is considered to be one of the best in the country. Professor Campbell is the author of *Fabrication Engineering at the Micro and Nanoscale*, one of the most widely used textbook on microfabrication. This text has been used in more than 60 US schools as well as many schools in Europe and Asia. After more than a dozen printings, it is now entering its fourth edition. Professor Campbell's teaching experience includes Microfabrication, Semiconductor Devices, Electromagnetic Fields, Analog Electronics, Linear Circuits, Circuits Lab, Senior Design, and Materials and Devices. In research, Professor Campbell is most well-known for pioneering efforts in high permittivity (aka high-k) materials for the gate insulator in deeply scaled MOSFETs. This revolution in transistor design has now been adopted by most of the leading-edge integrated circuit manufacturers. His other current interests include ultra-high-speed MEMS and efficient thin film photovoltaics. Professor Campbell serves as the Minnesota lead for the National Nanotechnology Coordinated Infrastructure (NNCI) network, established by NSF to support nanotechnology research. He directs the University's Nano Center (www.mnc.umn.edu) where has developed funding for many new pieces of equipment including a 2.5 M$ direct write e-beam lithography. Most recently he has been instrumental in developing support for construction of a new Physics and Nanotechnology Building.

1981-86 Sperry (Unisys), Semiconductor Operations
- Device Physicist, 1981-83
- Manager, MOS Process Development, 1983-84
- Manager, Silicon Research, 1984-86

Dr. Campbell held a variety of positions within Sperry relating to the research and development of high-speed silicon devices. He was the principal architect of Sperry's 1.25 micron CMOS technology. Dr. Campbell managed Sperry's silicon research group where he initiated and directed work in 0.5 micron CMOS, laser photochemical deposition, silicon SOI, super self aligned bipolar devices for high speed ECL, polyimide dielectrics, and novel BiMOS design approaches. He also represented Sperry on the Technical Advisory Board of the Semiconductor Research Corporation.

Consulting

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| 2019-2021 | Wilmer-Hale, Advanced CMOS Litigation |
| 2008: | 3M, Optoelectronic Devices |
| 2005-2007 | CIMA Nanotech: Nanoparticle materials |
| 2004-2005: | Precision Press: Thin film devices |
| 2003-2004: | Ennovato, Inc. A startup working on novel transistors for thin film displays |
| 1997-2000: | Offered IC fabrication short courses through UC Berkeley and independently |
| 1997 | Fusion Semiconductor Developed a design for radiative heating of 300 mm wafers. |
| 1994-96 | FSI Corporation Studied effects of wafer cleaning steps on gate oxide quality |
| 1991-93 | AG Associates, Modeling and design of rapid thermal processing equipment. |
| 1992, 94 | National Science Board, Naval Studies Board (JAST) |
| 1989-92 | Institute for Defense Analysis Participant, Defense Sciences Study Group |

Professional Activities and Affiliations

Life Fellow, IEEE

Conference Committee, Semiconductor Interface Specialists Conference (2002-2004)

Associate Editor, Journal of Semiconductor Technology and Science (2002- present)

Symposium Organizer, Gate Stacks, Materials Research Society Spring Meeting (MRS), 2000, 2001

Executive Committee and Technical Committee member, Bipolar Circuits and Technology Meeting (IEEE), 1995, 1996, 1997

Symposium Organizer, GeSi and Related Materials, Materials Research Society Spring Meeting (MRS), 1996

Member, Technical Advisory Board, Semiconductor Research Corp, 1983-86

Reviewer

- IEEE Transactions of Electron Devices
- IEEE Electron Device Letters
- Journal of Applied Physics
- Journal of the Electrochemical Society
- Journal of Vacuum Science and Technology

Awards and Honors

Russell J. Penrose Professorship in Science and Engineering (2015)

George W. Taylor Award for Distinguished Service, 2011

Sanford P. and Lenore Edgerton Bordeau Chair in Electrical and Computer Engineering (2007)

Institute of Electrical and Electronic Engineers (IEEE) Fellow 2007

Institute of Technology Distinguished Professor, 2006

George W. Taylor Award for Distinguished Teaching, 2005

IBM University Partnership Award, 1998

Outstanding EE Instructor Award, Inst of Technology Student Board, 1991

Presidential Young Investigator (National Science Foundation) 1989

Engineering Initiation Award (National Science Foundation) 1987

Sperry Outstanding Technical Achievement Award, 1986

President's Fellow, Northwestern University 1976 - 1977

Argonne National Laboratory Research Participant 1978 -1981

Graduate Students Advised - Degrees Completed

PhD

1. Abhimanyu Ravinadrath – "High Density Chronic Neural Probes PhDEE 2023.
2. Nezhueyotl Izquierdo – "Thin Film Growth of Black Phosphorus and Black Arsenic Phosphorus" (MatSci), September 2020.
3. Tim Bontrager – "Optimizing the Interactions Between the Buffer and Barrier Layers for CIGS Based Tandem Photovoltaics", PhDEE February 2019
4. Sehyun Wang – Growth and Characterization of Wide Bandgap CIAGS Solar Cell Material and Devices, PhDEE December 2018
5. Brian Benton – Electronic Transport in Semiconductor Nanocrystal Thin Films – PhDEE May 2018
6. Mandip Sibokati – Electrical Characterization and Device Modeling to Study Degradation Mechanisms in CIAGS Solar Cells– PhDEE June 2017
7. Liyuan Zhang – Earth Abundant CZTS Solar Cells – PhDEE 2016
8. Jun Young Lim – CNT Films and Processing, PhDEE 2015
9. Forrest Johnson – Broken Gap Junctions for Tandem Solar Cells – PhDEE 2015
10. Brijesh Kumar – Modeling of Embedded Quantum Dot Structures PhDEE 2013
11. Sang Ho Song – Characterization and Modeling of PV Devices – PhDEE 2013
12. Dan Yu – Si Nanoparticle Composites – PhDEE 2012
13. Maryam Jalali – An IR Scene Projector – PhDEE 2011
14. Min Woo Jang – Low Mass NEMS Switch – PhDEE 2011
15. Richard Liptak – Passivation of Si Nanoparticles – PhDEE 2009
16. Rebeccah Ligman - Si Nanoparticles in Organic LEDs– PhDEE May, 2007
17. Min Li – "Development and Characterization of Ultrathin Hafnium Titinates and High Permittivity Gate Insulators", Oct, 2005
18. Zhihong Zhang – "Hafnium Oxide gate Dielectrics for Deeply Scaled MOSFETs", Oct 2005
19. Ying Dong – Devices Made on Single Crystal Silicon Nanoparticles" – Sept. 2005
20. Zhe Shen – Nano-sized Silicon Particle Formation in Silane HDP", Sept 2004
21. Noel Hoilien – "Zirconium Based High k Materials", PhDEE, May 2004
22. Fang Chen – "Hafnium Based High k Materials", PhDEE Jan 2004
23. Taesung Kim - "Particle Measurement and Transport in $SiO_2$ CVD and Si HDPCVD", PhDME, March, 2002 (co-advised with Peter McMurry)
24. Tiezong Ma – High Permittivity Materials, PhDEE, August 2001 (co-advised with Wayne Gladfelter)
25. Boyong He – "High Permittivity FETs", March, 2000
26. Sandeep Nijawan - "Particle Measurement and Control in Silane CVD", PhDME, December, 1998 (co-advised with Peter McMurry)
27. David Gilbert - "The Deposition and Characterization of $TiO_2$ from Titanium Tetrakis Isopropoxide and from Tetrakis Nitrato Titanium", PhD Chem, May, 1998 (co-advised with Wayne Gladfelter)
28. Hyeong Saug Kim - "Electrical Characteristics and Reliability of High Permittivity FETs", PhDEE, March, 1998
29. Richard Tran - "GeSi Based Microwave ICs", July, 1995
30. Jinhua Yan - "High ε Dielectrics for MOS Transistors", March, 1995
31. John Leighton - "Rapid Thermal Vapor Phase Epitaxy - A Technique for Growing Thin Films of Silicon and Germanium-Silicon on Silicon", April, 1994
32. Karson Knutson - "Modeling of the Thermal Uniformity and Gas Phase Reactions in a Rapid Thermal Epitaxy System", August, 1993
33. Weihua Liu - "Performance of Deep Submicron GeSi Devices", June, 1993
34. Kyungho Lee - "Radiation Damage in Ultra Thin Dielectric Layers", May, 1993

MSEE

1. Maryam Jalali – A Restricted Channel Gas Sensor - January 2009
2. Gagan Aggrawal – Optical Transistor – August 2008
3. Richard Liptak – Passivation of Silicon Nanoparticles – August 2006
4. Bek Ligman – Nanoparticle LEDs June 2006
5. Dan Yu – CVD of SrHfO3 – MSEE, May, 2006
6. Niles Graf– Fine Alignment of an E-Beam Lithography System – MSEE, April, 2005
7. Paul Chen – CVD of Ternary High-k Materials MSEE May, 2005
8. Sharon Hilchie – "Si Nanoparticle Processing" MSEE, September 2004
9. Bek Ligman – "A Fine Comb Structure for Integrated Gas Sensors", MSEE, May 2004
10. Ying Dong – "Formation of Single Crystal Si Nanoparticles", MSEE, September 2003
11. Xiaorong Shi – "UHV Nitrides", MSEE, March 2003
12. Fang Chen – "Deposition of Titanium Nitride", MSEE June 2002
13. Henry Utomo – "A Control System for an ALD Reactor", MSEE June, 2001
14. Robert Rassel – "Particle Formation During Low-Pressure Chemical Vapor Deposition Of Silicon Dioxide From Silane And Oxygen: Measurement And Film Properties", MSEE June, 2001
15. Richard Rassel – "A Solenoid Type Microtransformer and Its Fabrication", MSEE June 2001
16. Mark Shriver – "UHV Nitridization", MSEE April, 2001
17. Hans Christianson "High Resistance Silicon Devices", MSEE March, 1999
18. Zhang Wu - Ultrafine Particle Control in Tungsten CVD, MSEE, May, 1998
19. Rongshan Wang - Semi-insulating Silicon, MSEE, April, 1998
20. Ray Tan – "High Resistance Silicon", MSEE, April, 1997
21. Bret Schwab - Effects of Surface Preparation on MOS Reliability, MSEE, July, 1996
22. Jay Meyer - Production and Performance of Semi-Insulating Silicon, MSEE, June, 1996
23. Hyeong Saug Kim - "Reliability of Ultrathin $SiO_2$", MSEE, May, 1994
24. Kai Ping Liu - Charge Pumping Measurements of Silicon MOSFETs, MSEE, February, 1992
25. Martin Kale - "Spreading Resistance Depth Profiling", MSEE, October 1991
26. Gregory Case - "Detection of Defects in Integrated Circuit Interconnects", MSEE, July, 1991
27. Karson Knutson - "Numerical Analysis of Rapid Thermal Processing", MSEE, April, 1991
28. Kyungho Lee - "Wafer Level Reliability Tests of IC's", MSEE, March, 1991
29. Kaseem Hamze - "Temperature Dependence of GeSi Mobility", January, 1991
30. Ling Shang - Particles in LPCVD Silicon Nitride", October, 1990
31. John Leighton - "Rapid Thermal Vapor Phase Epitaxy", November, 1989
32. Steve Guccione - "DC MOSFET Parameter Extraction", May, 1989

