

# Arthur P. Baddorf

Senior R&D Staff  
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## Education

Wheaton College, Wheaton, IL	Math and Physics	B.A., <i>Summa Cum Laude</i> , 1980
University of Pennsylvania, PA	Physics	Ph.D., 1987

## Professional Experience

2010–p	Group Leader, Imaging Functionality, Center for Nanophase Materials Sciences, Oak Ridge National Laboratory
2005–p	Senior Research Staff Member, Center for Nanophase Materials Sciences, Oak Ridge National Laboratory
1990–2007	Research Staff Member, Low Dimensional Materials By Design, Materials Science and Technology Division, Oak Ridge National Laboratory
1987–1989	Research Associate, Surface Physics Group, Solid State Division, Oak Ridge National Laboratory

## Professional and Synergistic Activities

2010–p	Group Leader, Imaging Functionality, Center For Nanophase Materials Sciences
2010–p	Program Advisory Board, Joint Institute for Advanced Materials
2008–2010	Team Leader, Scanning Probe Imaging, Center For Nanophase Materials Sciences
2008–2010	ORNL SEED Program Review Committee
1995–2004	Executive Board, Complex Materials Consortium Collaborative Access Team, Advanced Photon Source, Argonne, Ill.
1991–92, 2002–03	President, Tennessee Valley Chapter of the American Vacuum Society
2000	Lecturer, Louisiana State University Summer School
1988–p	Member: Materials Research Society, AVS, and American Physical Society
2005–p	Active in scientific outreach to K-12 students

## Honors and Awards

2009	ORNL Significant Event Award for organization of 5 <sup>th</sup> Annual Advanced PFM Workshop
2008	Cosslett Award for best invited paper at Microscopy & MicroAnalysis Conference
2006	ORNL Director's Award Outstanding Team Accomplishment in Science and Technology
2006	ORNL Award for Science and Technology

## Publications (Over 85 articles in refereed journals and books)

Full publication list follows CV.

## Research Synopsis

1. *Domain Engineering: Ferroelectrics*  
Extensions of Piezoresponse Force Microscopy are used to examine switching, domain growth, and domain control in thin film ferroelectrics.
2. *Conductivity at Ferroelectric Domain Walls*

We seek to identify and control the origins of enhanced conductivity observed at certain domain walls in ferroelectric materials such as bismuth ferrite and lead zirconate titanate using local conducting atomic force microscopy in a controlled environment.

3. *Transport in non-metallic oxides*

The transport of electrons in thin oxide films is mapped at nanometer length scales as a function of temperature, applied voltage, and internal polarization in ultra high vacuum as a tool to understand oxide behavior through injection, hopping, and vacancy motion.

4. *Ionic conductivity*

Electrochemical Strain Microscopy has been developed to map ionic motion near surfaces for both Li and oxygen vacancies. Materials useful for energy storage (batteries and fuel cells) are targeted.

5. *Atomic structure of oxide surfaces and interfaces*

Understanding and control of the wide range of properties discovered in oxide thin films and interfaces depend critically on the exact atomic structure, which we explore using scanning tunneling and non-contact force microscopies.

6. *Energy flow at the nanoscale*

We seek a fundamental understanding of energy flow and dissipation at nanometer scales using band excitation techniques in atomic force microscopy (tip surface dissipation) and inelastic tunneling spectroscopy in scanning tunneling microscopy (electronic excitation).

## Patents

*Asymmetric Ferroelectric Tunneling Element (AFTE) and Applications for Non-Volatile Random Access Memory,*

S. V. Kalinin, H. M. Christen, A. P. Baddorf, and V. Meunier, 2010.

*Ultra-high Density Ferroelectronic Storage and Lithography by Second Order Ferroelectroelastic Switching,*

S. V. Kalinin, A. Gruverman, Junsoo Shin, H. N. Lee, H. M. Christen, A. P. Baddorf, E. Karapetian, and M. Kachanov, 2006.

*Fourier Transform for Acoustic Microscopy,* S. Jesse, A. P. Baddorf, and S. V. Kalinin, patent disclosure.

