Lin Zhao

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Education

2014-2019 **Massachusetts Institute of Technology (MIT), Cambridge, MA**
Ph.D. in Mechanical Engineering
Thesis: Radiative Transport in Transparent Aerogels for Solar Energy Harvesting
Research interest: radiative transport, heat and mass transfer, optics and photonics, porous material

2012-2014 **University of Pennsylvania (UPenn), Philadelphia, PA**
M.S. in Nanotechnology
Thesis: Ultralight Shape-Recovering Plate Mechanical Metamaterials

2008-2012 **Tsinghua University, Beijing, China**
B.S. in Physics and Mathematics
Thesis: Photoanode Design for Quantum Dot Sensitized Solar Cells

Awards & Honors

2019 MIT Wunsch Foundation Silent Hoist and Crane Awards — Outstanding Graduate Research
2017-2019 MIT Tata Center Graduate Student Fellowship
2016 MIT Audience Award, Mechanical Engineering Research Exhibition
2014 Chee C. Tung (1966) Fellowship, MIT
2014 Pappalardo Fellowship, MIT
2014 John Henry Towne Fellow, UPenn
2008 Freshman Scholarship, Tsinghua (ranked 7 out of 118,000 in college entrance exam)

Work & Research

2019-present **Thin Film Optics Design Engineer, Transportation and Electronics Business Group Lab, 3M**
Birefringent Multilayer Polymeric Films for Light Control and Display Applications

- Developed an efficient optimization algorithm based on transfer matrix formalism to enable autonomous design of multilayer optical films for a spectral target
- Designed and optimized new multilayer optical films for display, light control, and radiative cooling applications and contributed to intellectual properties such as patents and trade secrets
- Built a comprehensive heat transfer model to assess the energy and cost-saving potential of using multilayer radiative cooling films on vehicles in the U.S.

2014-2019 **Research Assistant, Tata Fellow in Device Research Laboratory, MIT**
Advisor: Prof. Evelyn N. Wang
Ultra-Transparent Silica Aerogels for Solar Thermal Energy Applications

- Enabled new pathways to utilize solar energy by developing ultra-transparent low-thermal-conductivity silica aerogels and achieving a record-high stagnation temperature (265 °C) under natural sunlight
- Designed and fabricated a low-cost aerogel-based solar autoclave for off-grid clinics and initiated international collaborations to promote solar-powered autoclaves in India

- Developed aerogel solar thermal devices for high-efficiency multistage water desalination and atmospheric water harvesting
- Co-led the design, construction, and testing of a pilot-scale linear Fresnel Concentrating Solar Power (CSP) system with a high temperature (400 °C) heat transfer fluid loop for aerogel receiver testing

Radiation Transfer in Random Media

- Established a comprehensive radiative transfer model to predict the optical performance and guide the improvement of ultra-transparent aerogels based on their absorption and scattering properties
- Theoretically discovered and experimentally demonstrated a new mechanism to reduce haze in a random scattering medium using plasmonic nanoparticles

Natural Convection Suppression in High-Flux Evaporators

- Investigated Stefan flow induced natural convection suppression by analytical and numerical (CFD) models to reveal the underlying mechanism and guide design optimization for high-flux evaporators

2013-2014 **Graduate Student Fellow at Wolf Nanofabrication Facility, UPenn**
Advisor: Dr. Hiromichi Yamamoto

- Optimized lithography process by image analysis and created standard operating procedures (SOP) for lithography tools at the facility to help users consistently achieve the minimum feature size

2012-2014 **Research Assistant in Bargatin Group, UPenn**
Advisor: Prof. Igor Bargatin

- Applied finite element analysis and microfabrication techniques to design, optimize, and fabricate the thinnest man-made shape-recovering plate metamaterial. The developed material is the winner of the 2017 Y-Prize and the President's Innovation Prize at UPenn

2011-2012 **Research Assistant in Prof. Hong Lin's Laboratory, Tsinghua University**
Advisor: Prof. Hong Lin

- Synthesized and optimized porous TiO_2 photoanodes to enhance solar cell efficiency by 20%

