MARTIN HOLT

Scientist, Nanoscience

Electron and X-ray Microscopy Group

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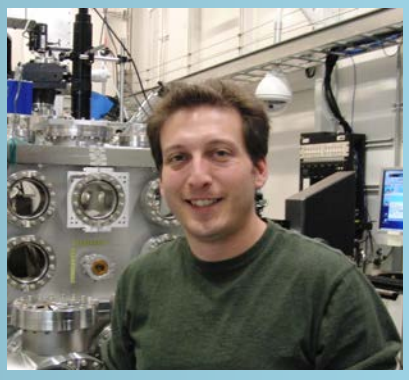


Education

Ph. D. Physics, University of Illinois Urbana-Champaign (2002)
B. A. Physics and Mathematics, Rice University (1998)

Research interests

- Predictive control of classical and quantum material response at the nanoscale through synchrotron microscopy of strain, scaling, and structural dynamics
- Coherent x-ray diffraction imaging and Bragg ptychography for nanoscale structural studies

Professional Experience

Argonne National Laboratory - Center for Nanoscale Materials (CNM) *2010-present*
Scientist, Nanoscience

- Beamline Director - CNM/APS Hard X-ray Nanoprobe Beamline (2016 – present)
  - Scientific productivity increase of ~2x over this time period
  - APS-U Beamline Enhancement awarded - "The 4D Nanoprobe"
- Scientific lead - CNM X-ray diffraction microscopy program (2010 – present)
  - Demonstrated 3D Bragg Projection Ptychography at ~20nm^3 resolution
  - Demonstrated 2D Bragg Projection Ptychography at 5nm spatial resolution
  - Observed large wave-vector phonon confinement in 10nm semiconductor membranes

Argonne National Laboratory – Center for Nanoscale Materials (CNM) *2004-2010*
Assistant Physicist

- Co-principal investigator of Hard X-ray Nanoprobe Beamline Project – design, construction, commissioning, and acceptance
- Development of a non-goniometer-based approach to hard x-ray nanoscale strain mapping at a strain sensitivity of dc/c ~10^{-5} at a spatial resolution of ~25nm

McGill University – Department of Physics *2002-2004*
Post-Doctoral Fellow

- Observation of geometrical pinning of strain fields to ferroelectric domain boundaries
- Separation of critical fluctuations from static disorder in displacive phase transitions

University Illinois Urbana-Champaign – Department of Physics *1998-2002*
Graduate Research Assistant

- Determination of phonon dispersions in elemental systems via hard x-ray thermal diffuse scattering

Awards and honors

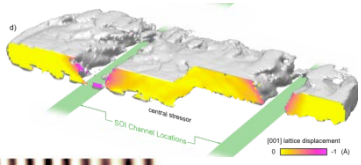
- R&D 100 Award – The Hard X-ray Nanoprobe (2009)

MARTIN HOLT

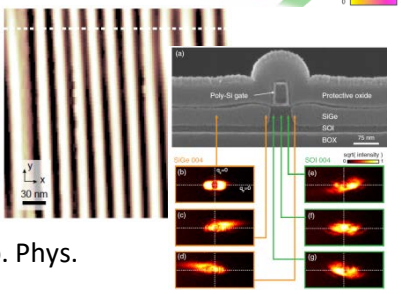
Publications

Strain imaging through nano-focused coherent Bragg diffraction ptychography

1. M. O. Hill, I. Calvo-Almazan, M. Allain, **M. V. Holt**, A. Ulvestad, J. Treu, G. Koblmuller, C. Huang, X. Huang, H. Yan, E. Nazaretski, Y. S. Chu, G. B. Stephenson, V. Chamard, L. J. Lauhon and S. O. Hruszkewycz. *"Measuring three-dimensional strain and structural defects in a single InGaAs nanowire using coherent x-ray multiangle Bragg projection ptychography"*, Nano Lett. 18 811-819 (2018)



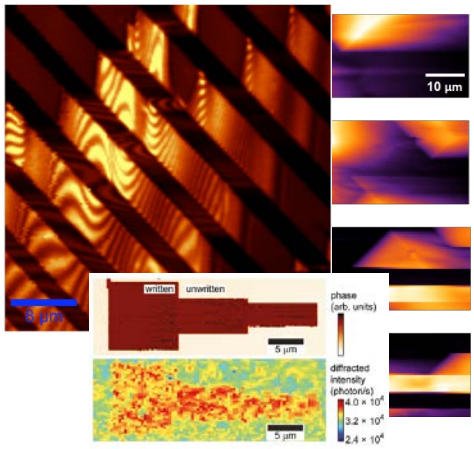
2. S. O. Hruszkewycz, M. Allain, **M. V. Holt**, C. E. Murray, J. R. Holt, P. H. Fuoss and V. Chamard. *"High-resolution three-dimensional structural microscopy by single-angle Bragg ptychography"* Nat. Mater. 16**,** 244 (2017)