## Graduate and Postdoc Advisors

### Past Ph.D. Students

J. Shin (2003-2007), Physics, The University of Tennessee-Knoxville with E. W. Plummer

### Current Postdoctoral Scholars

Qing Li, Yunseok Kim, Thomas Arruda, Kendal Clark, Shengyong Qin, Amit Kumar

### Recent Postdoctoral Scholars

Senli Guo (2009-2011), Bruker Research

Maxim Nikiforov (2008-2010), Hummingbird Scientific; Argonne National Laboratory

Katyayani Seal (2006-2009), University of Tennessee

Brian Rodriguez (2005-2007), Humboldt, Germany; University College Dublin

Stephen Jesse (2005-2007), Oak Ridge National Laboratory

Jing Zhou (2004-2006), University of Wyoming

## PUBLICATIONS

**Arthur Baddorf**

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1. S. V. Kalinin, S. Jesse, A. Tselev, A. P. Baddorf, N. Balke, "The Role of Electrochemical Phenomena in Scanning Probe Microscopy of Ferroelectric Thin Films," *ACS Nano*, **5**, 5683 (2011). [July11]
2. Peter Maksymovych, Anna N. Morozovska, Pu Yu, Eugene A. Eliseev, Ying-Hao Chu, Ramamoorthy Ramesh, Arthur P. Baddorf, Sergei V. Kalinin, "Tunable Metallic Conductance in Ferroelectric Nanodomains," submitted to *Nature Physics* Sept. 2011.
3. Vilas Shelke, Dipanjan Mazumdar, Gopalan Srinivasan, Amit Kumar, Stephen Jesse, Sergei Kalinin, Arthur Baddorf, and Arunava Gupta, "Reduced Coercive Field in BiFeO<sub>3</sub> Thin Films through Domain Engineering," *Adv. Mater.* **23**, 669 (2011). [Feb11]
4. Martyn A. McLachlan, David W. McComb, Mary P. Ryan, Anna N. Morozovska, Eugene A. Eliseev, E. Andrew Payzant, Arthur P. Baddorf, Stephen Jesse, Katyayani Seal and Sergei V. Kalinin, "Probing local and global ferroelectric phase stability and polarization switching in ordered macroporous PZT," *Adv. Funct. Mater.* **21**, 941 (2011). [Feb11]
5. P. Maksymovych, M. Pan, P. Yu, R. Ramesh, A. P. Baddorf, S. V. Kalinin, "Scaling and Disorder Analysis of Local I-V Curves from Ferroelectric Thin Films of Lead-Zirconate Titanate," *Nanotechnology* **22**, 254031 (2011). [May11]
6. P. Maksymovych, M. Huijben, M. Pan, S. Jesse, N. Balke, Y. H. Chu, H. J. Chung, A. Y. Borisevich, A. P. Baddorf, G. Rijnders, D. H. A. Blank, R. Ramesh, S. V. Kalinin, "The Ultrathin Limit and Dead-layer Effects in Local Polarization Switching of BiFeO<sub>3</sub>," submitted to *Physical Review B* in review (September 2010).
7. P. Maksymovych, J. Seidel, Y. H. Chu, P. Wu, A. P. Baddorf, L.-Q. Chen, S. V. Kalinin, R. Ramesh, "Dynamic Conductivity at Ferroelectric Domain Walls," *Nano Letters*, **11**, 1906 (2011). [April 2011]
8. A.-P. Li, S. Qin, T.-H. Kim, W. Ouyang, Y. Zhang, H. H. Weitering, C.-K. Shih, A. P. Baddorf, R. Wu, "Metallic Conductance Stabilized by Interwire Coupling in Self-Assembled Quantum Wires," *Science*, submitted.
9. J. Seidel, P. Maksymovych, Y. Batra, A. Katan, S. Y. Yang, Q. He, A. P. Baddorf, S. V. Kalinin, C. H. Yang, J.-C. Yang, Y.-H. Chu, E. K. H. Salje, H. Wormeester, M. Salmeron, R. Ramesh, "Domain Wall Conductivity in La-doped BiFeO<sub>3</sub>," *Phys. Rev. Lett.*, **105**, 197603 (2010). [Nov10]
10. Junsoo Shin, Albina Y. Borisevich, Vincent Meunier, Jing Zhou, E. Ward Plummer, Sergei V. Kalinin and Arthur P. Baddorf, "Oxygen-Induced Surface Reconstruction of SrRuO<sub>3</sub> and Its Effect on the BaTiO<sub>3</sub> Interface." *ACS Nano* **4**, 4190 (2010). [Jul10]