2010-2011 **Research Intern at Advanced Development & Research, Elekta BMEI Medical Equipment**
Advisor: Dr. John Allen

- Calculated and verified the RF waveguide resonant frequency of a linear particle accelerator to help guide and validate design improvements for next-generation products

Publications

1. **L. Zhao**, B. Bhatia, L. Zhang, E. Strobach, L. Zhang, A. Leroy, M. K. Yadav, S. Yang, T. A. Cooper, L. A. Weinstein, A. Modi, S. B. Kedare, and E. N. Wang, "A passive high-temperature high-pressure solar steam generator for medical sterilization," *Joule* 4, 2733–2745
2. Z. Xu[1], L. Zhang[1], **L. Zhao**[1], B. Li[1], B. Bhatia, C. Wang, K. L. Wilke, Y. Song, O. Labban, J. Gao, T. Li, J. H. Lienhard, R. Wang, and E. N. Wang, "Ultrahigh-efficiency desalination via thermally-localized multistage solar still," *Energy Environ. Sci.,* 13, 830–839, 2020
3. **L. Zhao**, M. Blackman, L. Zhang, B. Bhatia, A. Leroy, E. Strobach, E.N. Wang, "Plasmonic absorption-induced haze suppression in random scattering media," *Appl. Phys. Lett.*, 114(25), 251102, 2019
4. **L. Zhao**, B. Bhatia, S. Yang, E. Strobach, L.A. Weinstein, T.A. Cooper, G. Chen, E.N. Wang, "Harnessing Heat Beyond 200 °C from Unconcentrated Sunlight with Nonevacuated Transparent Aerogels," *ACS Nano*, 13(7), 7508-7516, 2019