3. J. A. Tilka, J. Park, Y. Ahn, A. Pateras, K. C. Sampson, D. E. Savage, J. R. Prance, C. B. Simmons, S. N. Coppersmith, M. A. Eriksson, M. G. Lagally, **M. V. Holt**, and P. G. Evans, "*Combining experiment and optical simulation in coherent X-ray nanobeam characterization of Si/SiGe semiconductor heterostructures*" J. App. Phys. 120 015304 (2016)
4. S. O. Hruszkewycz, **M. V. Holt**, M. Allain, V. Chamard, S. M. Polvino, C. E. Murray, and P. H. Fuoss. "*Efficient modeling of Bragg coherent x-ray nanobeam diffraction*." Optics Letters 40, 3241 (2015)
5. **M. V. Holt**, S. O. Hruszkewycz, C. E. Murray, J. R. Holt, D. M. Paskiewicz, and P. H. Fuoss. "*Strain imaging of nanoscale semicond uctor heterostructures with X-ray Bragg Projection Ptychography*." Phys. Rev. Lett. **112**, 165502 (2014)
6. S. O. Hruszkewycz**, M. V. Holt**, J. Maser, C. E. Murray, M. J. Highland, C. M. Folkman and P. H. Fuoss. "*Coherent Bragg nanodiffraction at the hard X-ray Nanoprobe beamline*." Phil. Trans. R. Soc. A **372**, 20130118 (2014)
7. S. O. Hruszkewycz, M. J. Highland, **M. V. Holt**, D. Kim, C. M. Folkman et al. "*Imaging local polarization in ferroelectric thin films by coherent x-ray Bragg projection ptychography*" Phys. Rev. Lett. **110**, 177601 (2013)
8. S. O. Hruszkewycz, **M. V. Holt**, C. E. Murray, J. Bruley, J. Holt et al. "*Quantitative nanoscale imaging of lattice distortions in epitaxial semiconductor heterostructures using nanofocused x-ray Bragg projection ptychography.*" Nano Lett. **12**(10): 5148-5154 (2012)
9. S. O. Hruszkewycz, **M. V. Holt**, A. Tripathi, J. Maser, and P. H. Fuoss, "*Framework for three-dimensional coherent diffraction imaging by focused beam x-ray Bragg ptychography*" Optics Letters, Vol. 36, Issue 12, pp. 2227-2229 (2011)
10. C. E. Murray, A. Ying, S. M. Polvino, I. C. Noyan, **M. V. Holt**, and J. Maser, "*Nanoscale silicon-on-insulator deformation induced by stressed liner structures*" J. Appl. Phys. 109, 083543 (2011);
11. A. Ying, B. Osting, I. C. Noyan, C. E. Murray, **M. V. Holt** and J. Maser. "*Modeling of kinematic diffraction from a thin silicon film illuminated by a coherent, focused X-ray nanobeam",* J. Appl. Cryst. 43, 587-595 (2010).

Nanoscale hard x-ray diffraction and fluorescence microscopy for *in-situ* structural imaging

12. J Lahnemann, MO Hill, J Herranz, O Marquardt, G Gao, AA Hassan, A Davtyan, SO Hruszkewycz, **MV Holt**, C Huang, IC Almazan, U Jahn, U Pietsch, LJ Lauhon, L Geelhaar, "Correlated nanoscale analysis of the emission from wurtzite vs zincblende InGaAs/GaAs nanowire core-shell quantum wells", Nano Letters DOI:10.1021/acs.nanolett.9b01241 (2019)
13. JP Correa-Baena, Y Luo, TM Brenner, J Snaider, S Sun, X Li, MA Jensen, NTP Hartono, L Nienhaus, S. Wieghold, JR Poindexter, S Wang, YS Meng, T Wang, B Lai, **MV Holt**, Z Cai, MG Bawendi, L Huang, T