11. Dipanjan Mazumdar, Vilas Shelke, Milko Iliev, Stephen Jesse, Amit Kumar, Sergei Kalinin, Arthur Baddorf, and Arunava Gupta, "Nanoscale Switching Characteristics of Nearly Tetragonal BiFeO<sub>3</sub> Thin Films," *Nano Letters*, **10**, 2555 (2010). [Jul10]
12. Sergei V. Kalinin, Brian J. Rodriguez, Albina Y. Borisevich, Arthur P. Baddorf, Nina Balke, Hye Jung Chang, Long-Qing Chen, Samrat Choudhury, Stephen Jesse, Peter Maksymovych, Maxim P. Nikiforov, Stephen J. Pennycook, "Defect-mediated polarization switching in ferroelectrics and related materials: From mesoscopic mechanisms to atomistic control," *Advanced Materials*, **22**, 314 (2010). [Jan10]
13. J. Waddell, R. Ou, C. J. Capozzi, S. Gupta, C. A. Parker, R. A. Gerhardt, K. Seal, S. V. Kalinin, and A. P. Baddorf, "Detection of percolating paths in polyhedral segregated network composites using electrostatic force microscopy and conductive atomic force microscopy," *Appl. Phys. Lett.* **95**, 233122 (2009). [Dec09]
14. J. Shin, V. B. Nascimento, G. Geneste, J. Rundgren, E. W. Plummer, B. Dkhil, S. V. Kalinin, and A. P. Baddorf, "Atomistic Screening Mechanism of Ferroelectric Surfaces: An In Situ Study of the Polar Phase in Ultrathin BaTiO<sub>3</sub> Films Exposed to H<sub>2</sub>O," *Nano Letters*, **9**, 3720 (2009). [Dec09]
15. N. Balke, S. Choudhury, S. Jesse, M. Huijben, Y.H. Chu, A.P. Baddorf, L.Q. Chen, R. Ramesh, and S.V. Kalinin, "Deterministic control of ferroelastic switching in multiferroic materials," *Nature Nanotechnology* **4**, 868 (2009).
16. J. Shin, S. V. Kalinin, E. W. Plummer, A. P. Baddorf, "Electronic Transport Through In Situ Grown Ultra-Thin BaTiO<sub>3</sub> Films," *Appl. Phys. Lett.* **95**, 32903 (2009). [Jul09]
17. P. Maksymovych, N. Balke, S. Jesse, M. Huijben, R. Ramesh, A. P. Baddorf, S. V. Kalinin, "Defect-induced asymmetry of local hysteresis loops on BiFeO<sub>3</sub> surfaces," *J. Materials Science* **44**, 5095 (2009). [Oct09]
18. P. Maksymovych, S. Jesse, P. Yu, R. Ramesh, A. P. Baddorf, and S. V. Kalinin, "Polarization Control of Electron Tunneling into Ferroelectric Surfaces," *Science* **324**, 1421 (2009). [Jun09]
19. C.-H. Yang, J. Seidel, S. Y. Kim, P. Rossen, P. Yu, M. Gajek, Y. H. Chu, L. W. Martin, M. B. Holcomb, Q. He, P. Maksymovych, N. Balke, S. V. Kalinin, A. P. Baddorf, S. R. Basu, M. L. Scullin, and R. Ramesh, "Electric Modulation of Conduction in Multiferroic Ca-doped BiFeO<sub>3</sub> Films," *Nature Materials* **8**, 485 (2009). [Jun09]
20. B. J. Rodriguez, S. Choudhury, Y. H. Chu, A. Bhattacharyya, S. Jesse, K. Seal, A. P. Baddorf, R. Ramesh, L.-Q. Chen, and S. V. Kalinin, "Unraveling Deterministic Mesoscopic Polarization Switching Mechanisms: Spatially Resolved Studies of a Tilt Grain Boundary in Bismuth Ferrite," *Advanced Functional Materials* **19**, 1 (2009). [Jul09]
21. P. Maksymovych, S. Jesse, M. Huijben, R. Ramesh, A. Morozovska, S. Choudhury, L.-Q. Chen, A. P. Baddorf and S. V. Kalinin, "Intrinsic Nucleation Mechanism and Disorder Effects in Polarization Switching on Ferroelectric Surfaces," *Phys. Rev. Lett.* **102**, 17601 (2009). [Jan09]
22. S. V. Kalinin, B. J. Rodriguez, S. Jesse, P. Maksymovych, K. Seal, M. Nikiforov, A. P. Baddorf, A. L. Kholkin, and R. Proksch, "Local Bias-Induced Phase Transitions," *Materials Today*, **11**, 16 (2008).

