

Lawrence Friedman

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EDUCATION

- 1999 Ph.D. Physics, University of California – Berkeley
Advised by Daryl Chrzan
Thesis: “Advances in the Theory of the Hall-Petch Relation,
Dislocation Pileups and Dislocation Sources”
- 1995 M.A. Physics, University of California – Berkeley
- 1993 B.A. Physics, University of Chicago

PROFESSIONAL EXPERIENCE

- 08/2002 – Present Assistant Professor
Department of Engineering Science and Mechanics
Pennsylvania State University
- 09/1999 – 07/2002 Postdoctoral “Metals” Fellow (Advised by Erik van der Giessen)
Netherlands Institute for Metals Research, Technical University
of Delft (The Netherlands), University of Groningen (The
Netherlands)
- 06/1999 – 08/1999 Postdoctoral Student (Advised by Daryl Chrzan)
Lawrence Berkeley National Laboratory, University of
California – Berkeley
- 08/1993 – 05/1999 Graduate Research/Teaching Assistant
Department of Physics and Department of Materials Science
University of California – Berkeley

REFEREED JOURNAL ARTICLES[†]

1. Lawrence H. Friedman, "Predicting and Understanding Order of Epitaxial Quantum Dots: Early Growth Stages," *Journal of Electronic Materials*, accepted August 6,

[†] links and downloads at <http://www.esm.psu.edu/wiki/research:lhf10:publications>

- 2007 and selected as a top paper for complimentary Open Choice program (19 pages) (arXiv:0705.2601v1 [cond-mat.mtrl-sci]).
2. Lawrence H. Friedman, "Order of epitaxial self-assembled quantum dots: Linear analysis," *Journal of Nanophotonics*, 1(1):013513 (42 pages), 2007.
 3. Lawrence H. Friedman, "Anisotropy and order of epitaxial self-assembled quantum dots," *Physical Review B*, 75(19):193302 (4 pages) (2007).
 4. C. Kumar and L. H. Friedman, "Simulation of thermal field directed self-assembly of epitaxial quantum dots," *Journal of Applied Physics*, 101(9):094903 (9 pages), 2007.
 5. L. Fang and L. H. Friedman, "Analytic treatment of metallic multilayer strength at all length scales: Influence of dislocation sources," *Acta Materialia*, 55(5):1505-1514 (2007).
 6. L. H. Friedman and J. Xu, "Feasibility study for thermal-field directed self-assembly of heteroepitaxial quantum dots," *Applied Physics Letters*, 88:093105 (3 pages) (2006).
 7. L. H. Friedman. "Exponent for Hall-Petch behaviour of ultra-hard multilayers," *Philosophical Magazine*, 86(11): 1443–1481 (2006).
 8. L. Fang and L. H. Friedman. "Strength of metallic multilayers at all length scales from analytic theory of discrete dislocation pileups", *Philosophical Magazine*, 85 (28): 3321-3355 (2005).
 9. L. H. Friedman and L. Fang, "Towards a full analytic treatment of the Hall-Petch behavior in multilayers: putting the pieces together." *TMS Letters*, 1(1):3-4 (2004).
 10. L. H. Friedman, "Towards a full analytic treatment of the Hall-Petch behavior in multilayers: putting the pieces together," *Scripta Materialia*, 50 (6): 763-767 (2004).
 11. P. A. Greaney, L. H. Friedman, and D. C. Chrzan, "Continuum simulation of dislocation dynamics: predictions for internal friction response," *Computational Materials Science*, 25(3): 387-403 (2002). (Contributing author)
 12. D. Weygand, L. H. Friedman, E. van der Giessen, and A. Needleman, "Aspects of boundary-value problem solutions with three-dimensional dislocation dynamics," *Modeling and Simulation in Materials Science and Engineering*, 10 (4): 437-468 (2002). (Contributing author)
 13. D. Weygand, L. H. Friedman, E. van der Giessen, and A. Needleman, "Discrete dislocation modeling in three-dimensional confined volumes," *Materials Science and Engineering A*, 309-310: 420-424 (2001). (Contributing author)
 14. K. Faradjian, L. H. Friedman, and D. C. Chrzan, "Frank-Read sources within a continuum simulation," *Modelling and Simulation in Materials Science and Engineering*. 7(4): 479-494 (1999). (Equal contributions by authors)
 15. L. H. Friedman and D. C. Chrzan, "Scaling theory of the Hall-Petch relation for multilayers," *Physical Review Letters*, 81(3): 2715-2718 (1998).