[1]equal contribution

5. **L. Zhao,** E. Strobach, B. Bhatia, S. Yang, A. Leroy, L. Zhang, and E. N. Wang, "Theoretical and experimental investigation of haze in transparent aerogels," *Opt. Express* 27(4), A39–A50, 2019
6. **L. Zhao**, S. Yang, B. Bhatia, E. Strobach, E. N. Wang, "Modeling silica aerogel optical performance by determining its radiative properties," *AIP Adv.* 6(2), 025123, 2016
7. L. Zhang[1], **L. Zhao**[1], and E. N. Wang, "Stefan flow induced natural convection suppression on high-flux evaporator," *Int.* Commun*. Heat. Mass.*, 104255, 2020
8. L. Zhang, R. Iwata, **L. Zhao**, S. Gong, Z. Lu, Y. Zhong, J. Zhu, S. Cruz, K. L. Wilke, P. Cheng, and E. N. Wang "Distribution of nucleation sites: a general theoretical framework with validation in droplet condensation," *Cell Reports Physical Science,* 2020 (in press)
9. A. LaPotin, Y. Zhong, L. Zhang, **L. Zhao**, A. Leroy, H. Kim, S. R. Rao, and E. N. Wang, "Dual-stage atmospheric water harvesting device for scalable solar-driven water production," *Joule,* 2020 (in press)
10. L. Zhang, Z. Xu, B. Bhatia, B. Li, **L. Zhao**, E. N. Wang, "Modeling and performance analysis of high-efficiency thermally-localized multistage solar stills," *Appl. Energy* 266, 114864, 2020
11. **L. Zhao**[1], L. Zhang[1], B. Bhatia, E.N. Wang, "Understanding anti-parity-time symmetric systems with a conventional heat transfer framework -- comment on "Anti-parity-time symmetry in diffusive systems"," *arXiv preprint*, 1906.08431, 2019
12. A. Leroy, B. Bhatia, C. C. Kelsall, A. Castillejo-Cuberos, M. Di Capua Hidalgo, **L. Zhao**, L. Zhang, A. Guzman Cuevas, and E. N. Wang, "High-performance sub-ambient radiative cooling enabled by optically selective and thermally insulating polyethylene aerogel," *Sci. Adv.* **5**, eaat9480, 2019
13. E. Strobach, B. Bhatia, S. Yang, **L. Zhao**, and E. N. Wang*,* "High Temperature Stability of Transparent Silica Aerogels for Solar Thermal Applications," *APL Mater.* 7(8), 081104, 2019
14. E. Strobach, B. Bhatia, **L. Zhao**, and E. N. Wang, "Thermal Performance of High-Efficiency Window Technologies," *Annual Review of Heat Transfer*, 2019
15. L. Zhang, Z. Lu, Y. Song, **L. Zhao**, B. Bhatia, K.R. Bagnall, E.N. Wang, "Thermal Expansion Coefficient of Monolayer Molybdenum Disulfide Using Micro-Raman Spectroscopy," *Nano Lett.* 19 4745–4751, 2019
16. L. Zhang, J. Zhu, K. Wilke, Z. Xu, **L. Zhao**, L. L. Goddard, and E. N. Wang, "Enhanced environmental scanning electron microscopy for condensing droplets analysis," *ACS Nano.* 13(2), 1953-1960, 2019
17. A. Leroy, B. Bhatia, **L. Zhao**, and E. N. Wang, "Specular side reflectors for high efficiency thermal-to-optical energy conversion," *Opt. Express* 26(10), A462–A479, 2018
18. B. Bhatia, A. Leroy, Y. Shen, **L. Zhao**, M. Gianello, D. Li, T. Gu, J. H, M. Soljačić, and E. N. Wang, "Passive directional sub-ambient daytime radiative cooling," *Nat. Commun.* 9(1), 5001, 2018
19. L. Zhang, Y. Zhu, Z. Lu, **L. Zhao**, S. R. Rao, and E. N. Wang, "Characterization of thin film evaporation in micropillar wicks using micro-Raman spectroscopy," *Appl. Phys. Lett.* 113(16), 163701, 2018
20. L. A. Weinstein, K. McEnaney, E. Strobach, S. Yang, B. Bhatia, **L. Zhao**, Y. Huang, J. Loomis, F. Cao, S. V. Boriskina, Z. Ren, E. N. Wang, and G. Chen, "A Hybrid Electric and Thermal Solar Receiver," *Joule* 2(5), 962-975, 2018
21. H. Kim, S. R. Rao, E. A. Kapustin, **L. Zhao**, S. Yang, O. M. Yaghi, and E. N. Wang, "Adsorption-based atmospheric water harvesting device for arid climates," *Nat. Commun.* 9(1), 1191, 2018
22. E. Strobach, B. Bhatia, S. Yang, **L. Zhao**, and E. N. Wang, "High Temperature Annealing for Structural Optimization of Silica Aerogels in Solar Thermal Applications," *J. Non. Cryst. Solids* 462, 72–77, 2017
23. K. Davami, **L. Zhao**, E. Lu, J. Cortes, C. Lin, D.E. Lilley, P.K. Purohit, and I. Bargatin, "Ultralight shape-recovering plate mechanical metamaterials," *Nat. Commun.* 6, 10019, 2015
24. Y. Oda, H. Shen, **L. Zhao**, J. Li, M. Iwamoto, and H. Lin, "Energetic alignment in nontoxic SnS quantum dot-sensitized solar cell employing spiro-OMeTAD as the solid-state electrolyte," *Sci. Technol. Adv. Mater.* 15(3), 035006, 2014

[1]equal contribution

25. H. Shen, J. Li, **L. Zhao**, S. Zhang, W. Wang, D. Oron, and H. Lin, "Synergistic recombination suppression by an inorganic layer and organic dye molecules in highly photostable quantum dot sensitized solar cells," *Phys. Chem. Chem. Phys.* 16(3), 6250-6256, 2014

26. K. Abe, H. Shen, X. Li, **L. Zhao**, X. Zhao, J. Li, M. Iwamoto, and H. Lin, "Optical and electrical properties of uniform non-toxic Cu_2ZnSnS_4 nanocrystal and its application in solar cells," Polyhedron 82, 148-153, 2014

27. H. Shen, H. Lin, **L. Zhao**, Y. Liu, and D. Oron, "Large Pore Size and High Porosity of TiO_2 Photoanode for Excellent Photovoltaic Performance of CdS Quantum Dot Sensitized Solar Cell," *J. Nanosci. Nanotechnol.* 13(2), 1095-1100, 2013