23. Z. Tan, A. L. Roytburd, I. Levin, K. Seal, B. J. Rodriguez, S. Jesse, S. Kalinin, and A. Baddorf, "Piezoelectric response of nanoscale PbTiO<sub>3</sub> in composite PbTiO<sub>3</sub>-CoFe<sub>2</sub>O<sub>4</sub> epitaxial films," *Appl. Phys. Lett.* **93**, 074101 (2008).
24. J. Shin, V.B. Nascimento, A.Y. Borisevich, E.W. Plummer, S.V. Kalinin, and A.P. Baddorf, "Polar distortion in ultra-thin BaTiO<sub>3</sub> films by in situ LEED-IV," *Phys. Rev. B* **77**, 245437 (2008).
25. J. Zhou, A. P. Baddorf, D. R. Mullins, S. H. Overbury, "Growth and characterization of Rh and Pd nanoparticles on oxidized and reduced CeO<sub>x</sub>(111) thin films by STM," *J. of Phys. Chem. C*, **112**, 9336 (2008).
26. K. Seal, P. Bintachitt, S. Jesse, A. Morozovska, A.P. Baddorf, S. Trolier-McKinstry, S.V. Kalinin, "Local Polarization Dynamics in Chemical Solution Deposited PZT Capacitors by Switching Spectroscopy PFM," *Proceedings of the International Society for Applications of Ferroelectrics* **1**, (2008).
27. Z. Y. Zhao, W. M. Zhang, C. Yi, A. D. Stiff-Roberts, B. J. Rodriguez, and A. P. Baddorf, "Doping Characterization of InAs/GaAs Quantum Dot Heterostructure by Cross-Sectional Scanning Capacitance Microscopy," *Appl. Phys. Lett.* **92**, 92101 (2008).
28. S. Jesse, S. V. Kalinin, R. Proksch, A. P. Baddorf, and B. J. Rodriguez, "Energy Dissipation Measurements on the Nanoscale: Band Excitation Method in Scanning Probe Microscopy," *Nanotechnology* **18**, 435503 (2007).
29. S. Jesse, B. J. Rodriguez, S. Choudhury, A. P. Baddorf, I. Vrejoiu, D. Hesse, M. Alexe, E. A. Eliseev, A. N. Morozovska, J. Zhang, L. Q. Chen, and S. V. Kalinin, "Direct Imaging of Spatial and Energy Distribution of Nucleation Centers in Ferroelectric Materials," *Nature Materials* **7**, 209 (2008).
30. B. J. Rodriguez, S. Jesse, K. Seal, A. P. Baddorf, and S. V. Kalinin, "Direct Measurement of Periodic Electric Forces in Liquids," *J. Appl. Phys.* **103**, 14306 (2008).
31. B. J. Rodriguez, S. Jesse, A. P. Baddorf, T. Zhao, Y. H. Chu, R. Ramesh, E. A. Eliseev, A. N. Morozovska, and S. V. Kalinin, "Spatially resolved mapping of ferroelectric switching behavior in self-assembled multiferroic nanostructures: strain, size, and interface effects," *Nanotechnology* **18**, 405701 (2007).
32. E. W. Plummer, A. P. Baddorf, S. V. Kalinin, A. P. Li, and M. Pan, "Imaging Functionality at the Nano-Scale," *Microscopy and Microanalysis* **13**, Supplement S02, 694 (2007).
33. B.J. Rodriguez, S. Jesse, K. Seal, A.P. Baddorf, S.V. Kalinin, and P. Rack, "Fabrication, Dynamics, and Electrical Properties of Insulated SPM Probes for Electrical and Electromechanical Imaging in Liquids," *Appl. Phys. Lett.* **91**, 93130 (2007) and *Virtual J. of Nanoscale Sci. Tech.* 10 Sept. 2007 and Erratum *Appl. Phys. Lett.* **91**, 202091 (2007).
34. S. V. Kalinin, S. Jesse, B. J. Rodriguez, K. Seal, A. P. Baddorf, T. Zhao, E.Y.H. Chu, R. Ramesh, E. A. Eliseev A. N. Morozovska, B. Mirman, and E. Karapetia, "Recent Advances in Electromechanical Imaging on the Nanometer Scale: Polarization Dynamics in Ferroelectrics, Biopolymers, and Liquid Imaging," *Jap. J. Appl. Phys.* **46**, 5674 (2007).
35. S. D. Senanayake, J. Zhou, A. P. Baddorf, D. R. Mullins, "The reaction of carbon monoxide with palladium supported on cerium oxide thin films," *Surf. Sci.* **601**, 3215 (2007).

