

David M. Tanenbaum

Assistant Professor
Dept. of Physics & Astronomy
Pomona College
610 N. College Ave.
Claremont, CA 91711

phone:(909) 621-8722
facsimile: (909) 621-8463

email: dtanenbaum@pomona.edu

ACADEMIC DEGREES

1995 *Ph.D., Physics*, University of Colorado, Boulder, Colorado.
1991 *M.S., Physics*, University of Colorado, Boulder, Colorado.
1988 *B.S., Physics*, Harvey Mudd College, Claremont, California.

POSITIONS

2003-present Associate Professor of Physics & Astronomy, Pomona College, Claremont, California.
1997-2003 Assistant Professor of Physics & Astronomy, Pomona College, Claremont, California.
1995-1997 Postdoctoral Fellow, Applied & Engineering Physics, Cornell University, Ithaca, New York.
1990-1993 Graduate Fellowship, National Renewable Energy Laboratory, Golden Colorado.
1988 Research Assistant, Newport Research Corporation, Fountain Valley, California.

HONORS AND AWARDS

Best Optical Micrograph EIPBN (2004) – “Warp speed ahead”
Most Bizarre Micrograph EIPBN (2004) – “Fishing with carbon nanotubes”
Best Photon Micrograph EIPBN (2001) – “Bright Lights – Nano-City”
Cover Image for Cornell Nanofabrication Facility Research Accomplishments 2000-2001

EXTERNAL GRANTS AND DONATIONS RECEIVED

National Science Foundation Major Research Instrumentation award for 2006-2007: \$159,886
Acquisition of EDS Microanalysis and Nanometer Pattern Generation Systems for Electron
Microscopy Facilities at a Primarily Undergraduate Consortium by D. M. Tanenbaum, C. J. Taylor,
and R. R. Gaines.

National Science Foundation NSEC Award to Cornell University Renewal for 2006-2010:
Center for Nanoscale Systems: \$11,600,000.
Subcontract to Pomona College: \$150,000.

Mellon Foundation Semester Research Leave for Spring 2005: \$35,000.

National Science Foundation Research Opportunity Award for 2004-2005:
Cornell University Center for Materials Research Visiting Collaboration: \$57,986.

National Science Foundation NSEC Award to Cornell University for 2001-2006:

Center for Nanoscale Systems: \$11,600,000, (Subcontract to Pomona: \$150,000.)
American Chemical Society – Petroleum Research Fund Type G Grant for 2000-2003:
Fabrication of Metallic Quantized Conductance Devices by Atomic Force Microscopy: \$25,000.

National Science Foundation Research Opportunity Award for 2000-2001:
Lithography and Novel Fabrication Processes for Nanoelectrical Mechanical Systems: \$42,531.

Research Corporation Cottrell College Science Award for 1998-2002:
Scanned probe anodic oxidation processing of ultra-thin metallic films for quantized-conductance device fabrication: \$39,980.

Council on Undergraduate Research: Materials Science Travel Grant 1999: \$500.

Dept. of Energy University - Laboratory Graduate Fellowship (SERI/NREL) for 1990 – 1993: ~\$45,000

Donation from *Schlumberger Automated Test Equipment* 1999 of:
IDS 5000 Probe System (Electron microscope with voltage probe analysis)
Prototype Focused Ion Beam system (Ga ion gun, stage, and vacuum chamber)

Donations from *Cornell University* of:
2002 Scanning Automated Ellipsometer.
1998 Scanning Tunneling Microscope.

PUBLICATIONS (Peer-reviewed)

1. I. W. Frank, D. M. Tanenbaum, A.M. van der Zande, and Paul L. McEuen “Mechanical Properties Of Suspended Graphene Sheets” in *Journal of Vacuum Science and Technology B*, Vol. 25, No. 6, 2558-2561 Nov/Dec. 2007.
2. J. Scott Bunch, Arend M. van der Zande, Scott S. Verbridge, Ian W. Frank, David M. Tanenbaum, Jeevak M. Parpia, Harold G. Craighead, and Paul L. McEuen “Electromechanical Resonators from Graphene Sheets” in *Science*, Vol. 315 (5811), 490-493, Jan 2007.
3. Jed D. Whittaker, Ethan D. Minot, David M. Tanenbaum, Paul L. McEuen, and Robert C. Davis “Measurement of the Adhesion Force between Carbon Nanotubes and a Silicon Dioxide Substrate” in *Nano Letters.*, Vol. 6, No. 5, 953-957 (2006).
4. J. David Musgraves, Brett T. Close, and David M. Tanenbaum, “A Maskless Photolithographic Prototyping System using a Low-cost Consumer Projector and a Microscope” in *American Journal of Physics*, October 2005, Vol. 73(10), 980-984.
5. D.M. Tanenbaum, Y. Chen, and H.G. Craighead “Dual Exposure Glass Layer Suspended Structures (DEGLaSS): A novel fabrication process for glass microfluidic nanostructures on planar substrates” in *Micro Total Analysis Systems 2001*, p.391 (2001).
6. D.M. Tanenbaum, A. Olkhovets, L. Sekaric “Dual Exposure Glass Layer Suspended Structures

