Curriculum Vitae

Stephen A. Campbell

Educational History

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

Employment History

1986 - Present University of Minnesota

Director, Nano Coordinating Office (2004 – Present)
Director, NanoFabrication Center (1999 – Present)
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 Infrastructure Network (NNIN), a network established by NSF to support nanotechnology research. He directs the University's NanoFabrication Center (www.nfc.umn.edu) where has developed funding for many new pieces of equipment including a 2.5 M$ direct write e-beam, and is the founding director of the University's Center for Nanostructure Applications (www.nano.umn.edu). Most recently he has been instrumental in developing support for construction of the 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

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

Professional Activities and Affiliations

Conference Committee, Semiconductor Interface Specialists Conference (2002-2004)
Fellow, IEEE
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, American Physical Society
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

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. Min Woo Jang – Low Mass NEMS Switch – PhDEE 2011
2. Richard Liptak – Passivation of Si Nanoparticles – PhDEE 2009
3. Rebeccah Ligman - Si Nanoparticles in Organic LEDs– PhDEE May, 2007
4. Min Li – "Development and Characterization of Ultrathin Hafnium Titinates and High Permittivity Gate Insulators", Oct, 2005
5. Zhihong Zhang – "Hafnium Oxide gate Dielectrics for Deeply Scaled MOSFETs", Oct 2005
6. Ying Dong – Devices Made on Single Crystal Silicon Nanoparticles" – Sept. 2005
7. Zhe Shen – Nano-sized Silicon Particle Formation in Silane HDP", Sept 2004
8. Noel Hoilien – "Zirconium Based High k Materials", PhDEE, May 2004
9. Fang Chen – "Hafnium Based High k Materials", PhDEE Jan 2004
10. Taesung Kim - "Particle Measurement and Transport in SiO_2 CVD and Si HDPCVD", PhDME, March, 2002 (co-advised with Peter McMurry)
11. Tiezong Ma – High Permittivity Materials, PhDEE, August 2001 (co-advised with Wayne Gladfelter)
12. Boyong He – "High Permittivity FETs", March, 2000
13. Sandeep Nijawan - "Particle Measurement and Control in Silane CVD", PhDME, December, 1998 (co-advised with Peter McMurry)
14. 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)
15. Hyeong Saug Kim - "Electrical Characteristics and Reliability of High Permittivity FETs", PhDEE, March, 1998
16. Richard Tran - "GeSi Based Microwave ICs", July, 1995
17. Jinhua Yan - "High ε Dielectrics for MOS Transistors", March, 1995
18. John Leighton - "Rapid Thermal Vapor Phase Epitaxy - A Technique for Growing Thin Films of Silicon and Germanium-Silicon on Silicon", April, 1994
19. Karson Knutson - "Modeling of the Thermal Uniformity and Gas Phase Reactions in a Rapid Thermal Epitaxy System", August, 1993
20. Weihua Liu - "Performance of Deep Submicron GeSi Devices", June, 1993
21. Kyungho Lee - "Radiation Damage in Ultra Thin Dielectric Layers", May, 1993

MSEE

1. Maryam Jalali – A Restrcited 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

<u>Current Graduate Students Advised - Degrees Anticipated</u>

Maryam Jalali –A High Temperatue IR Scene Projector – PhDEE 2011
Sang Ho Song – Characterization and Modeling of PV Devices – PhDEE 2011
Brijesh Kumar – Modeling of Embedded Quantum Dot Structures PhDEE 2012
Forrest Johnson – Tandem CIGS PV – PhDEE 2014
Liyuan Zhang – Photovoltaic Materials – PhDEE 2015
Jun Young Sung – NEMS switches – PhDEE 2015
Brian Benton – Graphene NEMS

Synopsis of Research Accomplishments
Director, Nanofabrication 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 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 nearly doubled over his tenure. This has led to the development of support for a new building, include a 9000 square foot (5000 under filter) clean room which will be the primary facility for nano research for current and future University researchers.

Professor Campbell has successfully allied the Laboratory with Stanford, Cornell, and 9 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. 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 the nation's only regional center in nano education at the AAS level.