36. K. Seal, S. Jesse, B. J. Rodriguez, A. P. Baddorf, and S. V. Kalinin, "High Frequency Piezoresponse Force Microscopy in the 1-10 MHz Regime," *Appl. Phys. Lett.* **91** (2007) 232904 and the December 17, 2007 issue of *Virtual J. of Nanoscale Sci. & Tech* and the December 15, 2007 issue of *Virtual Journal of Biological Physics Research*.
37. Z. Y. Zhao, W. M Zhang, C. Yi, A. D. Stiff-Roberts, B. J. Rodriguez, and A. P. Baddorf, "Doping Characterization of InAs/GaAs Quantum Dot Heterostructure by Cross-Section Scanning Capacitance Microscopy," Institute of Electrical and Electronics Engineers (IEEE) Lasers and Electro-Optics Society (LEOS) conference proceedings, July, 32 (2007).
38. J. Shin, S. V. Kalinin, A. Y. Borisevich, E. W. Plummer, and A. P. Baddorf, "Erratum: Layer-by-Layer and Pseudo-Two-Dimensional Growth Modes for Heteroepitaxial BaTiO<sub>3</sub> Films by Exploiting Kinetic Limitations," *Appl. Phys. Lett.* **91**, 249901 (2007).
39. J. Shin, S. V. Kalinin, A. Y. Borisevich, E. W. Plummer, and A. P. Baddorf, "Layer-by-Layer and Pseudo-Two-Dimensional Growth Modes for Heteroepitaxial BaTiO<sub>3</sub> Films by Exploiting Kinetic Limitations," *Appl. Phys. Lett.* **91**, 202901 (2007) and *AIP Virtual J. of Nanoscale Sci. and Tech.* 26 Nov 07.
40. J. Zhou, S. Dag, S. D. Senanayake, B. C. Hathorn, S. V. Kalinin, V. Meunier, D. R. Mullins, S. H. Overbury, and A. P. Baddorf, "Adsorption, Desorption, and Dissociation of Benzene on TiO<sub>2</sub>(110) and Pd/TiO<sub>2</sub>(110): Experimental Characterization and First-Principles Calculations," *Phys. Rev. B* **74**, 125318 (2006).
41. B. J. Rodriguez, S. Jesse, A. P. Baddorf, S.-H. Kim, and S. V. Kalinin, "Controlling Polarization Dynamics in a Liquid Environment: From Localized to Macroscopic Switching in Ferroelectrics," *Phys. Rev. Lett.* **98**, 247603 (2007).
42. A. P. Baddorf, "Scanning Tunneling Potentiometry: The Power of STM applied to Electrical Transport," book chapter in "Scanning Probe Microscopy: Electrical and Electromechanical Phenomena at the Nanoscale," eds. S. V. Kalinin and A. Gruverman, (Springer Verlag, New York, NY, 2006) pp 11-30.
43. S. Jesse, A. P. Baddorf, and S. V. Kalinin, "Switching Spectroscopy Piezoresponse Force Microscopy of Ferroelectric Materials," *Appl. Phys. Lett.*, **88**, 62908 (2006).
44. T. F. Juliano, Y. G. Gogotsi, T. E. Buchheit, C. S. Watson, S. V. Kalinin, J. Shin and A. P. Baddorf, "Detection of Indentation Induced FE-to-AFE Phase Transformation in Lead Zirconate Titanate," *J. Am. Cer. Soc.* **89**, 3557 (2006).
45. B. J. Rodriguez, S. V. Kalinin, J. Shin, S. Jesse, V. Grichko, T. Thundat, A. P. Baddorf, and A. Gruverman, "Electromechanical Imaging of Biomaterials by Scanning Probe Microscopy," *J. Structural Biology*, **153**, 151 (2006).
46. B. J. Rodriguez, S. Jesse, A. P. Baddorf, and S. V. Kalinin, "High Resolution Electromechanical Imaging of Ferroelectric Materials in a Liquid Environment by Piezoresponse Force Microscopy," *Phys. Rev. Lett.* **96**, 237602 (2006).
47. S. Jesse, A. P. Baddorf, and S. V. Kalinin, "Dynamic Behavior in Piezoresponse Force Microscopy," *Nanotechnology* **17**, 1615 (2006).
48. S. V. Kalinin, S. Jesse, J. Shin, A. P. Baddorf, A. Borisevich, and H. N. Lee, "Spatial Resolution, Information Limit and Contrast Transfer in Piezoresponse Force Microscopy," *Nanotechnology*, **17**, 3400 (2006).