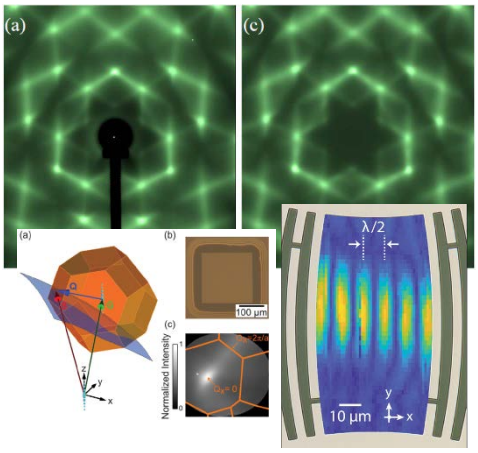
Buonassisi, DP Fenning, “Homogenized halides and alkali cation segregation in alloyed organic-inorganic perovskites” Science, 363 627-631 (2019).

14. X. Li, Y. Luo, **M. V. Holt**, Z. Cai, and D. P. Fenning, “Residual nanoscale strain in cesium lead bromide perovskite reduces stability and shifts local luminescence”, Chem. Mater. 31:8 2778-2785 (2019)
15. A Ulvestad, SO Hruszkewycz, **MV Holt**, MO Hill, I Calvo-Almazan, S Maddali, X Huang, H Yan, E Nazaretski, YS Chu, LJ Lauhon, N Rodkey, MI Bertoni, ME Stuckelberger, “Multimodal x-ray imaging of grain-level properties and performance in a polycrystalline solar cell”, Journ. Synch. Rad. DOI 10.1107/S1600577519003606 (2019)
16. D Papkov, N Delpouve, L Delbreilh, S Araujo, T Stockdale, S Mamedov, K Maleckis, Y Zou, MN Andalib, E Dargent, VP Dravid, **MV Holt**, C Pellerin, YA Dzenis, “Quantifying polymer chain orientation in strong and tough nanofibers with low crystallinity: towards next generation nanostructured superfibers” ACS Nano 13:5, 4893-4927 (2019)
17. Y. Chen, J. A. Tilka, Y. Ahn, J. Park, A. Pateras, T. Zhou, D. E. Savage, I. McNulty, **M. V. Holt**, D. M. Paskiewicz, D. D. Fong, T. F. Kuech and Paul G Evans, “Seeded lateral solid-phase crystallization of the perovskite oxide SrTiO3” J. Phys. Chem. C 123:12 7447-7456 (2019)
18. M. O. Ramirez, T. A. Lummen, I. Carrasco, E. Barnes, U. Aschauer, D. Stefanska, A. S. Gupta, C. de las Heras, H. Akamatsu, **M. V. Holt**, P. Molina, A. Barnes, R. C. Haismaier, P. J. Deren, C. Prieto, L. E. Bausa, N. A Spaldin and V Gopalan, “Emergent room temperature polar phase in CaTiO3 nanoparticles and single crystals” APL Mater 7 011103 (2019)
19. A. Singer, J.G. Ramirez, I. Valmianski, D. Cela, N. Hua, R. Kukreja, J.Wingert, O. Kovalchuk, J.M. Glownia, M. Sikiroski, M. Chollet, **M. Holt**, I.K. Schuller, O.G Shpyrko, "Non-equilibrium phase precursors to the insulator-metal transition in V2O3," Phys Rev Lett 120 207601 (2018)
20. May B. M., Yu Y., **Holt M. V**., Strobridge F. C., Boesenberg U., Grey C. P., and Cabana-jimenez J., "Nanoscale Detection of Intermediate Solid Solutions in Equilibrated LixFePO4 Microcrystals", Nano Letters, 17, 7364-7371, (2017)
21. Park J., Mangeri J., Zhang Q., Yusuf M., Pateras A., Dawber M., **Holt M. V**., Heinonen O. G., Nakhmanson S. M., and Evans P. G., "Domain Alignment within Ferroelectric/dielectric PbTiO3/SrTiO3 Superlattice Nanostructures", Nanoscale, 10, 3262-3271, (2018)
22. Pateras A., Park J., Ahn Y., Tilka J. A., **Holt M. V**., Reichl C., Wegscheider W., Baart T. A., Dehollain J., Mukhopadhyay U., Vandersypen L. M., and Evans P. G., "Mesoscopic Elastic Distortions in GaAs Quantum Dot Heterostructures", Nano Letters, 18, 2780-2786, (2018)
23. Pateras A., Park J., Ahn Y., Tilka J. A., **Holt M. V**., Kim H., Mawst L. J., and Evans P. G., "Dynamical Scattering in Coherent Hard x-ray Nanobeam Bragg Diffraction", Phys. Rev. B, 97, 235414, (2018)
24. J. Park, Y. Ahn, J. A. Tilka, K. C. Sampson, D. E. Savage, J. R. Prance, C. B. Simmons, M. G. Lagally, S. N. Coopersmith, M. A. Eriksson, **M. V. Holt** and P. G. Evans. *“Electrode-stress-induced nanoscale disorder in Si quantum electronic devices.”* APL Mater. **4**, 066102 (2016)
25. Y. Luo, S. Gamliel, S. Nijem, S. Aharon, **M. V. Holt**, B. Stripe, V. Rose, M. I. Bertoni, L. Etgar, and D. P. Fenning, “*Spatially heterogeneous chlorine incorporation in organic-inorganic perovskite solar cells”* Chem. Mater. 28 6536-6543 (2016)
26. T. A. Lummen, Y. Gu, J. Wang, S. lei, F. Xue, A. Kumar, A. T. Barnes, E. Barnes, S. Denev, A. Belianinov, **M. V. Holt**, A. N. Morozovska, S. V. Kalinin , L. Q. Chen, V. Gopalan. *“Thermotropic phase boundaries in classic ferroelectrics.”* Nature Communications **5**, 3172 (2014)