- (DEGLaSS): A simplified fabrication process for suspended nanostructures on planar substrates” *Journal of Vacuum Science and Technology B*, 19, 2829 (2001).
7. K. M. Satyalakshmi, A. Olkhovets, M.G. Metzler, C. K. Harnett, D. M. Tanenbaum, and H. G. Craighead, “Charge induced pattern distortion in low energy electron beam lithography” *Journal of Vacuum Science and Technology B*, 18, 3122 (2000).
 8. S. B. Hill, C. A. Haich, F. B. Dunning, G. K. Walters, J. J. McClelland, R. J. Celotta, H. G. Craighead, J. Han, and D. M. Tanenbaum “Patterning of octadecylsiloxane self-assembled monolayers on Si(100) using Ar(³P_{0,2}) atoms” *Journal of Vacuum Science and Technology B*, 17, 1087 (1999).
 9. C.S. Whelan, D.M. Tanenbaum, D.C. La Tulipe, M. Isaacson, and H.G. Craighead “Low energy electron beam top surface image processing using chemically amplified AXT resist” *Journal of Vacuum Science and Technology B*, Vol. 15, no. 6, p. 2555, Nov/Dec 1997.
 10. D.M. Tanenbaum, C.W. Lo, M. Isaacson, H.G. Craighead, M.J. Rooks, K.Y. Lee, W.S. Huang, and T.H.P. Chang "High resolution electron beam lithography using ZEP-520 and KRS resists at low and high voltage" *Journal of Vacuum Science and Technology B*, Vol. 14, no. 6, p. 3829, Nov/Dec 1996.
 11. Y. Sohda, D.M. Tanenbaum, S.W. Turner, and H.G. Craighead "Fabrication of arrayed glassy carbon field emitters" *Journal of Vacuum Science and Technology B.*, Vol. 15, no. 2, p. 343, Mar/Apr 1997.
 12. W.K. Lo, G. Parthasarathy, C.W. Lo, D.M. Tanenbaum, H.G. Craighead, and M.S. Isaacson "Titanium nitride coated tungsten cold field emission sources" *Journal of Vacuum Science and Technology B*, Vol 14, no. 6, p. 3787, Nov/Dec 1996.
 13. D.M. Tanenbaum, A. Laracuate, and A.C. Gallagher "Surface roughening during plasma-enhanced chemical vapor deposition of hydrogenated amorphous silicon on crystal silicon substrates" *Physical Review B.*, Vol. 56, no. 7, p. 4243, August 15, 1997.
 14. D.M. Tanenbaum, A. Laracuate, and A.C. Gallagher "Nanoparticle deposition in hydrogenated amorphous silicon films during rf plasma deposition" *Applied Physics Letters.*, Vol. 68, no. 12, p. 1705, March 18, 1996.
 15. D.M. Tanenbaum, A. Laracuate, and A.C. Gallagher "Growth and nucleation of hydrogenated amorphous silicon on silicon (100) surfaces" in *Amorphous Silicon Technology - 1995. MRS Proc.*
 16. D.M. Tanenbaum, A. Laracuate, and A.C. Gallagher "Nanoscale study of the hydrogenated amorphous silicon surface" in *Amorphous Silicon Technology - 1994. MRS Proc.*
 17. G. C. Stutzin, R. M. Ostrom, Alan Gallagher, and D. M. Tanenbaum "Nanoscale study of the as-grown hydrogenated amorphous silicon surface" *Journal of Applied Physics.*, Vol. 74, no. 1, p. 91, July 1, 1993.

18. R. M. Ostrom, D. M. Tanenbaum, and Alan Gallagher "Construction of silicon nanocolumns with the scanning tunneling microscope" *Applied Physics Letters*, Vol. 61, no. 8, p. 925, August 24, 1992.

PUBLICATIONS (not peer-reviewed)

1. David M. Tanenbaum "Understanding Materials Science (2nd Ed) by Rolf E. Hummel" Book Review for *American Journal of Physics*, Vol. 74(6), 559 June 2006.