Manuscripts in preparation and under review:

28. **L. Zhao**, B. Bhatia, E. Strobach, L. Zhang, A. Leroy, S. Yang, and E. N. Wang, "Transparent silica aerogel for solar thermal energy conversion: a review," in preparation for *Materials Today*

29. **L. Zhao,** L. Zhang, B. Bhatia, E. Strobach, S. Yang, and E. N. Wang, "Selective opacified silica aerogel by ITO nanoparticles," in preparation

Conference Proceedings

1. B. Bhatia, A. Leroy, Y. Shen, **L. Zhao**, M Soljačić, and E.N. Wang, "*Passive sub-ambient daytime radiative cooling*," Optical Devices and Materials for Solar Energy and Solid-state Lighting, PM2C. 2, 2019

2. **L. Zhao**, B. Bhatia, T. Cooper, E. Strobach, S. Yang, L.A. Weinstein, G. Chen, and E.N. Wang, "*Intermediate Temperature Solar Thermal Collector Enabled by Non-Evacuated Transparent Aerogel and Non-Tracking Compound Parabolic Concentrator,*" Proceedings of the 16th International Heat Transfer Conference, IHTC16-22236, 2018

3. L. Zhang, Y. Zhu, S.R. Rao, K.R. Bagnall, D.S. Antao, A. Leroy, **L. Zhao**, B. Bhatia, C.C. Kelsall, and E.N. Wang, "*In Situ Temperature Measurement of Evaporation in Micropillar Wick Structures using Micro-Raman Spectroscopy,*" Proceedings of the 16th International Heat Transfer Conference, IHTC16-23152, 2018

4. K. Davami, **L. Zhao**, I. Bargatin, "*ALD honeycomb plates enabling robust ultrathin*," IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS), 2014

Conference Presentations

1. **L. Zhao**, B. Bhatia, L. Zhang, E. Strobach, S. Yang, T. A. Cooper, L. A. Weinstein, G. Chen, and E. N. Wang "Ultra-transparent silica aerogel for solar thermal energy systems," 2nd Solar Energy Systems Conference, Aug. 2020

2. **L. Zhao**, E. Strobach, B. Bhatia, S. Yang, A. Leroy, L. Zhang, and E. N. Wang, "*Theoretical and experimental investigation of haze in transparent aerogels*," MRS Fall Meeting, Boston, MA, Nov. 29, 2018

3. B. Bhatia, S. Yang, **L. Zhao**, E. Strobach, L.A. Weinstein, T. Cooper, G. Chen, and E.N. Wang, "*Solar-Transparent Thermally Insulating Silica Aerogels for Concentrating Solar Power,*" MRS Fall Meeting, Boston, MA, Nov. 29, 2018

4. B. Bhatia, A. Leroy, Y. Shen, **L. Zhao**, M. Gianello, D. Li, T. Gu, J. Hu, M. Soljačić, and E.N. Wang, "*Passive Directional Sub-Ambient Daytime Radiative Cooling,*" ASME International Mechanical Engineering Congress & Exposition (IMECE), Pittsburgh, PA, Nov. 9-15, 2018

5. **L. Zhao,** B. Bhatia, T. Cooper, E. Strobach, S. Yang, L. A. Weinstein, G. Chen, and E. N. Wang, "*Intermediate Temperature Solar thermal collector enabled by non-evacuated transparent aerogel and non-tracing compound parabolic concentrator,*" 16th International Heat Transfer Conference, Beijing, China, Aug. 10-15, 2018

6. B. Bhatia, A. Leroy, Y. Shen, **L. Zhao**, M. Gianello, D. Li, T. Gu, J. Hu, M. Soljačić, and E.N. Wang, "*Passive Directional Sub-Ambient Daytime Radiative Cooling,*" ASME Power & Energy International Conference, Lake Buena Vista, FL, June 24-28, 2018