**Synopsis of Research Accomplishments**
**Director, Minnesota Nano Center**

Over the period 9/99 to the present, Professor Campbell has served as the Director of the MicroTechnology Lab, which changed its name in 2003 to the NanoFabrication Center. With a staff of 14 permanent employees and an annual budget of approximately 1.9 M$, the NFC has as its charter to act as a central resource at the University for all work involving the fabrication of micro and nano structures. The Lab is heavily used by many Departments at the University including EE, CEMS, ME, Physics, Chemistry, Plant Biology, Cellular Biology, and Biomedical Engineering. In addition, the Lab hosts outside users including many companies and researchers from other institutions.

During the period of Professor Campbell's appointment, the Lab upgraded its facilities considerably. One of the major accomplishments was the addition of a nanotechnology capability. Professor Campbell led the acquisition of a direct write electron beam lithography system and ultimately to a state of the art, 6 nm Vistec system. This machine has been widely adopted by academic users and has been augmented by a nano imprint tool. Lithography capabilities have also expanded with an i-line exposure tool. At the same time the Lab upgraded its sputtering capability, replacing a system built in the 1970's with two state of the art tools which are much better suited to the current faculty needs. Professor Campbell has started new Lab initiatives. As a result of this and other innovative incentive programs, usage of the Lab by University faculty has increased by a factor of five over his tenure. The lab conservatively estimates that these facilities enable approximately 10 M$ of research annually. This growth has led to the development of support for a new building, include a 10,000 square foot (5000 under filter) clean room which will be the primary facility for nano research for current and future University researchers. This building was occupied in late 2013.

Professor Campbell has successfully allied the Laboratory with Stanford, Cornell, and 11 other schools in a successful bid to become the National Nanotechnology Infrastructure Network (NNIN). This activity began in April, 2004, and has been renewed to March 2014. In 2015, Professor Campbell successfully led a team to ensure Minnesota participation in the follow-on NSF program, the National Nanotechnology Coordinated Infrastructure (NNCI) program. NNCI will provide support to critical nano facilities until at least 2020 and, if renewed, until 2025. Professor Campbell has also worked with local community colleges to spearhead a successful bid to develop a new nano education initiative at the 2-year level in a 3+1 format, becoming a regional center in nano education at the AAS level.

**Synopsis of Research Accomplishments**
**Thin Film Photovoltaics**

Our group is active in the area of thin film PV, particularly CIGS and related materials. We have built a molecular beam epitaxy system for depositing these films in an oxygen-free ambient. We are currently working on the development of tandem CIGS devices using the wide bandgap absorber material CIAGS and on improving the efficiency of the earth-abundant absorber CZTS. Supporting this work is 2D device modeling using DESIS, and a wide variety of characterization equipment including DLTS, photocapacitance spectroscopy, and a novel technique that we have developed to distinguish interface from bulk traps in these devices.

**Papers (Journal and Conference)**

1. Sreejith Karthikeyan, Sehyun Hwang, Mandip Sibakoti, Timothy Bontrager, Richard W. Liptak, Stephen A. Campbell, "Effect of rapid thermal annealing of Copper Indium Aluminium Gallium diSelenide device and its deposition challenges", Applied Surface Science **493**, pp. 105-111 (2019) https://doi.org/10.1016/j.apsusc.2019.06.279.

2. A High Stability Near-Broken Gap Junction for Multijunction Photovoltaics, Forrest Johnson, Joel Pankow, Glenn Teeter, Brian Benton, and Stephen A. Campbell, JVST A **37**(1) 011201 (2019).

3. Sreejith Karthikeyan, Liyuan Zhang, Sehyun Hwang, and Stephen A. Campbell, Experimental scheme for a stable molybdenum bilayer back contacts for photovoltaic applications" Applied Surface Science **449**, Pages 647-653 (2018).

4. Mandip Jung Sibakoti, Sreejith Karthikeyan1, Sehyun Hwang, Timothy Bontrager, Stephen Campbell, "Defects in Copper Indium Gallium Aluminum Diselenide (CIAGS) Films and their Impact on Photovoltaic Device Performance" Proceedings of the Spring 2017 Materials Research Conference.

5. "Interface Characterization and Modeling of CIAGS Devices", Mandip J. Sibakoti, Sreejith Karthikeyan, Sehyun Hwang, Timothy Bontrager and Stephen A. Campbell, Proceedings of the 42nd IEEE Photovoltaic Specialist Conference, Portland (2016).

6. "$Cu_2ZnSnS_4$ thin film growth optimization and post rapid thermal annealing of solar cells and its influence on device performance", Liyuan Zhang, Sreejith Karthikeyan, Mandip J. Sibakoti, Stephen A. Campbell, Proceedings of the 41st IEEE Photovoltaic Specialist Conference (2015).

7. "Metal Oxide Broken Gap Tunnel Junction for Copper Indium Gallium Diselenide Tandem Solar Cells", Sang Ho Song, Eray Aydil, and Stephen A. Campbell, Solar Energy Materials and Solar Cells Vol. 133C (2015) pp. 133-142 DOI 10.1016/j.solmat.2014.10.046.

8. "Sputtered Metal Oxide Broken Gap Junctions for Tandem Solar Cells", Forrest Johnson, Sang Ho Song, Joel Abrahamson, Richard Liptak, Boris Chernomordik, Eray Aydil, and Stephen A. Campbell, Solar Energy Materials and Solar Cells Vol. 132C (2015) pp. 515 522 DOI 10.1016/j.solmat.2014.09.042.

9. "Atomic Layer Deposition of Tin Oxide and Zinc Tin Oxide Using Tetraethyltin and Ozone", Ellis J Warner, Forrest Johnson , Stephen A. Campbell, and Wayne L.

Gladfelter, J. Vac. Sci. Technol. A 33, pp. 021517-1 to 021517-7 (2015). DOI: 10.1116/1.4907562.

10. "Challenges in deposition of wide band gap copper indium aluminum gallium selenide (CIAGS) thin films for tandem solar cells", Sreejith Karthikeyan, Mandip Sibakoti, Richard Liptak, Sang Ho Song, Joel Abrahamson, Eray S. Aydil and Stephen A. Campbell, 40th IEEE Photovoltaic Specialist Conference (2014).

11. "In-situ stress and thermal stability studies of molybdenum bilayer back contacts for photovoltaic applications", Sreejith Karthikeyan, Liyuan Zhang and Stephen A. Campbell, 40th IEEE Photovoltaic Specialist Conference (2014).

12. "Sputtered Metal Oxide Broken Gap Junctions", Stephen Campbell, Forrest Johnson, Sreejith Karthikeyan, Sang-Ho Song, Richard Liptak, Brian Benton, Proc of the Spring Meeting of the Electrochemical Society Orlando (2014).

13. "In-situ stress and thermal stability studies of molybdenum bilayer back contacts for photovoltaic applications", Sreejith Karthikeyan, Liyuan Zhang and Stephen A. Campbell, accepted for publication, IEEE J. Photovoltaics (2014).

14. "Heteroepitaxy and the performance of CIGS solar cells", Sang Ho Song and Stephen A. Campbell, Proceedings of the 39th IEEE Photovoltaic Specialist Conference (2013).

15. "Synthesis and Structural Characterization of Cu2ZnSnS4 Thin Films", Liyuan Zhang, Sreejith Karthikeyan,and Stephen A. Campbell, Proceedings of the 39th IEEE Photovoltaic Specialist Conference (2013).

16. "Sputtering of Metal Oxide Tunnel Junctions for Tandem Solar Cells", Forrest Johnson, Sang Ho Song, Richard Liptak, and Stephen A. Campbell, Proceedings of the 39th IEEE Photovoltaic Specialist Conference (2013).

17. "Efficient Continuous-Flow Chemical Bath Deposition of CdS Films as Buffer Layers for Chalcogenide-Based Solar Cells", B. Selin Tosun, Joel T. Abrahamson, Christopher Cheng, Stephen A. Campbell, Eray S. Aydil, Proceedings of the 39th IEEE Photovoltaic Specialist Conference (2013).

18. "A low temperature, single step, pulsed d.c magnetron sputtering technique for copper indium gallium diselenide photovoltaic absorber layers", Sreejith Karthikeyan, Kushagra Nagaich, Arthur E Hill, Richard D Pilkington, and Stephen A Campbell, Proceedings of the Spring Meeting of the MRS **1538** (2013) doi.org/10.1557/opl.2013.1008

19. "Tin dioxide as an alternative window layer for improving the Damp-Heat Stability of Copper Indium Gallium Diselenide Solar Cells", Selin Tosun, Rebekah K. Feist, Stephen A. Campbell and Eray S. Aydil, J. Vac. Sci. Techn. A **30**, 04D101 (2012).

20. "Improving the damp-heat stability of copper indium gallium diselenide solar cells with a semicrystalline tin dioxide overlayer", Tosun, B.S.; Feist, R.K.; Gunawan, A.; Mkhoyan, K.A.; Campbell, S.A.; Aydil, E.S. Solar Energy Mat and Solar Cells 101, p 270-6, (2012).