16. L. H. Friedman and D. C. Chrzan, “Continuum analysis of dislocations pile-ups: influence of sources” *Philosophical Magazine A*, 77(5): 1185-1204 (1998).

CONFERENCE PROCEEDINGS

1. D. Weygand, L. H. Friedman, E. van der Giessen, and A. Needleman, “Dislocation dynamics modeling in confined volumes,” *Advances in Mechanical Behavior, Plasticity and Damage. Proceedings of Euromat 2000* vol. 1: 293-298 (2000).
2. L. H. Friedman, D. Weygand, and E. van der Giessen, “Size effects and scaling in misfit dislocation formation in self-assembled quantum dots.” *Technical Proceedings of the 2002 International Conference on Computational Nanoscience*, 271-274 (2002).

CONFERENCE PRESENTATION AND INVITED TALKS

1. L. H. Friedman, “Faceting and Surface Energy Effects on the Self-Assembly of Epitaxial Quantum Dots,” TMS (The Minerals, Metals and Materials Society) 2008 Annual Meeting, New Orleans, LA, March 2008. (abstract accepted)
2. L. H. Friedman, “Dislocation Pileups and Strength of Multilayers,” Plasticity 2008, Kailua-Kona, Island of Hawaii, Feb., 2008. (invited speaker)
3. L. H. Friedman, “Morphology and Ordering of III-V Epitaxial Self-Assembled Quantum Dots,” MRS (Materials Research Society) Fall 2007 Meeting, Boston, MA, November 27, 2006. (abstract accepted)
4. C. Kumar and L. H. Friedman, “Effect of Elastic Inhomogeneity and Anisotropy on the Order of Epitaxial Quantum Dots” MRS (Materials Research Society) Fall 2007 Meeting, Boston, MA, November 26, 2006. (abstract accepted)
5. Lawrence H. Friedman, “Spatial Order of Self-Assembled Epitaxial Quantum Dots.” Dept. of Engineering Science and Mechanics, Penn State University. (invited to present October 10, 2007)
6. Lawrence H. Friedman, “Predicting and Understanding Order of Epitaxial Quantum Dots: Early Growth Stages,” Nanoscience Group Seminar, Department of Physics, University of Arkansas, Fayetteville, AR. May 22, 2007. (invited speaker)
7. L. H. Friedman, “Predicting and Understanding Order of Heteroepitaxial Quantum Dots,” SIMC-XIV (14th Semiconducting and Insulating Materials Conference), Fayetteville, AR, May 16, 2007.
8. L. H. Friedman, “Predicting and understanding order of heteroepitaxial quantum dots: early growth stages,” TMS (The Minerals, Metals and Materials Society) 2007 Annual Meeting, Orlando, FL, February 25, 2007.
9. L. H. Friedman, “Order, randomness and fluctuations in heteroepitaxial quantum dot growth,” MRS (Materials Research Society) Fall 2006 Meeting, Boston, MA, November 29, 2006.