49. S. V. Kalinin, B. J. Rodriguez, S. Jesse, J. Shin, A. P. Baddorf, P. Gupta, H. Jain, D. B. Williams, and A. Gruverman, "Vector Piezoresponse Force Microscopy," *Microscopy and Microanalysis*, **12**, 206 (2006).
50. S. V. Kalinin, B. J. Rodriguez, J. Shin, S. Jesse, V. Grichko, T. Thundat, A. P. Baddorf, and A. Gruverman, "Bioelectromechanical Imaging by Scanning Probe Microscopy: Galvani's Experiment at the Nanoscale," *Ultramicroscopy* **106**, 334 (2006).
51. K. T. Park, M. Pan, S. V. Kalinin, V. Meunier, A. P. Baddorf, and E. W. Plummer, "Surface defects on TiO<sub>2</sub>(110): from atomic and electronic structure to catalytic activity," in *Nanoporous and Nanostructured Materials for Catalysis, Sensor, and Gas Separation Applications*, ed. S. W. Lu, H. Hahn, J. Weissmuller, and J. L. Gole (Mater. Res. Soc. Symp. Proc. Vol. 876E, Warrendale, PA) R 4.6 2005.
52. B. J. Rodriguez, S. Jesse, A. P. Baddorf, S. V. Kalinin, A. Gruverman, "Visualizing Nano-Electromechanics by Vector Piezoresponse Force Microscopy," 2005 NSTI Nanotechnology Conference and Trade Show. NSTI Nanotech 2005, 2005, p 667.
53. S. Jesse, A. P. Baddorf, B. J. Rodriguez, A. Gruverman, and S. V. Kalinin, "Imaging Bio-electromechanics with Scanning Probe Microscopy: Unveiling Nature's Nanoscale Form and Function," 2005 NSTI Nanotechnology Conference and Trade Show. NSTI Nanotech 2005, 2005, p 67.
54. P. Gupta, H. Jain, D. B. Williams, S. V. Kalinin, J. Shin, and A. P. Baddorf, "Direct Observation of Ferroelectricity in a Confined Crystallite," *Microscopy and Microanalysis*, **11**, 1748 (2005).
55. P. Gupta, H. Jain, D. B. Williams, J. Shin, A. P. Baddorf, and S. V. Kalinin, "Observation of Ferroelectricity in a Confined Crystallite Using Electron-Backscattered Diffraction and Piezoresponse Force Microscopy," *Appl. Phys. Lett.* **87**, 172903 (2005).
56. K. T. Park, M. Pan, V. Meunier, W. Shelton, S. V. Kalinin, A. P. Baddorf, and E. W. Plummer, "Surface defect-mediated reactivity of Au/TiO<sub>2</sub>(110)," in *Nanoporous and Nanostructured Materials for Catalysis, Sensor, and Gas Separation Applications*, ed. S. W. Lu, H. Hahn, J. Weissmuller, and J. L. Gole (Mater. Res. Soc. Symp. Proc. Vol. 876E, Warrendale, PA) R 9.5 2005.
57. J. Shin, B. J. Rodriguez, A. P. Baddorf, T. Thundat, E. Karapetian, M. Kachanov, A. Gruverman, and S. V. Kalinin, "Simultaneous Elastic and Electromechanical Imaging by Scanning Probe Microscopy: Theory and Applications to Ferroelectric and Biological Materials," *J. Vac. Sci. Tech. B*, **23**, 2102 (2005) and *Virtual J. of Nanoscale Science* **12** (October 3, 2005) at <http://www.vjnano.org/>.
58. J. Shin, S. V. Kalinin, H. N. Lee, H. M. Christen, R. G. Moore, E. W. Plummer, and A. P. Baddorf, "Surface Stability of Epitaxial SrRuO<sub>3</sub> Films," *Surf. Sci.*, **581/2-3**, 118 (2005).
59. S. V. Kalinin, A. L. Gruverman, B. J. Rodriguez, J. Shin, A. P. Baddorf, E. Karapetian, and M. Kachanov, "Nanoelectromechanics of Polarization Switching by Piezoresponse Force Microscopy," *J. Appl. Phys.* **97**, 74305 (2005), and cond-mat/0406383.
60. S. V. Kalinin, J. Shin, G. M. Veith, A. P. Baddorf, M. V. Lobanov, H. Runge, and M. Greenblatt, "Real Space Imaging of the Microscopic Origins of the Ultrahigh Dielectric Constant in Polycrystalline CaCu<sub>3</sub>Ti<sub>4</sub>O<sub>12</sub>," *Appl. Phys. Lett.*, **86**, 102902 (2005), cond-mat/0407608.