21. "Sputter deposition of semicrystalline tin dioxide films", Tosun, B. Selin; Feist, Rebekah

K.; Gunawan, Aloysius; Mkhoyan, K. Andre; Campbell, Stephen A.; Aydil, Eray S. Thin Solid Films, v 520, n 7, p 2554-2561, January 31, 2012

22. "Structure and composition of ZnxCd1-xS films synthesized through chemical bath deposition", Tosun, B. Selin; Pettit, Chelsea; Campbell, Stephen A.; Aydil, Eray S. ACS Applied Materials and Interfaces, v 4, n 7, p 3676-3684, July25, 2012

23. Ozone Assisted ALD of Doped ZnO as a Transparent Metal Oxide", Hai Yuan, Bing Luo, Wayne L. Gladfelter, Stephen A. Campbell, ECS Transactions - Seattle, Washington" Volume 45, "Dielectrics for Nanosystems 5: Materials Science, Processing, Reliability, and Manufacturing, Seattle (2012).

24. "Atomic Layer Deposition of Al-doped ZnO films Using Ozone as the Oxygen Source: A Comparison of Two Methods to Deliver Aluminum", Hai Yuan, Bing Luo, Dan Yu, An-jen Chen, Stephen A. Campbell, and Wayne L.Gladfelter, J. Vac. Sci. Technol. A 30, 01A138 (2012); doi:10.1116/1.3666030.

25. B. S. Tosun, C. Pettit, S. A. Campbell and E. S. Aydil, "Structure and Composition of $Zn_xCd_{1-x}S$ Films Synthesized through Chemical Bath Deposition," *ACS Appl. Mater. Interfaces* **4**, 3676-3684 (2012).

26. "Atomic layer deposition of p-type phosphorus-doped zinc oxide films using diethylzinc, ozone and trimethylphosphite", H. Yuan, B. Luo, S. A. Campbell and W. L. Gladfelter, Electrochem. Solid-State Lett., Volume 14, Issue 5, pp. H181-H183 (2011).

27. "Imaging and phase identification of Cu2ZnSnS4 thin films using confocal Raman spectroscopy", A.-J. Cheng, M. Manno, A. Khare, C. Leighton, S. A. Campbell, and E. S. Aydil, J. Vac. Sci. Tech. v 29, n 5, (2011).

28. "Tin dioxide as an alternative window layer for improving the Damp-Heat Stability of Copper Indium Gallium Diselenide Solar Cells", Selin Tosun, Rebekah K. Feist, Stephen A. Campbell and Eray S. Aydil, J. Vac. Sci. Techn. A **30**, 04D101 http://dx.doi.org/10.1116/1.3692225 (*5 pages*) (2012).

29. "Sputter Deposition of Amorphous and Nanocrystalline Tin Dioxide Films," B. S. Tosun, R. K. L. Feist, S. A. Campbell and E. S. Aydil, Thin Solid Films **520**, pp. 2554-2561 (2011).

30. "Simultaneous Interface And Bulk Trap Characterization in CIGS Solar Cells", S. H. Song, S. Jeong, E. Aydil, B. Todd R. Feist, R. Haley, and S. A. Campbell, Proceedings of the IEEE Photovoltaics Specialists Conference (2011).

31. "Improving the Damp-Heat Stability of Copper Indium Gallium Diselenide Solar Cells with a Semicrystalline Tin Dioxide Overlayer" Selin Tosun, Rebekah Feist, Stephen A. Campbell, and Eray Aydil, accepted for publication, Solar Energy Materials and Solar Cells (2011).

32. "Wide Band-gap CuIn1-xGaxSe2 based chalcopyrite absorbers for Tandem cell applications", Kushagra Nagaich, Eray Aydil, and Stephen Campbell, Proceedings of the IEEE Photovoltaics Specialists Conference (2011).

33. "An analysis of temperature dependent current-voltage characteristics of Cu2O-ZnO heterojunction solar cells", Seong Ho Song, Sang Ho Song, Kushagra Nagaich, Stephen A. Campbell and Eray S. Aydil, Thin Solid Films v 519, n 19, p 6613-6619, July 29 (2011).

34. "Sulfurization Studies of the Potential Thin Film Solar Absorber $Cu_2ZnSnS_4$" An-Jen Cheng, Mike Manno, Rachel Frakie, Rachel Hoffman, Chris Leighton, Eray Aydil and Stephen A. Campbell, Proceedings of the IEEE Photovoltaics Specialists Conference, Honolulu (2010).

35. "Structure Optimization for a High Efficiency CIGS Solar Cell", S. H. Song, K. Nagaich, E. Aydil, R. Feist, R. Haley, and S. A. Campbell, Proceedings of the IEEE Photovoltaics Specialists Conference, Honolulu (2010).

**Patent**

1. "Optoelectronic Devices With Thin Barrier Films With Crystalline Characteristics That Are Conformally Coated Onto Complex Surfaces To Provide Protection Against Moisture", U.S. Provisional Patent Application, Attorney Docket No. 71385, Selin Tosun, Stephen Campbell, Eray Aydil, and Rebekah Feist , Dow Chemical (2012).

**Talks**

1. **Invited Talk** – "PV Technologies and Outlook: Mostly Sunny with Scattered Clouds", Reforming Electric Energy Systems Curriculum with Emphasis on Sustainability Workshop, National Academy of Engineering and NSF, Washington DC (2015).

2. **Invited Talk** – "Solar Outlook for Minnesota", Minnesota Power Systems Conference, Minneapolis (2014).

3. **Invited Talk** – "Transparent Metal Oxides for Tunnel Junctions", Spring Meeting of the Electrochemical Society Orlando (2014).

4. **Invited Talk** – "The Future of Solar Energy", Upper Midwest Power Conference, Pine City Minnesota (2014).

5. "Heteroepitaxy and the performance of CIGS solar cells", Sang Ho Song and Stephen A. Campbell, 39th IEEE Photovoltaic Specialist Conference, Tampa (June, 2013).

6. "Synthesis and Structural Characterizations of Cu2ZnSnS4 Thin Films", Liyuan Zhang, Sreejith Karthikeyan,and Stephen A. Campbell, 39th IEEE Photovoltaic Specialist Conference, Tampa (June, 2013).

7. "Sputtering of Metal Oxide Tunnel Junctions for Tandem Solar Cells", Forrest Johnson, Sang Ho Song, Richard Liptak, and Stephen A. Campbell, 39th IEEE Photovoltaic Specialist Conference, Tampa (June, 2013).

8. "Efficient Continuous-Flow Chemical Bath Deposition of CdS Films as Buffer Layers for Chalcogenide-Based Solar Cells", B. Selin Tosun, Joel T. Abrahamson, Christopher

Cheng, Stephen A. Campbell, Eray S. Aydil, 39th IEEE Photovoltaic Specialist Conference, Tampa (June, 2013).

9. "A low temperature, single step, pulsed d.c magnetron sputtering technique for copper indium gallium diselenide photovoltaic absorber layers", Sreejith Karthikeyan, Kushagra Nagaich, Arthur E Hill, Richard D Pilkington, and Stephen A Campbell, Proceedings of the Spring Meeting of the MRS (April, 2013)

10. "Continuous-Flow Chemical Bath Deposition of ZnxCd1-xS Thin Films For Chalcopyrite Solar Cells", Selin Tosun, Joel Abrahamson, Aloysius Gunawan, K. Andre Mkhoyan, Stephen A. Campbell and Eray S. Aydil, AVS Fall Meeting 2013.

11. "Efficient Continuous-Flow Chemical Bath Deposition of CdS Films as Buffer Layers for Chalcogenide-Based Solar Cells", B. Selin Tosun, Joel T. Abrahamson, Christopher Cheng, Stephen A. Campbell, Eray S. Aydil, 39th IEEE Photovoltaic Specialist Conference (2013).

12. "Copper Indium Aluminum Gallium diSelenide as a Potential Wide band-gap Absorber for CIGS based Tandem Photovoltaic Cells", Kushagra Nagaich*, Sreejith Karthikeyan* and Stephen A. Campbell, Spring meeting of the MRS (2013)

13. "Efficient Continuous-Flow Chemical Bath Deposition of CdS Films as Buffer Layers for Chalcogenide-Based Solar Cells", B. Selin Tosun, Joel T. Abrahamson, Christopher Cheng, Stephen A. Campbell and Eray S. Aydil. Photo Voltaics Spec Conf (2013).

14. "Synthesis and Structural Characterizations of Cu2ZnSnS4 Thin Films", Liyuan Zhang, Xin Zhang, Sreejith Karthikeyan, Stephen A. Campbell, Photo Voltaics Spec Conf (2013).

15. "Sputtering of Metal Oxide Tunnel Junctions for Tandem Solar Cell Applications", Forrest Johnson, Sang Ho Song, Ricard Liptak, Boris XXX, Eray Aydil, Stephen A. Campbell, Photo Voltaics Spec Conf (2013).

16. "Deposition and Structural Characterizations of Cu2ZnSnS4 Thin Films", Liyuan Zhang, Xin Zhang, Michael Manno, Melissa Johnson, Eray Aydil, Chris Leighton, Stephen Campbell, Minneapolis AVS Sectional Meeting Fall 2012.

17. "Electrical scanning probe microscopy of thin films for CIGS-based solar cells", Joel T. Abrahamson, B. Selin Tosun, Forrest Johnson, Greg Haugstad, Stephen A. Campbell, and Eray S. Aydil, Spring ACS (2013).

18. "Copper Indium Aluminum Gallium diSelenide as a Potential Wide band-gap Absorber for CIGS based Tandem Photovoltaic Cells", Kushagra Nagaich, Sreejith Karthikeyan and Stephen A. Campbell, Spring MRS (2013).

19. "A low temperature, single step, pulsed d.c magnetron sputtering technique for copper indium gallium diselinide photovoltaic absorber layers", Sreejith Karthikeyan, Kushagra Nagaich, Arthur Hill, Richard D Pilkington, and Stephen A. Campbell, Spring MRS (2013).

20. **Invited Talk** “Ozone Assisted ALD of Doped ZnO as a Transparent Metal Oxide", ", Hai Yuan, Bing Luo, Wayne L. Gladfelter, Stephen A. Campbell, Spring ECS meeting Seattle (2012).

21. 60th International AVS Symposium, Long Beach, California, “Continuous-Flow Chemical Bath Deposition of $Zn_xCd_{1-x}S$ Thin Films for Chalcopyrite Solar Cells,” B. S. Tosun, J. T. Abrahamson, A. A. Gunawan, K. A. Mkhoyan, S. A. Campbell and E. S. Aydil (speaker), October 2013.

22. 245th American Chemical Society National Meeting, New Orleans, Lousiana, “Synthesis of Compositionally Graded $Zn_xCd_{1-x}S$ Films using Chemical Bath Deposition,” B. S. Tosun (speaker), J. T. Abrahamson, A. A. Gunawan, C. Pettit, C. Cheng, K. A. Mkhoyan, S. A. Campbell and E. S. Aydil, April 2013.