7. B. Bhatia, A. Leroy, Y. Shen, **L. Zhao**, M. Gianello, M. Soljačić, and E.N. Wang "*Passive directional daytime radiative cooling,*" MRS Fall Meeting, Boston, MA, Nov. 26-Dec.1, 2017

8. **L. Zhao**, S. Yang, B. Bhatia, E. Strobach, L. A. Weinstein, T. A. Cooper, S. V. Boriskina, G. Chen, and E. N. Wang, "*Harvesting Unconcentrated Sunlight at Intermediate-Temperature for Industrial Process Heat,"* ASME 2017 Heat Transfer Conference, Bellevue, WA, July 9-12, 2017

9. B. Bhatia, S. Yang, **L. Zhao**, E. Strobach, X. Huang, L. A. Weinstein, T. Cooper, S. V. Boriskina, G. Chen, and E. N. Wang, *"Thermal Characterization of Transparent Silica Aerogels for Concentrated Solar Power,"* ASME 2017 Heat Transfer Conference, Bellevue, WA, July 9-12, 2017

10. T. Cooper, L. A. Weinstein, S. Yang, B. Bhatia, **L. Zhao**, E. Strobach, S. V. Boriskina, E. N. Wang, and G. Chen, *"Demonstration of a high-performance vacuum-free solar thermal collector enabled by optically-transparent thermally-insulating silica aerogel,"* ASME 2017 Heat Transfer Conference, Bellevue, WA, July 9-12, 2017

11. **L. Zhao**, S. Yang, B. Bhatia, E. Strobach, L.Weinstein, T. Cooper, S. V. Boriskina, G. Chen, E. N. Wang, *"Transparent Aerogels for Efficient Solar-Thermal Energy Conversion"*, ARPA-E Energy Innovation Summit, Washington D.C., February 27 – March 1, 2017

12. **L. Zhao**, S. Yang, B. Bhatia, E. Strobach, L.Weinstein, T. Cooper, S. V. Boriskina, G. Chen, E. N. Wang, "*Lab-Scale Investigation of Silica Aerogel Based Solar Thermal Receiver*" MRS Fall Meeting, Boston, MA, Nov. 27-Dec. 2, 2016.

13. L. Weinstein, S. Yang, **L. Zhao**, B. Bhatia, E. Strobach, D. Bierman, T. Cooper, L. Meroueh, S.B. Boriskina, E.N. Wang and G. Chen, "A Solar-Thermal Aerogel Receiver (STAR) for Cost-Effective Electricity Generation" MRS-EE3.1.08, MRS Spring Meeting, March 28 – April 1, 2016, Phoenix, AZ

14. S. Yang, **L. Zhao**, B. Bhatia, E. Strobach, L.Weinstein, T. Cooper, S. V. Boriskina, G. Chen, E. N. Wang, *"Transparent Aerogels for Efficient Solar-Thermal Energy Conversion"* MRS Spring Meeting, Phoenix, AZ, March 28-April 1, 2016.

15. **L. Zhao**, S. Yang, B. Bhatia, E. Strobach, L.Weinstein, T. Cooper, S. V. Boriskina, G. Chen, E. N. Wang, *"Efficient blackbody solar absorber enabled by OTTI aerogel",* MERE 2016, MIT, Boston, MA, Sept. 16, 2016.

16. L. Weinstein, J. Loomis, X. Huang, S. Yang, **L. Zhao**, Y. Huang, F. Cao, T. Sun, B. Bhatia, D. Bierman, E. Strobach, W.C. Hsu, G. Ni, L. Tang, S. Boriskina, Z. Ren, E. Wang, and G. Chen, "*Hybrid PV and Thermal Solar Receiver Using Silica Aerogel and Thin-Film Multi-Layer Spectral Splitting*" MRS Fall Meeting, November 29 – December 4, 2015, Boston, MA

17. E. Strobach, S. Yang, **L. Zhao**, B. Bhatia, L.Weinstein, T. Cooper, S. V. Boriskina, G. Chen, E. N. Wang, *"Solar Thermal Aerogel Receiver (STAR)",* MIT Energy Night, Cambridge, MA, October 16, 2015.