61. S. V. Kalinin, J. Shin, S. Jesse, D. Geohegan, A. P. Baddorf, Y. Lilach, M. Moskovits and A. Kolmakov, "Electronic transport imaging in a multiwire SnO<sub>2</sub> chemical field-effect transistor device." *J. Appl. Phys.* **98**, 044503 (2005) and cond-mat/0506621.
62. S. V. Kalinin, J. Shin, M. Kachanov, E. Karapetian, and A. P. Baddorf, "Nanoelectromechanics of piezoresponse force microscopy: contact properties, fields below the surface and polarization switching," *Ferroelectric Thin Films*, 12th Symposium ed. S. Hoffmann-Eifert, H. Funakubo, V. Joshi, A. I. Kingon, and I. P. Koutsaroff, (Mater. Res. Soc. Symposium Proceedings Vol.784), 2004, p 43-8.
63. V. Meunier, S. V. Kalinin, J. Shin, A. P. Baddorf, and R. J. Harrison, "Quantitative Analysis of Electronic Properties of Carbon Nanotubes by Scanning Probe Microscopy: from Atomic to Mesoscopic Length Scales," *Phys. Rev. Lett.*, **93**, 246801 (2004).
64. J. Shin, V. Meunier, A.P. Baddorf, and S.V. Kalinin, "Non-linear Transport Imaging by Scanning Impedance Microscopy," *Appl. Phys. Lett.* **85**, 4240 (2004).
65. J. Shin, S. V. Kalinin, H. N. Lee, H. M. Christen, R. G. Moore, E. W. Plummer, and A. P. Baddorf, "Surface Stability of Epitaxial SrRu<sub>3</sub> Thin Films in Vacuum," *J. Mater. Res.* **19**, 3447 (2004).
66. S. V. Kalinin, S. Jesse, J. Shin, A. P. Baddorf, M. A. Guillorn and D. B. Geohegan, "Scanning Probe Microscopy Imaging of Frequency-Dependent Electrical Transport Through Carbon Nanotube Networks in Polymers," *Nanotechnology* **15**, 907 (2004).
67. R. G. Moore, J. Zhang, S. V. Kalinin, Ismail, A. P. Baddorf, R. Jin, D. G. Mandrus, and E. W. Plummer, "Surface Dynamics of the Layered Ruthenate Ca<sub>1.9</sub>Sr<sub>0.1</sub>RuO<sub>4</sub>," *Physica Status Solidi*, **241**, 2363 (2004).
68. H. Zajonz, D. Gibbs, A. P. Baddorf, and D. M. Zehner, "Nanoscale Strain Distribution at the Ag/Ru(0001) Interface," *Phys. Rev. B* **67**, 155417 (2003).
69. G. A. Farnan, C. L. Fu, Z. Gai, M. Kremer, A. P. Baddorf, Z. Y. Zhang, and J. Shen, "Electronic Stability of Magnetic Fe/Co Superlattices with Monatomic Layer Alternation," *Phys. Rev. Lett.* **91**, 226106 (2003).
70. J. P. Alarie, A. B. Hmelo, S. C. Jacobson, A. P. Baddorf, L. C. Feldmen, and J. M. Ramsey, "Fabrication and Evaluation of 2D Confined Nanochannels," p. 9 in *Micro Total Analysis Systems 2003*, Vol. 1, ed. by M. A. Northrup, K. F. Jensen, and D. J. Harrison, Transducers Research Foundation, Cleveland Heights, Ohio, 2003.
71. Ismail, Ph. Hofmann, A. P. Baddorf, and E. W. Plummer, "Thermal Expansion at a Metal Surface: A Study of Mg(0001) and , " *Phys. Rev. B* **66**, 245414 (2002).
72. A. P. Baddorf, V. Jahns, D. M. Zhener, H. Zajonz, and Doon Gibbs, "Relaxation and Thermal Expansion of Ru(0001) Between 300 and 1870 K and the Influence of Hydrogen," *Surf. Sci.* **498**, 74 (2002).
73. H. Zajonz, D. Gibbs, A. P. Baddorf, and D. M. Zehner, "Growth of Strained Epitaxial Cu Films on Ru(0001) Monitored by Surface X-Ray Diffraction," p. 149 in *Exploration of Subsurface Phenomena by Particle Scattering*, ed. by N. Q. Lam, C. A. Melendres, and S. K. Sinha, International Advanced Studies Institute Press, North East, Maryland, 2000.
74. H. Zajonz, D. Gibbs, A. P. Baddorf, V. Jahns, and D. M. Zehner, "Structure and Growth of Strained Cu Films on Ru(0001)," *Surf. Sci.* **447**, 141 (2000).

75. H. Zajonz, A. P. Baddorf, D. Gibbs, and D. M. Zehner, "Structure of Pseudomorphic and Reconstructed Thin Cu Films on Ru(0001)," *Phys. Rev. B* **62**, 436 (2000).
76. A. P. Baddorf, "Single Crystal X-ray Diffraction," p. 1 in *Synchrotron Radiation Applications to Materials Science*, ed. by P. Sprunger and J. Hormes, Center for Advanced Microstructures and Devices, Louisiana State University, Baton Rouge, Louisiana, 2000.
77. Jiandi Zhang, Ismail, P. J. Rous, A. P. Baddorf, and E. W. Plummer, "Periodic Lattice Distortion Accompanying the Charge Density Wave Transition for Sn/Ge(111)," *Phys. Rev. B* **60**, 2860 (1999).
78. M. Okada, A. P. Baddorf, and D. M. Zehner, "Hydrogen Adsorption on the  $\text{Mo}_{1-x}\text{Re}_x(110)$ ,  $x=0-0.25$  Surfaces," *Surf. Sci.* **410**, 237 (1998).
79. A. P. Baddorf, V. Jahns, J. Zhang, J. M. Carpinelli, and E. W. Plummer, "Periodic Lattice Distortion Accompanying the (3x3) Charge Density Wave Phase of Sn/Ge(111)," *Phys. Rev. B* **57**, 4579 (1998).
80. W. L. Gardner, A. P. Baddorf, and W. M. Holber, "Temperature and Concentration Effects on Ozone Ashing of Photoresist," *J. Vac. Sci. Technol. A* **15**, 1409 (1997).
81. M. Okada, A. P. Baddorf, and D. M. Zehner, "LEED and HREELS Investigation of the Hydrogen-Covered Mo(110) Surface," *Surf. Sci.* **373**, 145 (1997).
82. A. T. Hanbicki, H. L. Davis, A. P. Baddorf, D. B. Poker, and E. W. Plummer, "Hydrogen Induced Structural Changes on NiAl(110)," *Surf. Sci. Lett.* **365**, L639 (1996).
83. M. Okada, A. P. Baddorf, D. M. Zehner, and E. W. Plummer, "Effects of Hydrogen on the Dynamics of the  $\text{Mo}_{0.95}\text{Re}_{0.05}(110)$  Surface," *Surf. Sci.* **363**, 416 (1996).
84. A. P. Baddorf, A. K. Swan, and J. F. Wendelken, "Comment on In-plane Lattice Reconstruction of Cu(001)," *Phys. Rev. Lett.* **76**, 3658 (1996).
85. A. P. Baddorf and S. S. Chandavarkar, "Identification of an Incommensurate  $\text{FeAl}_2$  Overlayer on FeAl(110) using X-ray Diffraction and Reflectivity," *Physica B* **221**, 141 (1996).
86. A. T. Hanbicki, A. P. Baddorf, E. W. Plummer, B. Hammer, and M. Scheffler, "The Interaction of Hydrogen with the (110) Surface of NiAl," *Surf. Sci.* **331-333**, 811 (1995).
87. H. Dürr and A. P. Baddorf, "Anharmonicity and Vibrational Relaxation on the Cu(110)-(2x1)O Surface," *Surf. Sci.* **312**, 369 (1994).
88. H. Dürr and A. P. Baddorf, "Anharmonicity on the Cu(110)-(2x1)O Surface," p. 691 in *Vibrations at Surfaces 1993*, ed. by M. Rocca, G. Bracco, and U. Valbusa, Elsevier, Amsterdam, 1993.
89. H. Dürr and A. P. Baddorf, "Anharmonicity on the Cu(110)-(2x1)O Surface," *J. Electron Spectroscopy and Related Phenomena* **64/65**, 691 (1993).
90. G. Helgesen, Doon Gibbs, A. P. Baddorf, D. M. Zehner and S. G. J. Mochrie, "X-ray Reflectivity of the Cu(110) Surface," *Phys. Rev. B* **48**, 15320 (1993).
91. A. P. Baddorf, D. M. Zehner, G. Helgesen, D. Gibbs, A. R. Sandy and S. G. J. Mochrie, "X-ray Scattering Determination of the Cu(110)-(2x3)N Structure," *Phys. Rev. B* **48**, 9013 (1993).