PROFESSIONAL PRESENTATIONS

Nanomechanical Measurements on Graphene Sheets, a poster presentation at the *Gordon Research Conference on Nanostructure Fabrication*, July 16, 2008, in Tilton, NH. This included the work of Pomona College students Ian Frank and Scott Berkley along with Cornell U. collaborators.

Nanoscale Mechanical Resonators, Physics Colloquium at Whittier College, April 18, 2008.

Mechanical Properties Of Suspended Graphene Sheets, was presented **by my student Ian Frank** as a talk at the *51st International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Denver, CO, USA, 29 May 2007.

Electrostatic Driving of Graphite Resonators, was presented **by my colleague Arend van der Zande** at the annual *March (2007) meeting of the American Physical Society* Denver, CO, USA.

Electromechanical Resonators from Atomically Thin Graphite was presented **by my colleague Scott Bunch** at the annual *March (2007) meeting of the American Physical Society* Denver, CO, USA.

"Nanoscale Mechanical Resonators" Physics Colloquium at California State University Los Angeles, October 5, 2006.

"Interactions Between Topographic Features and Carbon Nanostructures" a poster presentation at the *Gordon Research Conference on Nanostructure Fabrication*, Tilton, NH, USA, 18 July 2006. (This poster was also presented at the, Cornell Center for Nanoscale Systems annual meeting held in summer 2006.)

"Dual Exposure Glass Layer Suspended Structures." Brigham Young University (BYU) Condensed Matter Seminar March 16, 2006.

"Energy: Resources, Demands, Environmental Consequences and Goals." Physics Colloquium at Brigham Young University (BYU) March 15, 2006.

"Measurement of the mechanical adhesion between a single-walled carbon nanotube and a silicon dioxide substrate" a talk at the *51st AVS Symposium*, Anaheim, CA, USA, 17 November 2004.

“Interactions Between Topographic Features and Carbon Nanotubes” a poster presentation at the *Gordon Research Conference on Nanostructure Fabrication*, Tilton, NH, USA, 20 July 2004. (This poster was also presented at the, Cornell Nanofabrication Facility annual meeting held on October 5, 2004.)

“A maskless photolithographic prototyping system based on a low cost consumer projector and microscope” a poster presentation at the *48th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, San Diego, CA, USA, 2 June 2004.

“Fabrication of glass nanostructures: nano-mechanical systems and microfluidics” Physics Colloquium at University of California, Riverside, 8 May 2002.

“Fabrication of glass nanostructures: nano-mechanical systems and microfluidics” Physics Colloquium at California State University, Los Angeles, 24 January 2002.

“Fabrication of glass nanostructures: nano-mechanical systems and microfluidics” Physics Colloquium at Pomona College, 16 October 2001.

“Advances in three dimensional fabrication of glass nanostructures using electron beam lithography” a poster presentation at the *Gordon Research Conference on Nanostructure Fabrication*, Tilton, NH, USA, 4-9 August 2002.

Publication 5 was presented as a poster at the *μ Total Analysis Systems 2001 Symposium*, Monterey, CA, USA, 21-25 October 2001.

“Small liberal arts college academia” for Cornell Center for Materials Research. 18 June 2001

Publication 7 was presented as a talk at the *45th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Washington, D.C., USA, 29 May 2001.

“Teaching *Six Ideas* in a user-friendly classroom using iBooks” invited speaker at *American Association of Physics Teachers Summer Meeting*, Guelph, Canada, August 2000.

Publication 8 was presented as a poster at the *44th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Palm Springs, CA, USA May 2000.

Publication 10 was presented as a talk at the *41th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Dana Point, CA, USA May 1997.

Publication 11 was presented as a talk at the *40th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Atlanta, GA, USA May 1996.

Publication 13 was presented as a talk at the *40th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication*, Atlanta, GA, USA May 1996.

Publication 16 was presented as a talk at the *Materials Research Society Symposium*, San Francisco, CA, USA May 1995.

Publication 17 was presented as a talk at the *Materials Research Society Symposium*, San Francisco, CA, USA May 1994.

RESEARCH INTERESTS

Pomona College, Dept. of Physics and Astronomy

Sept 97 - present

In this research program I am working on the evolution of novel lithographic, growth, and characterization processes for use with thin films for microelectronics and photovoltaic technologies. As part of this program I have established a lab with facilities for wet chemistry, thermal evaporation of thin films, large sample atomic force microscopy, electron microscopy, optical microscopy, and growth and ultra violet ozone removal of self assembled monolayers. I have acquired equipment for both scanning tunneling microscopy and focused ion beam lithography as well, but these facilities are not currently in use. In addition I am working with students on microgravity research projects. I continue to collaborate with researchers at Cornell University, NIST, Rice University, IBM, Sumitomo, and ETEC on various research projects related to high resolution lithographic processing. During the 00-01 academic year I was on sabbatical leave at Cornell University where I developed a new simplified process (DEGLaSS) for fabrication of nanomechanical sensors and fluidic systems. The Cornell Research Foundation has a pending patent based on this work. In 2001 I began a new collaboration with Cornell and BYU to develop nanoscale electronics based on carbon nanotubes. This work focuses non interactions between nanotubes and surfaces, as well as fabrication of suspended nanotubes and graphene sheets.