27. K. D'Aquila, C. Phatak, **M. V. Holt**, B. D. Stripe, S. Tong, W. Ik Park, S. Hong, A. K. Petford-Long. "*Bipolar resistance switching in Pt/CuOx/Pt via local electrochemical reduction*". Applied Physics Letters 104, 242902 (2014).
28. D. M. Paskiewicz, D. E. S avage, **M. V. Holt**, P. G. Evans, M. G. Lagally. *"Nanomembrane-based materials for Group IV semiconductor quantum electronics."* Scientific Reports **4**, 4218 (2014)
29. **M. V. Holt**, R. Harder, R. Winarski, and V. Rose. "*Nanoscale Hard X-ray Microscopy Methods for Materials Studies.*" Annual Review of Material Research **43**:3.1-3.29 (2013)
30. C.E. Murray, S.M. Polvino, I.C. Noyan, Z. Cai, J. Maser, **M. V. Holt. "***Probing strain at the nanoscale with x-ray diffraction in microelectronic materials induced by stressor elements*" Thin Solid Films 530 85-90 (2013)
31. D. A. Czaplewski, **M. V. Holt**, L. E. Ocala. "*The range and intensity of backscattered electrons for use in the creation of high fidelity electron beam lithography patterns*" Nanotechnology 24: 305302 (2013)
32. RP Winarski, **M. V. Holt**, V. Rose, P. Fuesz, D. Carbaugh et al "*A hard x-ray Nanoprobe beamline for nanoscale microscopy.*" Journ. Synch. Rad. 19 1056-1060 (2012)
33. J. A. Klug, **M. V. Holt**, R. N. Premnath, A. Joshi-Imre, S. Hong, et al "*Elastic relaxation and correlation of local strain gradients with ferroelectric domains in (001) BiFeO3 nanostructures*",. Appl. Phys. Lett. **99**, 052902 (2011)
34. S. O. Hruszkewycz, C. M. Folkman, M. J. Highland, **M. V. Holt** et al. *"X-ray nanodiffraction of tilted domains in a poled epitaxial BiFeO3 thin film."* Appl. Phys. Lett. **99**:232903 (2011)
35. J. Y. Jo, P. Chen, R. J. Sichel, S. H. Baek, R. T. Smith, N. Balke, S. V. Kalinin, **M. V. Holt**, J. Maser, K. Evans-Lutterodt,| C. B. Eom, and P. G. Evans, *"Structural Consequences of Ferroelectric Nanolithography",* Nano Lett. **11**, 3080–3084 (2011)
36. M. I. Bertoni, D. P. Fenning, M. Rinio, V. Rose, **M. V. Holt**, J. Maser and T. Buonassisi, "*Nanoprobe X-ray fluorescence characterization of defects in large-area solar cells*" Energy Environ. Sci., 4, 4252 (2011)
37. H. Yan, V. Rose, D. Shu, E. Lima, H C Kang, R. Conley, C. Liu, N. Jahedi, A. T. Macrander, G. B. Stephenson, **M. V. Holt**, Y. S. Chu, M. Lu, and J. Maser, "*Two dimensional hard x-ray nanofocusing with crossed multilayer Laue lenses*" Opt Exp 19, 15070 (2011)
38. M. M. Qazilbash, A. Tripathi, A. A. Schafgans, Bong-Jun Kim, Hyun-Tak Kim, Zhonghou Cai, **M. V. Holt**, J. M. Maser, F. Keilmann, O. G. Shpyrko, and D. N. Basov, "*Nanoscale imaging of the electronic and structural transitions in vanadium dioxide*" Physical Review B **83**, 165108 (2011)
39. J P Strachan, G. Medeiros-Ribeiro, J. Joshua Yang, M.-X. Zhang, F. Miao, I. Goldfarb, **M. V. Holt**, V Rose, and R. S Williams, "*Spectromicroscopy of tantalum oxide memristors*" Appl. Phys. Lett. 98, 242114 (2011)
40. O. Heinonen, M. Siegert, A. Roelofs, A. K. Petford-Long, **M. V. Holt**, K. d'Aquila, and W. Li, "*Correlating structural and resistive changes in Ti:NiO resistive memory elements*", Appl. Phys. Lett. 96, 103103 (2010)
41. V Rose, **M V. Holt**, R Winarski and J Maser, *"Hard X-ray Nanoprobe Characterization of Advanced Materials"*. Microscopy and Microanalysis, 16(Suppl. 2), pp 900-901 (2010).
42. Kh. Hassani, M. Sutton**, M. V. Holt**, Y Zuo, and D Plant "X-*ray diffraction imaging of strain fields in a domain-inverted LiTaO3 crystal*" Journ App Phys 104 043515 (2008)
43. Kh. Hassani, M. Sutton, A. Tkachuk, and **M. V. Holt.** *"X-ray microdiffraction imaging of a silicon microcantilever"* Journ App Phys 101 063546 (2007)
44. **M. V. Holt**, Kh. Hassani, and M. Sutton "*Microstructure of ferroelectric domains in BaTiO3 observed via X-ray micro-diffraction.*" Phys. Rev. Lett. 95, 085504 (2005)