10. L. H. Friedman, "Origins of order and disorder in self-assembled epitaxial quantum dots," NANOMECH-06 Materials Science And Materials: Mechanics At The Nanoscale, Bari, Italy, November 23, 2006. (invited speaker)
11. C. Kumar and L. H. Friedman, "Simulation of thermal-field directed self-assembly of epitaxial quantum dots," Materials Science and Technology 2006 Conference, Cincinnati, OH, October 19, 2006.
12. Lawrence H. Friedman, "Order, Randomness and Fluctuations in Heteroepitaxial Quantum Dot Growth," Computational and Applied Mathematics Colloquium, Department of Mathematics, Penn State University, September 29, 2006. (invited speaker)
13. L. H. Friedman, "Crystal anisotropy and order of epitaxial self-assembled quantum dots," 43rd Annual Technical Meeting of the Society of Engineering Science, University Park, PA, August 14, 2006.
14. C. Kumar and L.H. Friedman, "Simulation of Thermal-Field Directed Self-Assembly of Epitaxial Quantum Dots," 43rd Annual Technical Meeting of the Society of Engineering Science, University Park, PA, August 14, 2006.
15. C. Kumar and L. H. Friedman, "Simulation of thermal-field directed self-assembly of epitaxial quantum dots," TMS (The Minerals, Metals and Materials Society) 2006 Electronic Materials Conference, University Park, PA, June 28, 2006.
16. L. H. Friedman and J. Xu, "Feasibility study of directed self-assembly of semiconductor quantum dots," 2006 NSTI Nanotechnology Conference and Trade Show, Boston, MA, May 9, 2006.
17. L. H. Friedman and J. Xu, "Feasibility study of directed self-assembly of semiconductor quantum dots," (poster), APS (American Physical Society) March Meeting 2006, Baltimore, MD, March 15 2006.
18. L. Fang and L. H. Friedman, "Analytic treatment of metallic multilayer strength at all length scales," APS (American Physical society) March Meeting 2006, Baltimore, MD, March 14, 2006.
19. L. Fang and L. H. Friedman, "Analytic treatment of metallic multilayer strength at all length scales," 2006 TMS Annual Meeting, San Antonio, TX, March 14, 2006 .
20. L. Fang and Lawrence H. Friedman, "Analytic treatment of metallic multilayer strength at all length scales," 2005 MRS Fall Meeting, Boston, MA, Dec. 2, 2005.
21. L. Fang and L. H. Friedman, "Strength of metallic multilayers at all length scales via a dislocation-based model," Annual Meeting of the Minerals, Metals and Materials Society (TMS), San Francisco, CA, February 14, 2005.
22. L. H. Friedman and L. Fang, "Towards a full analytic treatment of the Hall-Petch behavior in multilayers: *putting the pieces together*," Annual Meeting of the Minerals, Metals and Materials Society (TMS), Charlotte, NC, March 15, 2004.
23. Lawrence H. Friedman, "The Hall-Petch Behavior of Multilayer Coatings," Seminar, Dept. of Engineering Science and Mechanics, Penn State University, October 8, 2003. (invited speaker)

24. Lawrence H. Friedman, “Applications of Crystal Microplasticity: Modeling and Theory,” Department of Engineering Science and Mechanics, Penn State University, January 22, 2003. (invited speaker)
25. L. H. Friedman. “Analytic prediction of Hall-Petch exponent in multilayer coatings,” Materials Research Society Fall Meeting, Boston, MA, December 2, 2002.
26. L. H. Friedman, D. Weygand, and E. van der Giessen, “Size effects and scaling in misfit dislocation formation in self-assembled quantum dots,” International Conference on Computational Nanoscience, San Juan, Puerto Rico, 2002.
27. Lawrence H. Friedman, D. M. Weygand, and E. van der Giessen, “Size Effects and Scaling in Misfit Dislocation Formation in Self-Assembled Quantum Dots,” MRS (Materials Research Society) Fall Meeting, Boston, MA, 2002.
28. L. H. Friedman, D. M. Weygand, and E. van der Giessen, “3D simulation of misfit dislocations in epitaxial quantum dots,” Bond voor Materialkennis Materials Research, Veldhoven, The Netherlands, 2001.
29. Lawrence H. Friedman, “Scaling Theory of Hall-Petch Relation for Metallic Multilayers,” Department of Mechanical Engineering, Yale University, March 23, 2001. (invited speaker)
30. Lawrence H. Friedman, D. M. Weygand, and E. van der Giessen, “Three-dimensional simulation of misfit dislocations in islands in strained epitaxial systems.” 37th Annual Technical Meeting of SES (Society of Engineering Science, Columbus, SC, 2000.
31. Lawrence H. Friedman, “Scaling Theory of Hall-Petch Relation for Metallic Multilayers,” Max Planck Institute for Metallurgy (Stuttgart, Germany), July, 13, 2000. (invited speaker)
32. L. H. Friedman and D. C. Chrzan, “Scaling theory of dislocation pileups and the Hall-Petch relation,” Materials Research Society Fall Meeting, Boston, MA, 1998.
33. L. H. Friedman and D. C. Chrzan, “Generalization of the Hall-Petch relation to elastically inhomogeneous materials,” American Physical Society March Meeting, Los Angeles, CA, 1998.
34. L. H. Friedman and D. C. Chrzan, “Influence of Frank-Read sources on the Hall-Petch relation: a continuum analysis.” Materials Research Society Spring Meeting, San Francisco, CA, 1997.
35. Lawrence H. Friedman and D. C. Chrzan, “Influence of Frank-Read sources on the Hall-Petch relation: a continuum analysis,” 1997, American Physical Society March Meeting, Kansas City, MO, 1997.