Cornell University Dept. of Applied & Engineering Physics

May 95 - July 97

In this research program our group was working on the evolution of electron beam microcolumns for use in high resolution low energy electron beam nanolithography systems in collaboration with IBM Research. My work included demonstrations of high resolution patterning limits with low energy (1-2 keV) electron beams using a variety of ultra sensitive resist systems (in both positive and negative tone) as well as Monte-Carlo simulations. I also examined pattern transfer processes using ultra-thin imaging layers in multi-layer and top surface imaging resist processes. These involved research with conventional reactive ion etching (RIE) and high density plasma RIE systems as well as the creation of a system to study siliation of resists. My evaluation of metallization schemes compatible with low energy electron beam nanolithography has included work with selective oxidation and electroless plating techniques. A separate area of emphasis was on field emission electron sources to be used in future generations of microcolumns. This involved construction of a test system for stability and angular current density measurements of cold field emission sources as well as the development and evaluation of novel cold field emitters. My research on fabrication of self-aligned microlens elements for microcolumns used a focused ion beam (FIB) lithography system to ion mill apertures in stacked silicon membranes. I was responsible for all maintenance and management of the FIB system.

University of Colorado Joint Institute for Laboratory Astrophysics

May 89 - May 95

A large portion of my time as a graduate student centered on the design and construction of a new surface science laboratory to study nanostructures using an ultra-high vacuum (UHV) system including several scanning tunneling microscopes (STM), a low energy electron diffraction (LEED) and auger spectroscopy (AES) apparatus, ion sputtering gun, and

evaporation sources. I also helped design and build a custom plasma enhanced chemical vapor deposition (PECVD) system for silicon film growth. In addition I was responsible for maintenance of the scanning electron microscope (SEM) for general use. I used the STM to study the growth structure of hydrogenated amorphous silicon (my thesis topic), and to create and analyze nanoscale structures of silicon and metals on crystals and thin films. I worked on STM spectroscopy of semiconductor surfaces to develop a cross sectional study of band structure in solar cells. Additional studies involved photoluminescence, field emission, field ion desorption, chemical vapor deposition, and surface passivations. I participated in an atomic physics research group using laser spectroscopy to probe atomic collision processes and interactions in vapors.

National Renewable Energy Laboratory

August 90- August 93

I worked in the Amorphous Silicon group in the Basic Sciences branch through the Department of Energy Graduate Fellowship program. I focused on examining the surface structure and growth of hydrogenated amorphous silicon films used for photovoltaics. Studies emphasized the relationship of physical structure and electronic properties and their correlation to film growth parameters. This related to understanding the degradation of the electronic properties of the material upon long term exposure to light. I also worked with models of gas phase and surface reactions in growth of the material.

Newport Research Corporation

June - August 88

Research focused on structural rigidity of optical tables. I designed a portable measurement system incorporating Fourier analysis of compliance for optical tables in the field.

Harvey Mudd College

May 87 - May 88

My undergraduate thesis research was on thermally generated capillary wave motion at the water-air interface using inelastically scattered laser light and photon correlation spectroscopy.

TEACHING INTERESTS

- Pomona College, Dept. of Physics and Astronomy* Sept 97 - present
 Assistant Professor. Courses taught include:
 Quantum Mechanics, Solid State Physics, General Physics, General Physics Laboratory,
 Modern Physics Laboratory, Physics in Society (Energy Policy), Materials Science (with
 laboratory), Advanced Physics Laboratory, Senior Seminar, Nanotechnology in Science and
 Fiction (ID1), Independent Studies, and Senior Thesis Research.
- Cornell University* August 96 - December 96
 Instructor. Physics of Micro/Nano-fabrication: This is a graduate level course describing the
 physical processes used predominantly but not exclusively for semiconductor device
 fabrication..
- University of Colorado* August 88 - May 89
 Teaching Assistant for Undergraduate Physics (for biology, kinesiology, & pre-med students)
 Teaching Assistant for Freshman Physics (for engineers and physical science students)
 I was responsible for both recitation and laboratory sections.
- Harvey Mudd College*
 Physics Department Freshman Tutor August 87 - May 88
 Teaching Assistant for Sophomore Laboratory August - December 86
- Claremont Adult School and Claremont Unified School District* January 83 - June 84
 Instructor's Aide for Adult Education in Computer Science
 Instructor's Aide in programs to train public school teachers in computer applications.