18. K. Davami, **L. Zhao**, I. Bargatin, "*ALD Honeycomb Plates Enabling Robust Ultrathin MEMS"*, 27th IEEE Conference on Micro Electro Mechanical Systems MEMS 2014, San Francisco CA

Patents

1. Gang Chen, Evelyn N. Wang, Svetlana V. Boriskina, Lee A. Weinstein, Sungwoo Yang, Bikram Bhatia**, Lin Zhao**, Elise M. Strobach, Thomas A. Cooper, David M. Bierman, Xiaopeng Huang, James Loomis, "Solar thermal aerogel receiver and materials therefor," US20190100439A1

2. Evelyn N. Wang, Gang Chen, Xuanhe Zhao, Elise M. Strobach, Bikramjit S. Bhatia, **Lin Zhao**, Sungwoo Yang, Lee A. Weinstein, Thomas A. Cooper, Shaoting Lin, Energy efficient soundproofing window retrofits, Application number: 16/394,447, 2019

Teaching and Mentoring Experience

Malik Blackman, undergraduate researcher, MIT Summer Research Program, University of Illinois at Chicago, 2018

Arny Leroy, Ph.D. student, MIT, 2017-2019

Alina Dale LaPotin, Ph.D. student, MIT, 2018-2019

Manoj Yadav, Ph.D. student, Indian Institute of Technology Bombay, 2018-2020

Eric Lu, undergraduate researcher, UPenn, 2013-2014

Teaching Assistant for MEAM 503 Direct Energy Conversion: from Macro to Nano, UPenn, Fall 2013

Academic Services

Peer-Review Referees for Nature, Nature Materials, Nature Energy, Nature Communications, Microsystems & Nanoengineering, Joule, Proceeding of National Academy of Science, Advanced Materials, Nanoscale Advances, Optics Express, Applied Optics, Journal of Non-Crystalline Solids, Journal of Heat Transfer, Nanoscale and Microscale Thermophysical Engineering, International Journal of Thermal Sciences

Grant Writing for the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD), MIT Tata Center, Semiconductor Research Corporation (SRC), MIT Bose Grant, 3M Genesis Grant, and 3M Non-Tenured Faculty Award

Guest Editor of Frontiers in Energy Research

Selected Media Coverage

Solar-powered medical sterilization

"System can sterilize medical tools using solar heat," *MIT News* link

"Technology for sterilizing medical instruments goes solar," *Nature* link

"How to sterilise scalpels when no electricity is available," *The Economist* link

"Portable device uses solar power to sterilize medical equipment," *New Scientist* link

"Solar-powered device sterilizes medical equipment", *Physics World* link

Multistage solar-powered water desalination

"Top MIT research stories of 2020," *MIT News* link

"Simple, solar-powered water desalination," *MIT News* link

"Desalination by sunlight," *MIT Technology Review* link

"Superefficient solar desalination," *C&EN* link

"Solar-powered desalination systems could bring water to disaster zones," *New Atlas* link

Harnessing heat from unconcentrated sunlight using transparent aerogels

"Making a remarkable material even better - Transparent aerogels for solar devices, windows", *MITEI* link

"Getting more heat out of sunlight", *MIT News* link

"Getting more heat out of sunlight", *phys.org* link

"Ultra-clear aerogel designed for better, less costly solar collectors", *News Atlas* link

Passive radiative cooling

"A new way to provide cooling without power", *MIT News* link

"Device could provide refrigeration for off-grid locations", *Long Room* link

"System provides cooling with no electricity," *MIT News* link

Ultralight shape-recovering metamaterials

"Penn Researchers Make Thinnest Plates That Can Be Picked Up by Hand", *Penn press release* link

"A Nanoscale Object You Can Pick Up", *ASME Mechanical Engineering magazine* link

"Researchers make thinnest plates that can be picked up by hand", *Phys.org* link

"Researchers make thinnest plates that can be picked up by hand", *ScienceDaily* link

Atmospheric water harvesting

"Solar-powered system extracts drinkable water from "dry" air", *MIT news* link

"In field tests, device harvests water from desert air", *MIT news* link

"Researchers develop device that extracts water from desert air", *Engadget* link