PROFESSIONAL ASSOCIATIONS AND ACTIVITIES

- The Minerals, Metals and Materials Society (TMS), 2004 – present.

- American Society of Mechanical Engineers (ASME), 2004 – present.
- Society of Engineering Science (SES), 2001 – present.
- American Physics Society, 1998 – present.
- Materials Research Society, 1998 – present.
- Reviewer for *Acta Materialia*, *European Journal of Mechanics*, *Journal of Materials Science*, *Philosophical Magazine*, *Scripta Materialia*, *Thin Solid Films*.
- Proposal Reviewer for National Science Foundation, Air Force Office of Scientific Research.
- Chair-elect / Vice-chair (2007-2009) / Member (2004 – present) of TMS (The Minerals, Metals and Materials Society) Nanomechanical Material Behavior Committee.
- Organizing Committee Member, SES 2006 conference (Society of Engineering Science), University Park, PA, August 2006.
- Symposium organizer, “Pushing Mechanics to the Nanoscale Limit,” at SES 2006 (Society of Engineering Science) meeting, University Park, PA August 2006.
- Organizer, "Tutorial on Nanomechanical Characterization", TMS (The Minerals, Metals and Materials Society) 2008 Annual Meeting.
- Session Chair, “Theory of Self-Assembly” at MRS (Materials Research Society) Fall 2006 Meeting, Boston, MA, 11/30/06; Plenary Lecture of SES (Society of Engineering Science) 2006 Meeting, University, Park, PA, 8/15/06; General Topics Session of SES 2002 (Society of Engineering Science) meeting, University Park, PA (10/15/02 and 10/16/02).

AWARDS

Materials Research Society Graduate Student Silver Medal Award, December, 1998.

RESEARCH GRANTS

1. 1/1/06 – 12/31/08, “Electronanoindentation: fundamental investigations and applications to piezoelectric thin films,” awarded by National Science Foundation, Civil and Mechanical Systems Program (CMS), \$280,000 (candidate’s share = 50%), Candidate is P.I.
2. 7/01/03 – 6/30/05, “Nanostructured Protective Coatings Against Wear,” funded by Air Force Research Laboratory.” subcontracted by Russ Messier (ESM, Penn State) for \$7,500. Total project is \$833,000 (candidate’s share = 0.9%). Candidate was subcontracted researcher.

DOCTORAL STUDENTS IN PROGRESS

Lei Fang
Chandan Kumar

COURSES TAUGHT AT PENN STATE UNIVERSITY

- Nanomechanics (Graduate, created by L. H. Friedman)
http://www.esm.psu.edu/wiki/_media/research:lhf10:syllabus.pdf
- Finite Element Analysis (Graduate)
- Engineering Mechanics: Dynamics (Undergraduate)
- Equilibrium Mechanics (Undergraduate Honors)
- Mechanical Response of Engineering Materials (Undergraduate)

SOFTWARE DEVELOPED FOR RESEACH AND TEACHING

- Stochastic Simulations of Self-Assembled Epitaxial Quantum Dot Growth – Mathematica based simulation of epitaxial quantum dot formation. Features include linear and nonlinear evolution, stochastic initial conditions and stochastic surface diffusion using an adaptive stochastic Euler algorithm.
- Simple Examples of Stochastic Differential Equations – Mathematica based simulations of simple stochastic differential equations.
- Nanomechanics demo suite – Mathematica based calculations and simulations to aid in instruction of Graduate Nanomechanics
- Plane-Stress FEA Program – to aid in instruction of Graduate Finite Element Analysis
- Pileup Engine – Mathematica based simulation for calculating scaling exponent for Hall-Petch Behavior of Multilayers and plotting related elastic fields.
- 3D Dislocation Dynamics - Finite Element Method Simulation – Developed by D. M. Weygand, L. H. Friedman, E. van der Giessen and A. Needleman. Discrete 3D dislocation dynamics simulation coupled to finite element method to impose boundary conditions.
- 3D dislocations Dynamics Simulation – Developed by L. H. Friedman, A.K. Faradjian, P.A. Greaney and D. C. Chrzan.
- 2D Dislocation Pileup Simulator – Determines the yield stress of bilayers and trilayers based on microscopic and elastic parameters by simulating quasistatic formation of dislocation pileups.
- Sliding Wheels – Developed by L. H. Friedman and D. C. Chrzan. Simulates 2D system with local rotations and frictional dissipation as a toy model of microscopic rotations during mechanical deformation.