Current Research Projects and Grants

Current Sponsored Grants

Sponsor	Role	Area	Dates	2011-12 Total	2011-12 SAC	Project Total	SAC Total
NSF/ Cornell	Minn Lead	NNIN	3/04-2/14	$775,000		7,725 ,000	
NSF	Co-PI	Education	9/08 - 9/12	$750,000	$170,000	$3,000,000	$680,000
MRSEC	Participant	Nanoparticles	5/08–5/12	$250,000	$10,000	$250,000	$10,000
NSF	PI	MRI	3/10-2/12	$13950000	$13950000	$13950000	$13950000
NSF	Co-PI	Photovoltaics	9/9-8/12	$120,000	$40,000	$360,000	$120,000
DOE	PI	Photovoltaics	9/11-8/15	$375,000	$175,000	$1,500,000	$700,000
IREE (internal)	PI	Photovoltaics	9/11 – 8/14	$224,000	$100,000	$672,000	$300,000
IREE (internal)	Co-PI	Photovoltaics	9/11 – 8/14	$233,000	$90,000	$695,000	$270,000

Grant Proposals Pending

Sponsor	PI/ coPI	Area	Dates	Total	SAC Total
NSF	Co-PI	Nano ERC	10/12 - 9/17	$15,000,000	$500,000
NSF	PI	NEMS	7/12-6/15	$390,000	$390,000
NSF	Co-PI	Photovoltaics Science & Tech Center	10/13-9/18	$20,000,000	TBD

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 film 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. "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, accepted for publication, J. Vac. Sci. Technol. A 30, 01A138 (2012); doi:10.1116/1.3666030.

2. "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).

3. "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, in press, J. Vac. Sci. Tech. (2011).

4. "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, submitted to Appl. Phys. Lett. (2011).

5. "Sputter Deposition of Amorphous and Nanocrystalline Tin Dioxide Films," B. S. Tosun, R. K. L. Feist, S. A. Campbell and E. S. Aydil, in press, Thin Solid Films (2011).

6. "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).

7. "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, submitted to Solar Energy Materials and Solar Cells (2011).

8. "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).

9. "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).

10. "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).

11. "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).

Talks

1. "Imaging and phase identificationPhase Identification of Cu2ZnSnS4 thin filmsThin Films using confocalConfocal Raman spectroscopySpectroscopy", A.-J. Cheng,; M. Manno, A.; Ankur Khare, C.; Chris Leighton, S. A. Campbell, and E. S. Aydil, submitted to Fall AVS Meeting, Minneapolis (2011).

2. "Sputter Deposition of Amorphous and Nanocrystalline Tin Dioxide Films" Selin Tosun, Rebekah Feist, Steve Campbell and Eray S. Aydil, American Institute of Chemical Engineering Conference, Minneapolis (2011).

3. "p-Type phosphorus-doped zinc oxide films deposited by atomic layer deposition: Microstructural effects", Wayne L. Gladfelter, Hai Yuan, Bing Luo, and; Stephen A. Campbell, ALD Conference, Cambridge MA (2011).

4. "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, IEEE Photovoltaics Specialists Conference, Seattle (2011).

5. "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).

6. "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).

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

8. “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.

9. “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 recently, we have developed processes that produce extremely uniform silicon nanoparticles, and 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. "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, submitted to IEEE Trans Electron Devices (2011).

2. "Photostability of Fluorine-Etched Silicon Nanocrystals", R. W. Liptak, J. Yang, U. Kortshagen, and S. A. Campbell, submitted to Applied Physics Letters (2011).

3. "Electron energy band alignment at the NiO/SiO2 interface", V. V. Afanas'ev, M. Badylevich, M. Houssa and A. Stesmans, G. Aggrawal, and S. A. Campbell, Appl. Phys. Lett. L09-11903 (2010).

4. "Surface Chemistry Dependence of Native Oxidation Formation on Silicon Nanocrystal", R. W. Liptak, U. Kortshagen, and S. A. Campbell, JAP **106**, p. 064313 (2009).

5. Sang Ho Song and S. A. Campbell, "The Effect of Composition on Surface Morphology and Electrical Characteristics of Cosputtered Ytterbium Silicide", accepted for publication, Thin Solid Films v. 517(24), 30 October 2009, Pages 6841-6846 (2009).

6. "SF_6 Dry Etching of Silicon Nanocrystals", R. W. Liptak, J. H. Thomas III, U. Kortshagen, and S. A. Campbell, Nanotechnology v 20, n 3, p 035603, Jan 21 (2009).

7. "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, Proceedings of the UGIM (2008).

8. "Air-stable full-visible-spectrum emission from silicon nanocrystals synthesized by an all-gas-phase plasma approach", X. D. Pi, R. W. Liptak, J Deneen Nowak, N. P. Wells, C B Carter, S A Campbell and U Kortshagen, Nanotechnology **19** 245603 (2008).

9. "Doping Efficiency, Dopant Location, and Oxidation of Si nanocrystals", X. D.