PROFESSIONAL MEMBERSHIPS

American Physical Society (APS)
 American Vacuum Society (AVS)
 Materials Research Society (MRS)
 International Society for Optical Engineering (SPIE)
 Council on Undergraduate Research (CUR)
 Project Kaleidoscope Faculty for the 21st Century (PKAL F21)
 American Association of Physics Teachers (AAPT)

PROFESSIONAL SERVICE

AAPT History and Philosophy Committee Member 2001-2003
 NSF Panel Reviewer 2001,2003
 Reviewer for the American Chemical Society – PRF grants
 Reviewer for *Langmuir*
 Reviewer for *American Journal of Physics*
 Reviewer for Journal of Vacuum Science and Technology B

ACADEMIC SERVICE*Pomona College*

Elected Member of the Faculty Personnel Committee	2005-2008
Elected Member Faculty Grievance Committee	1999-2003
Member of Sustainable Energy Committee	2001-2004
Member of Environmental Analysis (EA) Program	1999-
Physics Liaison to Public Policy Analysis (PPA) program	1997-
Physics Liaison to Science Technology and Society (STS) program	1997-
Advisor for Junior/Senior Physics Majors & other students	1998-
Faculty Leader for Orientation Adventure Program	1998
Member Academic Standards and Academic Disciplinary Board	1998-99, 2003-4
Faculty Mentor/Advisor for Club Physics	1997-

University of Colorado Physics Department

President of Physics Graduate Students	1991-92
Member of Graduate Admissions Committee	1990-91
New Graduate Student Orientation Committee	1989-92
Graduate Peer Advisor	1989-92
Organizer of Department Coffee Hour and Picnics	1989-90
Graduate Representative for Faculty Meetings	1988-89

Harvey Mudd College

Co-President of Physics Students	1987-88
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OUTREACH ACTIVITIES

GEMS Gateway to Exploring Mathematical Sciences Workshop designed to reach seventh, eighth and ninth grade students who may have an interest in mathematics or science. *The Ultimate Speed Trap, Measuring the Speed of Light* at Harvey Mudd College, December 13, 2008.

I hosted the March 29, 2008 Southern California American Association of Physics Teachers (SCAAPT) Meeting here on the Pomona College campus, lining up invited speakers, making arrangements for rooms, facilities, and food. We had well over 50 area physics teachers in attendance.

I gave a presentation the CIPT Physics lending library at the March SCAAPT meeting held at Pomona College, March 29, 2008.

Workshop and Lecture *Light Speed Ahead* for Los Angeles Area high school science teachers held at Pomona College, 23 Feb 2008.

Workshop and Lecture *Cool and Groovy Physics* for Los Angeles Area high school science teachers held at Pomona College, 24 Feb 2007.

Workshop and Lecture *Photonics* for Los Angeles Area high school science teachers held at Pomona College, 11 Feb 2006.

Workshop for Los Angeles Area high school science teachers held at Whittier Union School District, 25 Feb 2005.

Workshop and Lecture *Electronics in Circuits and Consumer Products* for Los Angeles Area high school science teachers held at Pomona College, 26 Feb 2005.

Workshop *Seeing the Light: Energy, Photons, & LEDs* for Los Angeles Area high school science teachers held at Whittier Union School District, 25 Feb 2005.

Program *Optical Microscopy and Beyond* for elementary school students held at Sycamore Elementary School and Pomona College, 25-27 May 2004.

Workshop and Lecture *Seeing the Light: Energy, Photons, & Astronomy* for Los Angeles Area high school science teachers held at Pomona College, 15 Feb 2004.

Workshop and Lecture *Observing the Tiniest Building Blocks of Matter* for Los Angeles Area high school science teachers held at Pomona College, 15 Feb 2003.

Lecture “Nanotechnology in Science and Fiction” for Johns Hopkins CTY program, Feb. 2003.

Lecture “Nanotechnology: Small stuff hits the big time” for Claremont University Club, 19 Feb. 2002.

Workshop on Friction at the Ithaca Science Center, 16 June 2001.

PERSONAL

Married to Judith G. Tanenbaum (1993-) and father of Robin R. (1998-) and Arlo A. (2003-)
Whitewater rafting guide, also enjoy skiing, hiking, mountain biking, camping, and folk music.
Commute by foot or bicycle daily.