23. 245th American Chemical Society National Meeting, New Orleans, Lousiana, “Electrical Scanning Probe Microscopy of Thin Films for CIGS-based Solar Cells,” J. T. Abrahamson (speaker), B. S. Tosun, F. Johnson, G. Haugstad, S. A. Campbell and E. S. Aydil, April 2013.

24. 59th International AVS Symposium, Tampa Bay, Florida, "$Zn_xCd_{1-x}S$ Thin Films For Chalcopyrite Solar Cells Deposited Through Batch and Continuous-Flow Chemical Bath Deposition," B. S. Tosun, C. Pettit, S. A. Campbell and E. S. Aydil, October 2012.

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29. “Wide Band-gap CuIn1-xGaxSe2 based chalcopyrite absorbers for Tandem cell applications”, Kushagra Nagaich,; Eray Aydil, and Stephen Campbell, IEEE Photovoltaics Specialists Conference, SeattleAVS 58th Annual International Symposium and Exhibition (2011).

30. “Sulfurization Studies of the Potential Thin Film Solar Absorber $Cu_2ZnSnS_4$” An-Jen Cheng, Mike Manno, Rachel Frakie, Rachel Hoffman, Chris Leighton, Eray Aydil and Stephen A. Campbell, IEEE Photovoltaics Specialists Conference, Honolulu (2010).

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**32.** "Solar Cells from Abundant Nontoxic Materials: Copper Zinc Tin Sulfide Photovoltaics", Eray S. Aydil, Ankur Khare, An-Jen Cheng, Michael Manno, Melissa Johnson, David Norris, Chris Leighton and Stephen Campbell", E3 Conference (an IREE sponsored event), 2010.

**33.** "An Overview of Lab-Scale Fabrication of High Performance PVs", S. A. Campbell, Colorado Workshop on Photovoltaics, Boulder (2010).

## Semiconductor Nanoparticles

Collaborators in Mechanical Engineering developed particle beam mass spectroscopy (PBMS) as a tool to measure nanoscale particle size distributions in low pressure processing chambers in real-time. We have observed and sized particles as small as 5 nm in diameter with a sensitivity of ~1 $cm^{-3}$. More working with Professor Kortshagen, have developed techniques for making cubic, single crystal Si nanoparticles. These could have tremendous applications in building three dimensional, multi-material integrated systems on a chip and in low substrate temperature electronic applications. We have built both n- and p- channel devices and are working on optimizing the device structure. We have also developed processes for making light emitting silicon quantum dots, single crystal silicon nanoparticles that emit all colors (depending on size) and have made the first hybrid silicon OLED.

**Papers (Journal and Conference)**


1. Brian T. Benton, Benjamin L. Greenberg, K. V. Reich, B. I. Shklovskii, Uwe R. Kortshagen, S. A. Campbell, Variable Range Hopping Conduction in ZnO Nanocrystal Thin Films, Nanotechnology **29**(41) 415202 (2018).

2. UV and Air Stability of High-Efficiency Photoluminescent Silicon Nanocrystals, Jihua Yang, Richard Liptak, Stephen Campbell, Uwe Kortshagen, James Casey and Jon Hannington, Applied Surface Science Vol. 323 pp. 54-58 (2014).

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4. "Tunneling Conduction in Dense Silicon Quantum Dot/PMMA Composites, "D. Yu, R. W. Liptak, G. Aggarwal, A. –J. Cheng, and S. A. Campbell, Thin Solid Films 527, pp 261-266 (2013). http://dx.doi.org/10.1016/j.tsf.2012.11.056

5. "Environmental Photostability of SF6-Etched Silicon Nanocrystals", Richard W. Liptak, Jihua Yang, Uwe R. Kortshagen, and Stephen A. Campbell, Nanotechnology 23(39), 395205 (7 pp.) (2012).

6. "Comparing Direct Charge Injection and Forster Energy Transfer into Quantum Dots to Maximize Light Output in Hybrid Organic/Inorganic QD-LEDs" Brijesh Kumar, Ryan Hue, Wayne L. Gladfelter, Stephen A. Campbell, J. Applied Physics 112(3), August 2012 (2012).

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14. "Full Spectrum Emission and Hybrid OLEDs from Silicon Nanoparticles", X. Pi, R. Liptak, R. Ligman, U. Kortshagen, and S. A. Campbell, Proceedings of the 4th International Conference on Group Four Photonics Workshop, IEEE/LEOS, Tokyo (2007).

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17. "Electroluminescence from Surface Oxidized Silicon Nanoparticles Randomly Dispersed within a Polymer Matrix", Rebekah K Ligman, Lorenzo Mangolini, Uwe Kortshagen, Stephen A Campbell, proceedings of Nano Science and Technology International, Santa Clara (2007).

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48. "Particle Formation During Low-Pressure Chemical Vapor Deposition From Silane And Oxygen: Measurements, Modeling, and Film Properties", T. Kim, S-M. Suh, S. L. Girshick, M. R. Zachariah and P. H. McMurry, R. M. Rassel, and S. A. Campbell, Journal of Vacuum Science & Technology A-Vacuum Surfaces & Films. v 20 n 2 March/April 2002. p 413-423.

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**Presentations**

1. "Spectroscopic Characterization of Thermal Emission from Trap States in Group IV Semiconductor Nanocrystals", Brian Benton, Katharine Hunter, Uwe Kortshagen, and Stephen A. Campbell, accepted, Gordon Conference on Colloidal Semiconductor Nanoparticles (2016).

2. "UV and air stability of high-efficiency photoluminescent silicon nanocrystals", Jihua Yang, Richard Liptak, Steve Campbell, Uwe Kortshagen, James Casey and Jon Hannington, Fall Meeting of the MRS, Boston (2013).

3. "Silicon Nanocrystals Based Light Emitting Diodes Integrated Utilizing All Inorganic Metal Oxide as the Charge Transport Layers", A.-J. Cheng, R. W. Liptak, U. Kortshagen, and S. A. Campbell, SPIE OPTO: Optoelectronic Materials, Devices and Applications Symposium, SPIE Photonics West, San Francisco (2010).

4. "Light Emitting Devices using Silicon Quantum Dots in PMMA" Dan Yu, Gagan Aggarwal, Richard Liptak, Uwe Kortshagen, and Stephen A. Campbell, Organic Microelectronics & Optoelectronics Workshop V, San Francisco, (2009).

5. Light Emitting Transistors using Silicon Quantum Dots in an Organic Matrix" Gagan Aggarwal, Xiaodong Pi, Ryan P. Lu, Ayax D. Ramirez, Uwe Kortshagen, and Stephen A. Campbell, 5th International Conference on Group Four Photonics Workshop, IEEE/LEOS, Sorrento (2008).

6. Plenary Talk: Nanoparticles: A Route to Post-Shrink Information Systems", S. A. Campbell, R. Liptak, S. H. Song, R. Ligman, Yongping Ding, Ying Dong, A. Bapat, F. Gali, X. D. Pi, U. Kortshagen, UGIM, Nashville (2008).

7. "Light Emitting Transistors using Silicon Quantum Dots in an Organic Matrix", Gagan Aggarwal, Xiaodong Pi, Ryan Lu, Ayax Ramirez, Uwe Kortshagen, and Stephen A. Campbell, MRS Conference on Organic Transistors and Devices (2008).

8. "Boron- or phosphorus-doped silicon nanoparticles for solar cells", Xiaodong Pi, Stephen Campbell, Uwe Kortshagen, Spring MRS Conference (2008).

9. "Full Spectrum Emission and Hybrid OLEDs from Silicon Nanoparticles", X. Pi, R. Liptak, R. Ligman, U. Kortshagen, and S. A. Campbell, 4th International Conference on Group Four Photonics Workshop, IEEE/LEOS, Tokyo (2007).

10. Characterization of Ytterbium Silicide Thin Films", J. Deneen Nowak, S. Song,* S.A. Campbell,* and C. Barry Carter, MSA (Microscopy Society of America) and MAS (Microbeam Analysis Society) Annual Meeting, Fort Lauderdale, FL (August 5-9 in 2007).

11. "Electroluminescence from Surface Oxidized Silicon Nanoparticles Randomly Dispersed within a Polymer Matrix", Rebekah K Ligman, Lorenzo Mangolini, Uwe Kortshagen, Stephen A Campbell, NSTI Nanotechnology Conference, Santa Clara (2007).

12. "400-900 nm Light Emitting Silicon Nanoparticles Produced By An All-Gas Phase Approach", R. W. Liptak, X.D. Pi, U. Kortshagen and S. A. Campbell, NSTI Nanotechnology Conference, Santa Clara (2007).

13. "N-channel Single Crystal Si Nanoparticle Schottky Barrier Transistor", Sang Ho Song, Yongping Ding, Ameya Bapat, Uwe Kortshagen, Stephen A. Campbell, NSTI Nanotechnology Conference, Santa Clara (2007).

14. "Silicon Light Source for Optical Computing and Communications" R.P. Lu and A.D. Ramirez, S. A. Campbell, U. Kortshagen, R. Ligman, R. Liptak, and X. Pi, Spring MRS (2007).

15. "Focused Assembly of Nanoparticles Using Localized Fringing Fields", Chad R. Barry,

Stephen A. Campbell, Uwe Kortshagen, and Heiko O. Jacobs, Spring MRS (2007).

16. "Materials and Processes for Building Single Nanoparticle Transistors", Yongping Ding, Ying Dong, Ameya Bapat, Sang Ho Song, Julia Daneen, C. Barry Carter, Uwe R. Kortshagen, and Stephen A. Campbell, Electronic Materials Conference, Penn State (2006).

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18. Nanoparticle Devices, C. Barry Carter, Heiko Jacobs, Uwe R. Kortshagen, and Stephen A. Campbell, NSF Conference on Nano Manufacturing, St. Louis (2006).

19. "Nanoparticle-Based Devices", C. Barry Carter, Heiko Jacobs, Uwe R. Kortshagen, and Stephen A. Campbell, DARPA Workshop on Nanotubes and Nanowires, Napa Valley, (2006).

20. **Invited talk** - "Coulomb-Force Directed Assembly and Transfer of Nanomaterials", C. R. Barry, A. M. Welle, T. Hatch, U. Kortshagen, S. A. Campbell, and H. O. Jacobs, MRS Symposium on Flexible Electronics, Fall (2005).