Pi, R. Gresback , R. W. Liptak , S. A. Campbell , and U. Kortshagen, APL 92, 123102 (2008).

10. "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).

11. "Nonthermal plasma Synthesis of Faceted Germanium Nanocrystals", Patrizio Cernetti, Ryan Gresback,, Stephen A. Campbell, and Uwe Kortshagen, Chemical Vapor Deposition **13**, Issue 6-7, July, 2007, Pages: 345-350 (2007).

12. "TEM Study of Ytterbium Silicide Thin Films", J Deneen Nowak, S H Song1, S A Campbell1 and C B Carter, Proceedings of the Microscopy of Semiconducting Materials Conference (2007).

13. "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).

14. "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, proceedings of Nano Science and Technology International, Santa Clara (2007).

15. "N-channel Single Crystal Si Nanoparticle Schottky Barrier Transistor", Sang Ho Song, Yongping Ding, Ameya Bapat, Uwe Kortshagen, Stephen A. Campbell, proceedings of Nano Science and Technology International, Santa Clara (2007).

16. X. D. Pi, R. W. Liptak, S. A. Campbell and U. Kortshagen, "In-Flight dry etching of Si nanocrystals synthesized by nonthermal plasma", Appl. Phys. Lett. **91**, 083112 (2007).

17. Rebekah K. Ligman, Stephen A. Campbell, Lorenzo Mangolini and Uwe Kortshagen "Electroluminescence from Surface Oxidized Silicon Nanoparticles Dispersed Within a Polymer Matrix", Applied Physics Letters **90**, 061116 (2007), also appears in February 19, 2007 issue of Virtual Journal of Nanoscale Science & Technology (APS).

18. Patrizio Cernetti, Ryan Gresback, Stephen A. Campbell and Uwe Kortshagen, "Nonthermal plasma synthesis of highly oriented Germanium nanocrystals", Cherm Vap Dep. **13**, pp. 345–350 (2007).

19. Ameya Bapat, Marco Gatti, Yong-Ping Ding, Stephen Campbell and Uwe Kortshagen, "A plasma process for the synthesis of cubic-shaped silicon nanocrystals for nanoelectronic devices", J. Applied Phys. D **40** No 8 (21 April 2007) 2247-2257 (2007).

20. X. D. Pi, L. Mangolini, J. Schidmit, and U. Kortshagen, and S. A. Campbell, "Room-

temperature atmospheric oxidation of Si nanocrystals after etching in HF acid vapor" Physical Review B **75**, March 15 p. 085423-1 to 085423-5 (2007).

21. Yongping Ding and S. A. Campbell, "Quantum Size Effect in the Nanostructure PtSi/Si Contacts", Applied Physics Letters **89**, 093508 (2006).

22. Yongping Ding, Ying Dong, Ameya Bapat, Julia Deneen, C. Barry Carter, Uwe R. Kortshagen, and Stephen A. Campbell, "A Single Nanoparticle Silicon Transistor", IEEE Trans. Elect. Dev. **53**(10), pp. 2525-2531 (2006).

23. Barry, Chad R. (University of Minnesota); Campbell, Steven; Jacobs, Heiko O. "Nanoxerography: Electrostatic force directed printing of nanomaterials" Digital Fabrication 2005 - Final Program and Proceedings, Digital Fabrication 2005 - Final Program and Proceedings, 2005, p 25

24. S. A. Campbell, Y. Dong, Y. Ding, A. Bapat, J. Deneen, Uwe R. Kortshagen, and C. Barry Carter, "Single Nanoparticle Semiconductor Devices", Nanofabrication: Technologies, Devices, and Applications II, W. Y. Lai, L. E. Ocola, and S. Pau, Eds., SPIE Boston (2005).

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

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

27. T. J. Belich, Z. Shen, C. Blackwell, S. Campbell and J. Kakalios, "Conductance Fluctuations in Amorphous Silicon Nanoparticles", Proceedings of Symposium A-Amorphous and Nanocrystalline Science and Technology Spring 2005 MRS meeting

28. S. A. Campbell, U. Kortshagen, A. Bapat, Y. Dong, S. Hilchie, Z. Shen, **Invited Paper**, "The Production and Electrical Characterization of Free Standing Cubic Single Crystal Silicon Nano Particles", JOM 56(10), pp. 26-28 (2004).