Imaging phonons and structural dynamics in phase active and quantum materials

45. H. Wen, M. J. Cherukara and M. V. Holt, "Time-resolved x-ray microscopy for materials science", Annu. Rev. Mater. Res. 49:12.1-12.27 (2019)



46. S. J. Whiteley, G. Wolfowicz, C. P. Anderson, A. Bourassa, H. Ma, M. Ye, G. Koolstra, K. J. Satzinger, M. V. Holt, F. J. Heremans, A. N. Cleland, D. I. Schuster, G. Galli, D. D. Awschalom, "Spin-phonon interactions in silicon carbide addressed by Gaussian acoustics" Nature Physics 15, 490–495 (2019)
47. D. J. Keavney, Y. Choi, **M. V. Holt**, V. Uhlii, D. Arena, E. E. Fullerton, P. J. Ryan, and J. W. Kim, "Phase coexistence and kinetic arrest in the magnetostructural transition of the ordered alloy FeRh", Sci. Rep. 8: 1778 (2018)
48. K. M. McElhinny, G. Gopalakrishnan, D. E. Savage, D. A. Czaplewski, M. G. Lagally, **M. V. Holt**, P. G. Evans, "*Synchrotron x-ray thermal diffuse scattering probes for phonons in Si/SiGe/Si trilayer nanomembranes*" MRS Advances 1 3263-3268 (2016)
49. G. Gopalakrishnan, **M. V. Holt**, K. M McElhinny, J. W Spalenka, D. A. Czaplewski, T. U. Schulli, and P. G. Evans. *"Thermal diffuse scattering as a probe of large-wave-vector phonons in Silicon nanostructures."* Phys. Rev. Lett. **110**, 205503 (2013)
50. M. M. Qazilbash, A. Tripathi, A. A. Schafgans, Bong-Jun Kim, Hyun-Tak Kim, Zhonghou Cai, **M. V. Holt,**J. M. Maser, F. Keilmann, O. G. Shpyrko, and D. N. Basov, "*Nanoscale imaging of the electronic and structural transitions in vanadium dioxide*" Phys Rev B 83, 165108 (2011)
51. H. Hong, R. Xu, A. Alatas, **M. V. Holt**, T.-C. Chiang. *"Central peak and narrow component in x-ray scattering measurements near the displacive phase transition in SrTiO3."* Phys. Rev. B **78** (10), 104121-1-104121-4 (2008)
52. **M. V. Holt**, M. Sutton, P. Zschack, H. Hong, and T.-C. Chiang, *"Dynamic fluctuations and static speckle from critical x-ray scattering in SrTiO3"* Phys. Rev. Lett. **98**, 065501 (2007)
53. Hong, H., C.M. Wei, M.Y. Chou, Z. Wu, L. Basile, H. Chen, **M. V. Holt**, and T.C. Chiang, "*Alternating Layer and Island Growth of Pb on Si by Spontaneous Quantum Phase Separation*," Phys. Rev. Lett. 90, 076104-1 to 076104-4 (2003).
54. J. Wong,, **M. V. Holt**, H. Hong, M. Wall, A.J. Schwartz, P. Zschack, and T.-C. Chiang, "*Intensity Patterns of Diffuse X-ray Scattering from Thermally Populated Phonons in fcc [delta]-Pu-Ga*," Plutonium Futures 673:221–223, American Institute of Physics (2003).
55. **M. V. Holt**, P. Czoschke, H. Hong, P. Zschack, H. K. Birnbaum, T. -C. Chiang. *"Phonon dispersions in niobium determined by x-ray transmission scattering."* Phys. Rev. B **66**, 64303 (2002)
56. **M. V. Holt**, P. Zschack, H. Hong, M. Y. Chou, T.-C. Chiang "*X-ray studies of phonon softening in TiSe2*." Phys. Rev. Lett. **86**, 3799 (2001)
57. **M. V. Holt**, Z. W u, H. Hong, P. Zschack, P. Jemian, et al. "*Determination of phonon dispersions from x-ray transmission scattering: The example of silicon."* Phys. Rev. Lett. **83**, 3317 (1999)