21. "Single Crystal Nanoparticle Vertical Surround-Gate Field-Effect Transistor", Yongping Ding, Ameya Bapat, Ying Dong, Uwe R. Kortshagen, and Stephen A. Campbell, Fall MRS (2005).

22. **Invited Talk,** "Single Nanoparticle Semiconductor Devices", S. A. Campbell, Y. Dong, Y. P. Ding, A. Bapat, J. Deneen, U. R. Kortshagen, and C. B. Carter, Nanofabrication: Technologies, Devices, and Applications II, SPIE, Fall (2005).

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24. "Microscopy of nanoparticles for semiconductor devices", J Deneen, C R Perrey, Y Ding, A Bapat, S A Campbell, U Kortshagen and C B Carter, Microscopy of Semiconductors Conference MSMXIV Oxford (2005).

25. "Conductance Fluctuations in Free-Standing Hydrogenated Amorphous Silicon Nanoparticles", T. J. Belich, Z. Shen, C. Blackwell, S. Campbell and J. Kakalios, Third SPIE International Symposium on Fluctuations and Noise - 23-26 May, 2005, Austin, Texas.

26. "Conductance Fluctuations in Amorphous Silicon Nanoparticles", T. J. Belich, Z. Shen, C. Blackwell, S. Campbell and J. Kakalios, Spring 2005 MRS meeting.

27. "Low-pressure plasma synthesis of crystalline silicon nanoparticles for novel electronic devices," Uwe Kortshagen, Ameya Bapat, Christopher Perrey, C. Barry Carter, Ying Dong, Stephen A. Campbell, Proceedings International Workshop on Plasma Nano-Technology and its Future Vision, Takayama, Japan, Feb. 5-6, 2004.

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30. "Plasma synthesis of highly oriented single crystal silicon nanoparticles for device applications,” A. Bapat, E. Thimsen, L. Mangolini, Ying Dong, C. R. Perrey, C. B. Carter, S.A.Campbell, and U. Kortshagen, Satellite Workshop to Nano2004, Duisburg, Germany, June 25-26, 2004.

31. “Plasma synthesis of single crystal silicon nanoparticles for novel electronic device applications,” Ameya Bapat, Curtis Anderson, Christopher R. Perrey, C. Barry Carter, Stephen A. Campbell, and Uwe Kortshagen, Proceedings 31st European Physical Society Conference on Plasma Physics, 28 June - 2 July 2004 Imperial College, London, U.K.

32. “Remote Plasma Synthesis of Highly Oriented Silicon Nanoparticles and Single-Nanoparticle Electronic Devices,” Ameya Bapat, Curtis Anderson, Uwe Kortshagen, Yongping Ding, Ying Dong, Stephen A. Campbell, Bulletin of the American Physical Society, Vol. 49 (5), p. 13, 2004

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39. “Nanoparticles: A New Approach for Hyper Integration and 3D ICs”, S. A. Campbell, IGERT Seminar Series, University of Minnesota (2003).

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43. “Low –Temperature Plasma Synthesis of Single-Crystal Silicon Nanoparticles”, A. Bapat, U.Kortshagen, S.A. Campbell, C.Perrey, and C.Barry Carter, 16 th International Symposium on Plasma Chemistry, 2003.

44. “Non-Gaussian 1/f Noise as a Probe of Long-Range Structural and Electronic Disorder in Amorphous Silicon”, T. J. Belich, J. Kakalios, Z. Shen and S. A. Campbell, presented at SPIE Symposium on Fluctuations and Noise, Santa Fe, NM, June 2003.

45. **Invited Talk** - “Particles: Problems and Potential”, S. A. Campbell, Plenary Speaker, Minnesota Particle Society Annual Symposium, Bloomington, Minnesota, October 14, 2002.

46. “Experimental Investigation of Nanosized Silicon Particle Formation in an Inductively Coupled Plasma System”, Z. Shen and S. A. Campbell, T. Kim, U. Kortshagen and P. H. McMurry, Gaseous Electronics Conference, Minneapolis, October 2002.

47. “Synthesis of Crystalline Monodisperse Silicon Nanoparticles in a Inductively Coupled Silane Plasma”, Ameya Bapat, Uwe Kortshagen, and S. A. Campbell, Fall 2002 Meeting MRS.

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**Synopsis of Research Accomplishments**
**High Permittivity Insulators and Ultrathin $SiO_2$ for Deeply Scaled CMOS**

Our group has played a pioneering role in the developments of high permittivity layers for deeply scaled MOSFETs. We were the first in the rapidly growing area of research. Papers in 1996 and 97 proved seminal and sparked research efforts at many schools and companies into the use of high permittivity materials as gate insulators. Together with Professor Gladfelter, we have developed new precursors for depositing $TiO_2$, $ZrO_2$, $HfO_2$, and other materials, and have demonstrated the formation of, and electrical effects of, a thin interfacial layer. We have measured the effects of charge injection in these composite gate insulator systems, developed techniques for controlling the interfacial layer thickness, and investigated binary oxides. More recently we have also explored the use of high k materials on SiC, producing the highest quality SiC MOSCAPs ever published.

**Books**

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**Presentations**

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Misra, R. Nemanich, G. Parsons, D. Schlom, S. Stemmer, R. Wallace, and J. Whitten, Symposium on High Permittivity Gate Stacks, ECS Fall Meting, Cancun (2006) **Invited Talk**.

4. "Recent Progress in High Permittivity Materials as Gate Insulators", S. A. Campbell and Z. Zhang, **Invited Talk**, CIMTEC, Sicily 2006

5. Zhihong Zhang and Stephen A. Campbell ,"Effect of Deposition Chemistry on Charge Removal in Cr gated HfO2 Stacks", submitted to SISC Washington DC (2005).

6. "Study Of Charge And Its Effect On The Inversion Layer Mobility Of $HfO_2$ Gate Stacks", Z. Zhang and S. A. Campbell, Electrochemical Society Spring Meeting: High Dielectric Constant Gate Stacks III, Los Angeles (2005).

7. "Properties of High K And Extremely Thin Silicon Nitride Stacks", Z. Zhang, Y. Fedorenko, L. Truong, X. Shi, V. Afanas'ev, A. Stesmans, and S. A. Campbell, **Invited Talk**, Eighth International Symposium On Silicon Nitride And Silicon Dioxide Thin Insulating Films And Other Emerging Dielectrics, Electrochemical Society Spring Meeting, Quebec (2005).

9. "High Permittivity $Hf_xTi_{1-x}O_2$ Gate Dielectrics", M. Li, Z. Zhang, W. L. Gladfelter, and S. A. Campbell, SISC, San Diego (2004).

10. "Improvement of Electrical Properties of $HfO_2$ Gate Stacks and Effects of Annealing on Charge in the Stacks", Z. Zhang and S. A. Campbell, SISC, San Diego (2004).

11. "Impact of nitrogen incorporation on interface states in (100)Si/$HfO_2$", Y. G. Fedorenko, L. Truong, V. V. Afanas'ev, and A. Stesmans, Z. Zhang and S. A. Campbell, 13'th Workshop of Dielectrics in Microelectronics (2004).

12. "Mixtures of $HfO_2$ and $TiO_2$ as High-k Gate Dielectrics", F. Chen, B. Xia, C. Hella, X. Shi, W. L. Gladfelter, and S. A. Campbell, Spring meeting of the ECS 2004

13. "Effects of Contaminants in $HfO_2$", B. Xia, A. Stesmans, F. Chen, Z. Zhang, W. L. Gladfelter, and S. A. Campbell, Spring meeting of the ECS 2004

14. "Mixtures of $HfO_2$ and $TiO_2$ as High-k Gate Dielectrics", F. Chen, B. Xia, C. Hella, X. Shi, W. L. Gladfelter, and S. A. Campbell, Washington DC SISC 2003

15. "The Deposition of HfO2 from Hf t-butoxide and Nitric Oxide", Z. Zhang and S. A. Campbell, SISC 2003

16. "Search for New High-ε Dielectrics by Combinatorial Chemical Vapor Deposition", B. Xia, R. Smith, F. Chen, S. A. Campbell, and W. L. Gladfelter, Spring Meeting of the Materials Research Society (2003).

17. "A New Method for Extracting EOT for Leaky Insulators", F. Chen, N. Hoilien, and S. A. Campbell, INFOS 2003, Barcelona.

**18.** "A Study of Mixtures of $HfO_2$ and $TiO_2$ as High-k Gate Dielectrics", F. Chen, W. L. Gladfelter, and S. A. Campbell, INFOS 2003, Barcelona.

19. C.M. Osburn, S.K. Han, I. Kim, S. Campbell, E. Garfunkel, T. Gustafson, J. Hauser, T.-J. King, A. Kingon, D.-L. Kwong, S.J. Lee, C.H. Lee, J. Lee, C.S. Kang, G. Lucovsky, J.G. Hong, T.P. Ma, W. Zhu, Z. Luo, J.P. Maria, D. Wicaksana, V. Misra, J.J. Lee, Y.S. Suh, G. Parsons, D. Niu, and S. Stemmer, "Integration Issues with High k Gate Stacks", Spring ECS (2003).

20. **Invited Talk** "High Permittivity Insulators As $SiO_2$ Replacements", S. A. Campbell, W. L. Gladfelter, T. K. Higman, F. Chen, N. Hoilien, X. Shi, and R. Smith, Katholic University of Leuven, July, 2002

21. "Combinatorial Chemical Vapor Deposition: Continuous Compositional Spread Method For Screening Of Dielectric Constant Of $(TiO_2)_X(SnO_2)_Y(HfO_2)_Z$ Films", Great Lakes Chemistry Conf. 2002

22. "Chemical Vapor Deposition Of Zirconium Dioxide From Zirconium Tetra-*Tert*-Butoxide And Zirconium Nitrate: Microstructure And Growth Kinetics", Great Lakes Chemistry Conf. 2002

23. **Invited Talk** "High Permittivity Insulators As $SiO_2$ Replacements", S. A. Campbell, W. L. Gladfelter, T. K. Higman, F. Chen, N. Hoilien, X. Shi, and R. Smith, CIMTEK 2002

24. "Effect of $HfO_2$ Deposition Rate on Interfacial Layer Thickness" F. Chen, R. Smith, S. A. Campbell, W. L. Gladfelter, Rapid Thermal and Other Short-Time Processing Technologies III, ECS Spring Meeting 2002.