92. B. S. Itchkawitz, A. P. Baddorf, H. L. Davis, and E. W. Plummer, "Shear Displacement of the K(110) Surface," *Phys. Rev. Lett.* **68**, 2488 (1992).
93. A. P. Baddorf and B. S. Itchkawitz, "Identification of Oxygen Species on Single Crystal K(110)," *Surf. Sci.* **264**, 73 (1991).
94. A. P. Baddorf and J. F. Wendelken, "High Coverages of Oxygen on Cu(110) Investigated with XPS, LEED, and HREELS," *Surf. Sci.* **256**, 264 (1991).
95. A. P. Baddorf and E. W. Plummer, "Enhanced Surface Anharmonicity Observed in Vibrations on Cu(110)," *Phys. Rev. Lett.* **66**, 2770 (1991).
96. K.-D. Tsuei, D. Heskett, A. P. Baddorf, and E. W. Plummer, "Electron Loss Spectra from Thin Alkali Films on Al(111)," *J Vac. Sci. Technol. A* **9**, 1761 (1991).
97. A. P. Baddorf and E. W. Plummer, "Surface Anharmonicity: Temperature Dependence of Phonon Energies on Cu(110)." p. 541 in *Vibrations at Surfaces 1990*, ed. by Y. T. Chabal, F. M. Hoffman, and G. P. Williams, Elsevier, New York, 1990.
98. A. P. Baddorf and E. W. Plummer, "Surface Anharmonicity: Temperature Dependence of Phonon Energies on Cu(110)," *J. Electron Spectroscopy and Related Phenomena*, **54/55**, 541 (1990).
99. A. P. Baddorf and D. M. Zehner, "Chemisorption of Nitrogen on Cu(110): Coverage and Site Determination." *Surf. Sci.* **238**, 255 (1990).
100. D. Heskett, K.-H. Frank, K. Horn, E. E. Koch, H.-J. Freund, A. Baddorf, K.-D. Tsuei, and E. W. Plummer, "Correlation Between Electron Loss and Inverse Photoemission Measurements of Alkali Metals on Metal Surfaces," *Phys. Rev. B* **37**, 10387 (1988).
101. D. Heskett, A. P. Baddorf, and E. W. Plummer, "Nitrogen-Induced Reconstruction of Cu(110): Formation of a Surface Nitride," *Surf. Sci.* **195**, 94 (1988).
102. J. M. Mundenar, A.P. Baddorf, E.W. Plummer, L.G. Sneddon, R.A. DiDio, and D.M. Zehner, "Oxygen Chemisorption on the Copper(110) Surface," *Surf. Sci.* **188**, 15 (1987).
103. A. P. Baddorf, I.-W. Lyo, E. W. Plummer, and H. L. Davis, "Removal of Surface Relaxation of Cu(110) by Hydrogen Adsorption," *J. Vac. Sci. Technol. A* **5**, 782 (1987).
104. A. P. Baddorf, J. M. Mundenar, and E. W. Plummer, "Intrinsic and Adsorbate-modified Vibrations of the Copper (110) Surface," *J. Electron Spectroscopy and Related Phenomena* **38**, 219 (1986).