Invited talks

- "Hard X-ray coherent diffraction imaging using nanoscale focusing optics" TMS 2019
- "High Resolution Operando X-ray Microscopy of Nanostructures" ALS User's Meeting 2017
- "Coherent diffraction using nanoscale focusing optics" Petra IV Upgrade Coherence Workshop 2017
- "Coherent diffraction suing nanoscale focusing optics" ATOMIC APS-U Workshop 2017
- "Nanoscale Hard X-ray Microscopy." Denver X-ray Conference, Westminster CO (DXC 2015)
- "Strain Imaging of Nanoscale Semiconductor Heterostructures with Bragg Projection Ptychography." The 12th Biennial Conference on High-Resolution X-ray Diffraction and Imaging, Grenoble France (XTOP 2014)

- "Hard X-ray Nanoscale Structural Imaging of Ferroelectric Thin Films" 11th International Conference on X-ray Microscopy, Aug 5-10 Shanghai China 2012
- "Hard X-ray Nanoscale Structural Imaging of Multiferroic Thin Films" Frontiers in electronic materials: Correlation effects and memristive phenomena. Jun 17-20 Aachen, Germany 2012
- "Nanoscale diffraction microscopy at the CNM/APS Hard X-ray Nanoprobe Beamline", Materials Science and Technology Pittsburgh PA 2009
- "Nanoscale diffraction microscopy at the CNM/APS Hard X-ray Nanoprobe Beamline", International Semiconductor Device Research Symposium, College Park MD - ISDRS 2009
- "Nanoscale Diffraction Microscopy at the CNM/APS Hard X-ray Nanoprobe Beamline" Denver X-ray Conference, Denver CO 2008
- "Observing nanoscale phenomena near phase transitions via diffraction microscopy at the nanoprobe beamline" Northern Iowa University Seminar Series 2008
- "Scientific applications of the hard x-ray Nanoprobe" American Geophysical Union AGU Joint Assembly, Baltimore MD 2006

Patents

- No. 7,331,714 *A optoelectronic structure for a multifunctional hard x-ray Nanoprobe instrument*. D. Shu, J. Maser, B. Lai, S. Vogt, **M. Holt**, C. Preissner, R. P. Winarski, and G. B. Stephenson

Teaching Experience

- Guest lecturer: "Nanomaterials" Northwestern University 2013 - 2014
- Neutron and X-ray Summer School "The Hard X-ray Nanoprobe" 2010, 2012
- CNM Short Course "Science with the Hard X-ray Nanoprobe" 2010-2018

Professional service

- Member - Chicago Quantum Exchange
- Member - ANL Quantum Information Science Incubator
- Member – APS Partner User Council
- NSLSII X-ray Microscopy and Imaging Proposal Review Panel 2016-present
- Journal review: JACRA, PRB, ACS Nano, PNAS, JSR
- LDRD proposal review - Innovate / Prime / PSE / Hard X-ray Sciences
- Member - EXM, XSD, and MSD staff hiring committees
- Technical design review teams APS-U ATOMIC, CHEX, Velociprobe

References

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