25. "High Mobility $HfO_2$ N- and P- Channel Transistors", S. A. Campbell, T. Z. Ma, R. Smith, W. L. Gladfelter, and F. Chen, 2001 Insulating Films of Silicon Conference, Udine, Italy (2001).

26. "Chemical Vapor Deposition Of Amorphous Films Of Titania, Zirconia Or Hafnia Alloyed With Silica", W. L. Gladfelter, R. C. Smith, C. J. Taylor, J. T. Roberts, N. Hoilien, S. A. Campbell, M. Tiner, R. Hegde, and C. Hobbs, Gate Stacks and Silicides II, MRS Spring Meeting (2001).

27. "Zirconium Oxide CVD on Si(100) from Zirconium Tetra-tert-Butoxide: Growth Kinetics and Film Microstructure", M. Shriver, D. J. Burleson, J. T. Roberts, W. L. Gladfelter, S. A. Campbell, and R. C. Smith, ECS Spring Meeting (2001).

28. "High-K Oxide Gate Stacks On Silicon Incorporating UHV Silicon Nitride Interfacial Layers", M. A. Shriver, A. M. Gabrys, T. K. Higman, and S. A. Campbell, Gate Stacks and Silicides II, MRS Spring Meeting (2001).

29. Transistors Built With $ZrO_2$ and $HfO_2$ Deposited From Nitratos, S. A. Campbell, N. Hoilien, T. Ma, F. Chen, R. Smith, and W L. Gladfelter, Gate Stacks and Silicides II, MRS Spring Meeting (2001).

30. "Anhydrous Metal Nitrates as CVD and ALD Precursors to Metal Oxide Insulators on Silicon", J. Roberts, W. Gladfelter, S. A. Campbell, R. Smith, D. Burlesen, and N. Hoilien, ECS Spring Meeting (2001).

31. **Invited Talk –** Semiconductor Interface Specialists Conference IEEE, San Diego, December, 2000.

**32. Invited Talk -** "Interface Layer Inhibition in the CVD of Column IVB Metal Oxides", S. A. Campbell, High-k Gate Dielectrics Workshop, MRS, New Orleans, June, 2000.

34. "Chemical Vapor Deposition of Amorphous MxSi1-xO2 Films where M = Ti, Zr and Hf", Ryan C. Smith, Noel Hoilien, Charles J. Taylor, Jeffrey Roberts, Stephen A. Campbell, Mike Tiner, Rama Hegde, Christopher Hobbs, and Wayne L. Gladfelter, Gate Stacks and Silicides, MRS Spring Meeting (2000).

**35. Invited Talk -** "Column IVB Metal Oxides as High Permittivity Gate Insulators", S. A. Campbell, T. Ma, N. Hoilien, B. He, R. Smith, C. Hobbs, C. Taylor, and W. L. Gladfelter, March Meeting of the American Physical Society (2000).

37. **Invited Talk –** "Performance of Group IVB Oxides as High Permittivity Gate Insulators", S. A. Campbell, B. He, R. Smith, T. Ma, N. Hoilien, C. Taylor, W. L. Gladfelter, Materials Research Society, Fall Meeting, Boston (1999).

38. "Reliability of Group IVB Oxides as High Permittivity Gate Insulators", S. A. Campbell – Sematech Topical Research Conference on Reliability of Sub 0.1 Micron Transistors, Austin, Texas (1999).

39. Anhydrous Zirconium (IV) Nitrate as a CVD Precursor for $ZrO_2$" R. Smith, N. Hoelien, C. Taylor, T. Ma, S. A. Campbell, W. L. Gladfelter, Jeffrey T. Roberts, M, Copel, D. Buchanan, M. Gribelyuk, Fall Meeting of the American Vacuum Society (1999).

40. "High Permittivity Gate Insulators $TiO_2$ and $ZrO_2$", B. He, N. Hoilien, R. Smith, T. Ma, C. Taylor, I. St. Omer, S. A. Campbell, W. L. Gladfelter, M. Gribelyuk, and D. Buchanan, UIGMS (1999).

41. "Composite $TiO_2$ Gate Insulator Stacks Formed on Thermally Nitrided Silicon", B. He, T. Ma, S. A. Campbell, D. C. Gilmer, C. Hobbs, R. Hegde, W. L. Gladfelter, and P. Tobin, 1998 IEDM.

42. "Composite $TiO_2$ Gate Insulator Stacks Formed on Thermally Nitrided Silicon", B. He, T. Ma, S. A. Campbell, W. L. Gladfelter, G. D. Wilk, and C. Hobbs, SRC 1998 Techcon.

43. **Invited Talk -** "Experience and Projections in High Permittivity Gate Insulators", S. A. Campbell, SRC Topical Research Conference, Austin (1997).

44. "Electrical Reliability of High Permitivity $TiO_2$ Gate Dielectric MOS Field Effect Transistors", H. S. Kim, S. A. Campbell, and D. C. Gilmer, IEEE Int. Rel. Phys. Symp., Denver, 1997.

45. "Charge Trapping and Degradation Properties of PZT Thin Films", H. S. Kim, D. L. Polla, and S. A. Campbell, presented at the Fall Meeting of the MRS (1996).

46. "Charge Trapping and Degradation Properties of High Permitivity $TiO_2$ Dielectric Metal-Oxide-Semiconductor Field Effect Transistors", H. S. Kim, S. A. Campbell, D. C. Gilmer, and D. L. Polla, presented at the Fall Meeting of the MRS (1996).

47. "The Performance of High Permittivity $TiO_2$ Dielectric MOSFETs", S. A. Campbell, D. C. Gilmer, X. Wang, M. T. Hsieh, H. S. Kim, W. L. Gladfelter, and J. H. Yan, IEEE Device Res. Conf. (1996).

48. "An Ozone Water Last Cleaning Process and the Effect on Gate Oxide Quality", S. Nelson, T. Fayfield, B. Schwab, and S. A. Campbell, Third Symposium on the Physics and Chemistry of $SiO_2$ and the Si--$SiO_2$ Interface, Spring Meeting of the ECS (1996).

49. "The Deposition of $TiO_2$ from TTIP and $H_2O$", S. A. Campbell, J. Yan, D. C. Gilmer, and W. L. Gladfelter, Fall Meeting of the Electrochemical Society, Chicago (1995).

50. "X-ray Lithography Processing at CXrL From Beamline to Quarter-Micron NMOS Devices", R. Nachman, G. Chen, M. Reilly, G. Wells, H. H. Lee, A. Krasnoperova, P. Anderson, E. Brodsky, E. Ganin, S. A. Campbell, and F. Cerrina, SPIE 1994.

51. "Low Temperature Nitridation of Silicon by Direct Amonnia Nitridation in a Molecular Beam Epitaxy Reactor", T. K. Higman, R. T. Fayfield, M. S. Hagedorn, K. H. Lee, S. A. Campbell, J. N. Baillargeon, and K. Y. Cheng, 1992 North American Conference on Molecular Beam Epitaxy.

**Synopsis of Research Accomplishments**
**Rapid Thermal Processing and GeSi Technology**

Rapid thermal processing, and its application to the growth of epitaxial layers, comprised a significant fraction of my research efforts from 1991-94. Our group was the first to apply computational fluid dynamics, along with conventional radiative transfer, to model the rapid thermal processing chamber. We developed code for 2 and 3 dimensional steady state calculations and 2 dimensional transient analysis of two chambers. The first was an experimental, single side heated system in which we did GeSi epitaxial growth. The other was an industry standard, Heat Pulse, manufactured by AG Associates. We demonstrated with our model the need for multizone heating and the tendency of wafer edges to overheat during thermal transients. In the area of RTCVD, we demonstrated the effect of dopant addition to the growth chemistry. Specifically we demonstrated that arsine poisoned the surface, raising the activation energy for the growth to that of conventional silicon. This provided significant support to the growth rate enhancement model of Sturm, et. al.

**Papers (Journal and Conference)**

1. "A Critical Review - The Epitaxial Growth of Semiconductors By Rapid Thermal Chemical Vapor Deposition" S. A. Campbell, Materials Science & Engineering R - Reports **20**, pp 1-36 (1997).

2. "Rapid Thermal Processing", in *Computational Modeling in Semiconductor Processing*, M. Meyyappan, Ed., Artech Publishing (1994)

3. "A Kinetics and Transport Model of Dichlorosilane Chemical Vapor Deposition", K. L. Knutson, S. A. Campbell, and R. Carr, J. Crystal Growth **140**, p. 191 (1994).

4. "The Development of an Anisotropic Si Etch Process Selective to GexSi1-x Underlayers", J. Electrochem. Soc. **141**, p. 507 (1994).

5. "Three Dimensional Temperature Uniformity Modeling of a Rapid Thermal Processing Chamber", K. Knutson, S. A. Campbell, and F. Dunn, IEEE Trans. Semicon. Man.**7**, p. 68 (1994).

6. "A Kinetics and Charge Transport Model of Dichlorosilane Chemical Vapor Deposition", K. L. Knutson, R. W. Carr, W. H. Liu, and S. A. Campbell, Proc. Am Chem Soc (1993).

7. "Arsenic Doping of GeSi Epitaxial Layers in the Dichlorosilane/Germane System", W. H. Liu, J. D. Leighton, and S. A. Campbell, Appl Phys Lett. **61** pp 1676-1678 (1992).

8. "Dopings Effects During the CVD Growth of GeSi", W. H. Liu, S. A. Campbell, and J. D. Leighton, Proceedings of the Fall 1992 American Vacuum Society Symposium on GeSi.

9. "Transient Effects in Rapid Thermal Processing", S. A. Campbell and K. L. Knutson, IEEE Trans on Semicon Man. **5**, p. 302 (1992).

10. "Thermal Effects of Gasses in Rapid Thermal Processing", K. L. Knutson and S. A. Campbell in Rapid Thermal and Integrated Processing: Materials Research Society Proceedings, Vol 224 Materials Research Society, (1991).

11. "Steady State Thermal Uniformity and Gas Flow Patterns in a Rapid Thermal Processing Chamber", S. A. Campbell, K. H. Ahn, K. L. Knutson, B. Liu, and J. D. Leighton, IEEE Trans on Semicon Man, 4, (1991).

12. "Modeling of Ge-Si Heterojunction Bipolar Transistors For Use In Silicon Monolithic Millimeterwave Integrated Circuits", S. A. Campbell and A. Gopinath, IEEE Microwave Theory and Tech 37, pp. 2046-2051 (1989).