29. Y. P. Ding, Y. Dong, S. A. Campbell, H. O. Jacobs, A. Bapat, U. Kortshagen, C. Perrey, and C. B. Carter, "Field-Effect Transistor Built with a Single Crystal Si Nanoparticle", Proceedings of the Design, Service, and Manufacturing Research Conference, Scottsdale, Arizona (2005)

30. A. Bapat, C. Anderson, C. R Perrey, C B. Carter, S. A Campbell, and U. Kortshagen, "Plasma Synthesis of Single-Crystal Silicon Nanoparticles For Novel Electronic Device Applications", Plasma Phys. Control. Fusion **46,** pp. 1–13 (2004).

31. Silicon nanoparticle synthesis using constricted mode capacitive silane plasma, Bapat, A.; Ying Dong; Perrey, C.R.; Carter, C.B.; Campbell, S.A.; Kortshagen, U. Source:

Nanoparticles and Nanowire Building Blocks-Synthesis, Processing, Characterization and Theory, p 405-10, (2004).

32. Z. Shen, U. Kortshagen, P. L. McMurry, and S. A. Campbell, "Electrical Characterization of Amorphous Silicon Nanoparticles", J. Appl. Phys. **96**(4) pp. 2204-2209 (2004).

33. Y. Dong, A. Bapat, S. Hilchie, U. Kortshagen, and S. A. Campbell, "The Generation of Free-Standing Single Crystal Silicon Nanoparticles", JVST B **22**(4), pp. 1923-1930 (2004).

34. Y. Dong, A. Bapat, Z. Shen, C. R. Perrey, C. B. Carter, U. Kortshagen, and S. A. Campbell, Single Crystal Nanoparticles for 3D Integrated Systems, Proceedings of the Future of Ultra Large Scale Integration of Silicon Workshop, Leuven Belgium (2004).

35. Y. Dong and S. A. Campbell, "Nano-sized Silicon Plasma Particle Generation", Proceedings of Conference on Advanced Manufacturing, Dallas (2004).

36. A. Bapat, U. Kortshagen, S. Campbell, C. Perrey, and C. Barry Carter, "Low – Temperature Plasma Synthesis of Single-Crystal Silicon Nanoparticles", Proceedings of the 16'th International Symposium on Plasma Chemistry, Taormina, Italy (2003).

37. T. J. Belich, Z. Shen, S. A. Campbell, J. Kakalios, "Non-Gaussian 1/f noise as a probe of long-range structural and electronic disorder in amorphous silicon," in Proceedings of SPIE Vol. 5112 *Noise as a Tool for Studying Materials*, edited by Michael B. Weismann, Nathan E. Israeloff, A. Shulim Kogan, (SPIE, Bellingham, WA, 2003) 67-77.

38. Ameya Bapat, Christopher R. Perrey, Stephen A. Campbell, C. Barry Carter, and Uwe Kortshagen, "Synthesis of highly oriented, single-crystal silicon nanoparticles in a low-pressure inductively coupled plasma" J. Appl. Phys. **94**(3), 1969-1974 (2003).

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Presentations

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4. 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).

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18. **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).

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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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Garfunkel, T. Gustafsson, A.I. Kingon, J. Lee, D.J. Lichtenwalner, G. Lucovsky, T.P. Ma, J.P. Maria, V. Misra, R.J. Nemanich, G.N. Parsons, D.G. Schlom, S. Stemmer, R.M. Wallace, and J. Whitten, ECS Transactions, 3(3), 389 (2006). Invited

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12. "Charge in HfO_2 Gate Stacks", Zhihong Zhang, Min Li, Stephen A. Campbell, Trans. Electron. Dev. **52**(8) p. 1839-1844 (Aug, 2005).

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2. "Synthesis and Structures of Bis(2-dimethylaminoethyl)amine Adducts of Strontium Bis(2,2,6,6-tetramethylheptane-3,5-dionate) and Their Use in the Chemical Vapor Deposition of Cubic Strontium-doped Hafnium Dioxides", D. Yu, S. A. Campbell, W. L. Gladfelter, Division of Inorganic Chemistry for the 233rd ACS National Meeting, Chicago (2007).

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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).

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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.

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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)

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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).

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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).

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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).

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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).

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1. "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).

2. "Suspended and Highly Aligned Carbon Nanotube Thin-Film Structures Using Open Microfluidic Channel Template", Dongjin Lee, Zhijiang Ye, Stephen A. Campbell, and Tianhong Cui, Accepted for publication, Sensors and Actuators A: Physical (2011).

3. "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.).

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9. 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).

10. “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).

11. “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).

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14. "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.

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2. "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).

3. "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.

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5. "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).

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

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

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

10. 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).

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

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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).

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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).

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