13. "Very Thin Silicon Epitaxial Layers Grown Using Rapid Thermal Vapor Phase Epitaxy", S. A. Campbell, J. D. Leighton, G. H. Case, and K. Knutson, J Vac Sci and Tech B 7, pp. 1080-1083 (1989).

**Presentations**

1. "Three Dimensional Temperature Uniformity Modeling of a Rapid Thermal Processing Chamber", K. L. Knutson, S. A. Campbell, and F. Dunn, 1993 Spring Meeting of the Materials Research Society.

2. "A Kinetics and Transport Model of Dichlorosilane Chemical Vapor Deposition", K. L. Knutson, W. H. Liu, S. A. Campbell, and R. W. Carr, The American Institute of Chemical Engineers, Fall Meeting, 1993.

3. "Dopings Effects During the CVD Growth of GeSi", W. H. Liu, S. A. Campbell, and J. D. Leighton, Fall 1992 American Vacuum Society Symposium.

4. "Selective Removal of GeSi Layers", L. Shang, S. A. Campbell, W. H. Liu, and J. D. Leighton, Fall 1992 American Vacuum Society Symposium.

5. "Thermal Effects of Gasses in Rapid Thermal Processing", K. L. Knutson and S. A. Campbell, Spring Meeting of the Materials Research Society, (1991).

6. "Gas Flow Patterns and Thermal Uniformity in Rapid Thermal Processing Equipment", S. A. Campbell, K. L. Knutson, K. H. Ahn, J. D. Leighton, and B. Liu, 1990 International Electron Devices Meeting.

**Synopsis of Accomplishments**
**Semiconductor Processing Education and Technology**

*The Science and Technology of Microelectronic Fabrication,* was released in March, 1996 by Oxford University Press. The first edition went through seven printings before the second edition was released in 2001. The third edition is now in preparation. Approximately 50 US institutions have adopted it as a course textbook, including Stanford, Berkeley, Cornell, and UT Austin. Numerous schools in Europe, the Middle East, and the Pacific Rim have also adopted the book, and the book has been translated into Chinese. A major new initiative has been the development of new AAS capstone experience at the University. This was developed in collaboration with Dakota County Technical. Minnesota State College - Southeast Technical recently joined and will be submitting students to the program in 2009. Four other schools have joined with the University and DCTC to create an upper Midwest consortia in nano education. Finally, this section covers several small research projects including MEMS-related work and one project funded by ONR on the formation of semi-insulating silicon wafers by the addition of Au as a Fermi level pinning impurity.

**Books**

1. S. A. Campbell, *The Science and Technology of Microelectronic Fabrication*, Oxford University Press, New York (1996, 2001).
2. S. A. Campbell, *Fabrication Engineering at the Micro and Nanoscale*, Oxford University Press, New York (2006, 2013).

**Papers (Journal and Conference)**

1. Nezhueyotl Izquierdo, Jason C. Myers, Prafful Golani, Nicholas C. A. Seaton, Steven J. Koester, and Stephen A. Campbell, "Growth of Black Arsenic Phosphorus Thin Films and its Application for Field-Effect Transistors", Nanotechnology 32 325601 (2021).

2. Sushil K. Pandey (IEEE Member), Nezhueyotl Izquierdo and Stephen A. Campbell, "Growth of very large MoS2 single crystals using out-diffusion transport and their use in field effect transistors", Accepted for publication, IEEE Trans. Nano (2021).

3. Zachary DeGregorio, Jason Myers, Stephen Campbell, "Rational Control of WSe2 Layer Number via Hydrogen-Controlled Chemical Vapor Deposition" Nanotechnology, **31** 315604 (2020).

4. Nezhueyotl Izquierdo, Jason Myers, Nicholas C.A. Seaton, Sushil K. Pandey and Stephen A. Campbell, "Deposition of Surface Passivated Black Phosphorus Thin Films", *ACS Nano* 13(6) pp. 7091-7099 (2019).

5. Sushil Kumar Pandey, Hussain Alsalman, Javad Ghasemi Azadani, Nezhueyotl Izquierdo, Tony Low, and Stephen A. Campbell, Controlled p-type substitutional doping in large-area monolayer WSe2 crystals grown by chemical vapor deposition, *Nanoscale*, 2019, **11**, 365 - 365.

6. Yong-hua Zhang, Stephen A. Campbell, Sreejith Karthikeyan, Finite element analysis of hollow out-of- plane HfO2 microneedles for transdermal drug delivery applications, Biomedical Microdevices (2018) 20:19.

7. Yong-hua Zhang, Stephen A. Campbell, Sreejith Karthikeyan, Preparation of hollow out-of-plane hafnium oxide microneedle arrays for transdermal drug delivery, Microsyst Technol (2017) 23:5887–5892 DOI 10.1007.

8. Yonghua Zhang and Stephen A. Campbell, "Finite element analysis of hollow hafnium oxide microneedles for transdermal drug delivery", Proceedings of the Biomedical Engineering and Informatics Conference, Shanghai ( 2017).

9. Sushil Kumar Pandey, Nezhueyotl Izquierdo and Stephen Campbell "Use of passivation layer to improve thermal stability and quality of phosphorene/AZO heterojunction diode", RSC Advances **7**, pp. 46201 - 46207 (2017).

10. Yong-hua Zhang, Stephen A. Campbell, Liyuan Zhang, Sreejith Karthikeyan, "Sandwich structure based on back-side etching silicon (100) wafers for flexible electronic technology", Microsyst Technol **23**, pp. 739–743 (2017). DOI 10.1007/s00542-015-2737-7

11. Sushil Pande, Stephen A. Campbell, "Effect of Passivation Layer of the Thermal Stability of a Few-Layer Phosphorene/AZO Heterostructure", Spring Meeting of MRS 2017.

12. Younghua Zhang and Stephen A. Campbell, Preparation of hollow hafnium oxide microneedles for transdermal drug delivery, Proceedings of the 9th International Conference on BioMedical Engineering and Informatics (BMEI), Datong, China (2016).

13. Jie Zhu, Haechan Park, Junyang Chen, Hu Zhang, Sreejith Karthikeyan, Nathaniel Wendel, Stephen A. Campbell, Matthew Dawber, Du Xu, Mo Li, Jianping Wang, and Xiaojia Wang, "Probing the Anisotropic Thermal Conductivity of Black Phosphorous with Time-Resolved Magneto-Optical Kerr Effect", Advanced Materials 2(5) 1600040, (2016).

14. Younghua Zhang and Stephen A. Campbell, Polymer-sandwiched Ultra-thin Silicon(100) Layer for Flexible Electronics', Proceedings of the 8th International Conference on BioMedical Engineering and Informatics (BMEI), Shenyang City, China (2015).

15. "Electromechanical Switches Fabricated by Electrophoretic Deposition of Single Wall Carbon Nanotube Films" Junyoung Lim and Stephen A. Campbell, submitted to Sensors and Actuators A (2015).

16. "Properties of electrophoretically deposited single wall carbon nanotube films" Junyoung Lim, Maryam Jalali, Stephen A. Campbell, *Thin Solid Films* 589 278-285 (2015). doi/10.1016/j.tsf.2015.05.042

17. "A Low-Cost Hands-On Laboratory to Introduce Lithography Concepts", Maryam Jalali , James Marti, Allison Kirchhoff, Frances Lawrenz, and Stephen A. Campbell, IEEE Trans. Education (2012).

18. "Suspended and Highly Aligned Carbon Nanotube Thin-Film Structures Using Open Microfluidic Channel Template", Dongjin Lee, Zhijiang Ye, Stephen A. Campbell, and Tianhong Cui, Sensors and Actuators A: Physical vol 188, pp. 434 - 441 (2012).

19. "A three-terminal single-walled carbon nanotube thin film MEMS switch for digital logic applications", Jang, Min-Woo; Chen, Chia-Ling; Partlo, Walter E; Patil, Shruti R; Lee, Dongjin; Ye, Zhijiang; Lilja, David; Taton, T. Andrew; Cui, Tianhong; Campbell, Stephen A., 2011 16th International Solid-State Sensors, Actuators and Microsystems Conference, TRANSDUCERS'11, p 1705-1708, 16th International Solid-State Sensors, Actuators and Microsystems Conference (2011).

20. "An All Carbon Nanotube Thin Film Based Three Terminal Switch", Min-Woo Jang, Chia-Ling Chen, Walter E Partlo III, Shruti R Patil, Dongjin Lee, Zhijang Ye, David Lilja, T. A. Taton, T. Cui and Stephen A. Campbell, Applied Physics Letters 98, 073502 (2011), also February 28, 2011 issue of Virtual Journal of Nanoscale Science & Technology.).

21. "A Pure Single-Walled Carbon Nanotube Thin Film Based 3-Terminal MEMS Switch", Min-Woo Jang, Chia-Ling Chen, Walter E Partlo III, Shruti R Patil, Dongjin Lee, Zhijang Ye, David Lilja, S. A. Campbell, *Applied Physics Letters*, v 98, n 7, February 14, 2011

22. "Suspended Carbon Nanotube Thin Film Structures with High Degree Of Alignment For NEMS Switch Applications", Dongjin Lee, Zhijiang Ye, Stephen A. Campbell, and Tianhong Cui, Proceedings of the IEEE Transducers Conference, Bejing (2011).

23. "Thermally Enhanced Single-Walled Carbon Nanotube Microfluidic Alignment", Zhijiang Ye, Dongjin Lee, Stephen A. Campbell, and Tianhong Cui1, *Microelectronic Engineering*, v 88, n 9, p 2919-2923, September 2011

24. "Characterization of Carbon Nanotube Nanoswitches with Gigahertz Resonance Frequency and Low Pull-in Voltages Using Electrostatic Force Microscopy", Miao Lu, Xuekun Lu, Min-Woo Jang, Stephen A. Campbell, and Tianhong Cui, Journal of Micromechanics and Microengineering, v 20, n 10 (2010).

25. "Aligned Dense SWNT Beams and Cantilevers for NEMS Applications", Miao Lu, Min-Woo Jang, Stephen A. Campbell, and Tianhong Cui", Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures, v 28, n 3, p 522-526, May 2010

26. Well-Aligned and Suspended Single-Walled Carbon Nanotube Membranes: Directed Self Assembly, Patterning, and Characterization", Miao Lu, Min-Woo Jang, Greg Haugstad, Stephen A. Campbell, and Tianhong Cui1, Applied Physics Letters **94**, p. 261903 (2009).

27. "High Temperature Materials for Resistive IRSPs", Steven Solomon, Robert Ginn, Stephen A. Campbell, Maryam Jalali, and George Goldsmith, in Technologies for Synthetic Environments: Hardware-in-the-Loop Testing XI, part of the SPIE Defense and Security Symposium, Orlando (2006).

28. "Fabrication and Characterization of a Solenoid-Type Microtransformer", R. J. Rassel, F. Hiatt, J. DeCramer, and S. A. Campbell, IEEE Trans. on Magnetics **39** (1) pp. 553-558 (2003).

29. "Semi-insulating Silicon Substrates for Silicon Based RF Integrated Circuits", R. Wang, S. A. Campbell, R. Tan, J. Meyer, and Y. Cai, Proceedings of the Silicon Materials for RF

Integrated Circuits Symposium, IEEE (1998).

30. "Semi-Insulating Silicon", S. A. Campbell and J. Meyer, Proceedings of the 1995 Silicon on Insulator Workshop, IEEE (1995).

31. "Interconnect for Layered Integrated Circuit Assembly", S. Bezuk, T. Gheewala, S. A. Campbell, and R. Baseman, US Patent Number 4,845,542, July 4, 1989.

32. "Mobility Degradation Coefficients in CMOS Devices at Low Temperature", S. A. Campbell and P. Anderson, IEE Proceedings, 135, pp. 17-19 (1988).

33. "Initial Investigations of Transistor FET Logic (TFL)", J. Jorgenson, S.A. Campbell, J. Granger, and T. Gheewala in Proceedings of the 1986 Gull Lake Technical Symposium.

34. "Laser Direct Writing of Semiconductor Structures: High Aspect Ratio Structures for IC-Chip Carrier Connections", R. Baseman, S. Bezuk, S.A. Campbell, and T. Gheewala in Proceedings of the 1986 Gull Lake Technical Symposium.

35. "A New Super Self Aligned Bipolar Technology", J. Seefeldt, D. Gibson, G. Thomes, and S.A. Campbell in Proceedings of the 1985 Gull Lake Technical Symposium.

36. "Design Methodology of a 1.2 um Double-Level-Metal CMOS Technology", N. Prekshot, S.A. Campbell, W. Heikkila, D. Dokos, R. Passow, W. Grant, D. Schultz, and J. Victorey IEEE Transactions and IEEE Electron Devices, February (1984).

37. "MOS III A One Micron CMOS Technology", S.A. Campbell, D. Dokos, W. Grant, and J. Victorey in Proceedings of the 1983 Gull Lake Technical Symposium.

**Presentations**

1. Nezhueyotl Izquierdo and Stephen A. Campbell, “Single-Step, Direct Silicon-Substrate Growth of Black Phosphorus with in-situ Sn passivation”, Presented at the Fall Meeting of the MRS (2018).

2. Sushil Kumar Pandey, Nezhueyotl Izquierdo and Stephen Campbell, “Effect of Passivation Layer of the Thermal Stability of a Few-Layer Phosphorene/AZO Heterostructure”, presented at spring MRS meeting 2017 (Phoenix).

3. Sushil Kumar Pandey, Nezhueyotl Izquierdo and Stephen Campbell, “Ion bombardment free plasma thinning of black phosphorus for integration of phosphorene/ZnO based optoelectronics devices applications”, presented at fall MRS meeting 2017 (Boston).

4. Yonghua Zhang and Stephen A. Campbell, “Finite element analysis of hollow hafnium oxide microneedles for transdermal drug delivery”, Biomedical Engineering and Informatics Conference, Shanghai ( 2017)

5. Abhimanyu Ravindranath; Joshua G. Puhl; Morgan Newhoff; Kang Xiong-Hang; Christy L. Haynes; Karen A. Mesce; Stephen A. Campbell. 2016. High Signal-to-Noise Detection of Neuronal Activity Using Novel Mutli-Channel Microfabricated Electrode Arrays.

Institute for Engineering in Medicine, Retreat (poster), University of Minnesota, Minneapolis, 2016.

6. Revealing the Origins of Three-Dimensional Anisotropic Thermal Conductivities of Black Phosphorus submitted to the IMECE2016.

7. Nathaniel Wendel, Ryan J. Wu, Nazila Haratipour, Matthew C. Robbins, K. Andre Mkhoyan, Steven Koester, and Stephen A. Campbell, "Black Phosphorus Synthesis and Characterization Enabling High Performance Phosphorene Transistors", MRS Fall Meeting, 2015, accepted for oral presentation.

8. "Device for quantifying neural response and other conditions by measuring sweat gland function", Jun Young Lim, Ming-Lun Wu, William R. Kennedy, Stephen A. Campbell, Design of Medical Devices Conference (2014).

9. "A Pure Single-Walled Carbon Nanotube Thin Film Based 3-Terminal MEMS Switch", Min-Woo Jang, Chia-Ling Chen, Walter E Partlo III, Shruti R Patil, Dongjin Lee, Zhijang Ye, David Lilja, T. A. Taton, T. Cui and Stephen A. Campbell, Proceedings of the IEEE Transducers Conference, Bejing (2011).

10. "Suspended Carbon Nanotube Thin Film Structures with High Degree Of Alignment For NEMS Switch Applications", Dongjin Lee, Zhijiang Ye, Stephen A. Campbell, and Tianhong Cui, Proceedings of the IEEE Transducers Conference, Bejing (2011).

11. "Functional 1.6ghz MEMS Switch Using Aligned Composite CNT Membrane By Dielectrophoretic Self-Assembly", M.W. Jang, M. Lu, T. Cui and S. A. Campbell, IEEE Transducers Conference (Denver) 2009.

12. "A 1.6 GHz MEMS Switch Using Aligned Composite CNT Membranes", M.W. Jang, M. Lu, T. Cui and S. A. Campbell, IEEE Device Research Conference, 2009.

13. "High Temperature Materials for Resistive IRSPs", Steven Solomon, Robert Ginn, Stephen A. Campbell, Maryam Jalali, and George Goldsmith, at Technologies for Synthetic Environments: Hardware-in-the-Loop Testing XI, part of the SPIE Defense and Security Symposium Symposium, Orlando (2006).

14. "Semi-insulating Silicon Substrates for Silicon Based RF Integrated Circuits", R. Wang, S. A. Campbell, R. Tan, J. Meyer, and Y. Cai, Silicon Materials for RF Integrated Circuits Symposium, IEEE (1998).

15. "Fabrication and Microwave Performance of Semi-Insulating Silicon", S. A. Campbell and J. Meyer, Spring Meeting of the Materials Research Society (1996).

16. "Semi-Insulating Silicon", S. A. Campbell and J. Meyer, 1995 Silicon on Insulator Workshop, Phoenix (1995).

17. Invited Talk "The Possibility of Semi-insulating Silicon Wafers", S. A. Campbell, Silicon RF Technologies Workshop, 1995 Microwave Theories and Techniques Conference, Orlando (1995).

18. Invited Talk "Si-Ge Based Microwave Circuits", S. A. Campbell, A. Gopinath, and S. Taub, IEEE International Workshop on Silicon Based High Frequency Devices and Circuits", Ulm, Germany (1994).

19. "Possibility of Silicon Monolithic Millimeterwave Integrated Circuits", S. A. Campbell and A. Gopinath, 1989 Microwave Theory and Techniques Symposium, Long Beach, Cal.

20. "A 1.2 Micron Double Level Metal CMOS Technology", S.A. Campbell, D. Dokos, W. Grant, J. Victorey in Proceedings of the 1983 Custom Integrated Circuits Conference.

21. "Multiple Layer Techniques in Optical Lithography: Applications to Fine Line MOS Production", M.A. Listvan, M. Swanson, A. Wall and S.A. Campbell, Optical Microlithograhpy III: Technology for the Next Decade, p. 85, SPIE **470** (1983).

## Additional Publications

### Papers (Journal and Conference)

1. "Anisotropy of the Fermi Surface, Fermi Velocity, Many-Body Enhancement and Super Conducting Energy Gap in Nb", G. W. Crabtree, D. H. Dye, D. P. Karim, S.A. Campbell, J. B. Ketterson, Phys. Rev. B, 35, pp. 1728-1741 (1987).

2. "Critical Field Measurements in Superconductors using AC Inductive Techniques", S. A. Campbell, J. B. Ketterson, and G. W. Crabtree, Rev. Sci. Inst. 54, pp. 1191-1198 (1983).

3. "Observation of a First-Order Phase Transition in Single Crystal ErRh4B4 at Hc2", F. Behroozi, G.W. Crabtree, S.A. Campbell, and D.G. Hinks, Phys. Rev. B 27 (1983).

4. "Anisotropic Superconducting and Magnetic Properties of Single Crystal ErRh4B4", G.W. Crabtree, F. Behroozi, S.A. Campbell, and D.G. Hinks Phys. Rev. Letters 49 (1982).

5. "Magnetic Free Energy of ErRh4B4 in Paramagnetic and Superconducting States", G.W. Crabtree, F. Behroozi, S.A. Campbell, D.G. Hinks, and M. Levy, J. Low Temp. Physics, 49 (1982).

6. "Precision Magnetization and Susceptibility Measurements on ErRh4B4 in the Ferromagnetic and Superconducting Phases", F. Behroozi, G.W. Crabtree, S.A. Campbell, D.R. Snider, M. Levy, D.C. Johnston, and B.T. Matthias, in Ternary Superconductors, ed. by G.K. Shenoy, B.D. Dunlop, and F.Y. Fradin (Elsevier North Holland, Amsterdam 1981).

7. "Fermi Surface and Many Body Enhancements in Pd", D.H. Dye, S.A. Campbell, G.W. Crabtree, J.B. Ketterson, N.B. Sandersara, and J.J. Vuillemin, Phys. Rev. B 23 (1981).

### Presentations

1. "Experimental Determination of Paramagnetic and Superconducting Free Energies of ErRh4B4", F. Behroozi, G.W. Crabtree, S.A. Campbell, D.R. Snider, M. Levy, and D.C. Johnston, Bull. Am. Phys. Soc. 26 (1981).

2. "Anisotropy of the Fermi Surface and Many Body Effects in Palladium", S.A. Campbell, W.W. Crabtree, D.H. Dye, J.B. Ketterson, N.B. Sandersara, and J.J. Vuillemin, Bull. Am. Phys. Soc. 24 (1978).