Women in Engineering and Science

Pamela M. Norris
Lisa E. Friedersdorf *Editors*

Women in Nanotechnology

Contributions from the Atomic Level and Up

Springer

Women in Engineering and Science

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ISSN 2509-6427 ISSN 2509-6435 (electronic)
Women in Engineering and Science
ISBN 978-3-030-19950-0 ISBN 978-3-030-19951-7 (eBook)
https://doi.org/10.1007/978-3-030-19951-7

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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Just as we were getting started with this project, we were deeply saddened by the passing of Dr. Mildred "Millie" Dresselhaus, perhaps one of the most impactful women scientists of all time. Beyond her technical contributions to science, she was an inspiration with her perseverance to overcome obstacles and with the passion with which she mentored students and faculty alike, including some of the authors included in this book.

Preface

Dr. Mildred "Millie" Dresselhaus was perhaps one of the most impactful women scientists of all time. In the spirit of this edition celebrating the contributions of women scientists and engineers to nanotechnology and telling their stories, a few brief details of Millie's inspiring life story are provided here. Authors also share memories of their interactions with Millie and the profound impact these interactions had on their careers.

Pamela Norris, coeditor, shares her first opportunity for significant interactions with Millie during the Seventh Japan-US Symposium on Nanoscale Transport Phenomena in Shima, Japan, in 2011: "We both arrived early, following the very long trip to Japan, and we were tired. But there was a dragon festival occurring that evening, and we were not going to miss the opportunity for first-hand observation. That evening as we soaked in the sights and sounds of Japan, I heard the amazing story of Millie's academic journey. I heard of her trials and hardships along the way, but I never heard a hint of resentment from a woman who had clearly blazed a new trial for women scientists. We discussed the challenges of balancing motherhood and academia, and I came to understand that the struggles along the path are just part of the journey. The science which motivates us, the contributions our science makes to improving the world and the human condition, and the privilege we have of working in a free world where the choices are ours to make and the path is ours to define, these are all things worth great work and effort and we are indeed blessed."

Millie was born in 1930 to immigrant parents and grew up in the Bronx during the Great Depression. A talented violin player, she attended a music school on scholarship. It was there she became aware of better educational opportunities and applied to Hunter College High School for Girls. She then attended Hunter College where she majored in liberal arts, but took as many science and math classes as she could. At Hunter, her physics instructor, Roslyn Yalow (who later became the first American woman to win a Nobel Prize for her work in the development of the radioimmunoassay technique), encouraged Millie to become a scientist. Millie saw a notice about a fellowship on a bulletin board, and after graduating in 1951, she was awarded a Fulbright Fellowship to spend a year working in the Cavendish Laboratory at the University of Cambridge in England. (The Cavendish Laboratory was established in 1874, first led by James Clerk Maxwell, to focus on experimental physics.) Millie earned her master's from Radcliffe College in 1953 and her PhD from the University of Chicago in 1958 where her dissertation focused on superconductivity. After a postdoctoral position at Cornell University, she joined Lincoln Laboratory as a staff scientist.

Millie was at Lincoln Lab from 1960 through 1967, a time when there was much focus on semiconductors. She focused, however, on semimetals, and her research led to early knowledge of the electronic structure of these materials, including graphite. In the 7 years she was at Lincoln Lab, Millie and her husband, Gene, had four children. The difficulty balancing four small children with a new laboratory policy mandating an 8 am start to the day led Millie to explore other opportunities. Millie joined the Department of Electrical Engineering at MIT on a fellowship from the Rockefeller Family Endowment aimed at promoting scholarship of women in science and engineering. One of the many notable contributions Millie made at MIT was changing the admissions criteria. The school had different standards for admitting women as opposed to men, "so the first thing that we did was to have equal admission that would be on the same criteria, academic criteria. That fact increased the women by about a factor two, just overnight." Millie spent the remainder of her career as a faculty member at MIT.

Millie's contributions to the advancement of scientific understanding are vast. Beginning with her work characterizing the electron band structure of carbon at Lincoln Labs, Millie became well known for her research studying the properties of carbon-based materials. She studied the effects of intercalation on graphite's electrical properties, in some cases inducing superconductivity. She also studied the novel properties of carbonaceous nanomaterials such as fullerenes and carbon nanotubes. Her experiments and calculations showed that the electrical properties were dependent on the chirality of the tube and that they can behave as a metal or a semiconductor (Dresselhaus et al. 1995). Due to her contributions to the field, including authoring four books on carbon, she earned the nickname, "Queen of Carbon." She is also credited with opening the field of low-dimensional thermoelectricity, as discussed in the chapter by Zebarjadi.

Millie was contributing author Mona Zebarjadi's co-advisor during her 3 years of postdoctoral studies at MIT. She has shared with us one of the many lessons that she learned from Millie. "The power of collaboration and net-working: Millie was constantly trying to put people in contact with each other. She was trying to bring scientists from different fields to sit in the same room and to share their ideas. She had a great vision over many fields as she served as an advisor for several government departments. She wanted her colleagues to reach out and expand their view points. In particular, she knew female scientists are not as well connected as male scientists, perhaps because of their much lower percentage. When I got my first job, she told me to establish my network, to go around and introduce myself to other faculties and make sure that I understand what they are working on even if I think their work is not relevant to mine. Later on, she followed up with me and asked me if I have found collaborators. Upon naming them, she said: 'Well, you are in good hands!'."

Although coeditor Lisa Friedersdorf did not have the opportunity to work with Millie, she reflects on her impact. “I recall attending presentations given by Millie at major conferences, the large room was always packed. I remember the ease in which she presented and answered, sometimes quite aggressive, questions. She was confident and the audience was differential as only in the presence of a well-respected scientist. Although not given to me directly, I often got second hand advice from those she mentored, men and women alike. ‘Have you written your results?’ They told me she’d say, always pushing them to do their best. I also heard a lot about collaboration, and helping others. I had the fortune to talk with Millie at the social time before her Kavli Prize Laureate Lecture at the Carnegie Institution for Science in 2013 and what struck me most was the personal attention she gave me, asking questions, listening, and offering encouragement. She was not only a world class scientist, but a genuinely nice person.”

Contributing author, Evelyn Wang, fondly remembers Millie visiting her home while she was in middle school during Millie’s visits with her father at CalTech. Millie always brought her violin with her, and Evelyn and Millie would play together. Evelyn shares “I hope that as we honor Millie, we remember both her scientific accomplishments—and her incredible way of putting those around her at ease. It’s something I, personally, will never forget.”

Indeed, in addition to advancing science, Millie was a passionate mentor and a well-known voice and an advocate for women in science. Her passion impacted generations of students at MIT and beyond. She was the recipient of many awards celebrating both her scientific and mentoring accomplishments, including the Medal of Freedom (the highest civilian award in the USA) bestowed by President Obama in 2014 and the Medal of Science awarded by President Bush in 1990. More information about Millie’s exceptional life can be found at the sites listed below:

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Note from the Editors

As part of the Women in Engineering and Science series, this book celebrates just a few examples of the many women who have advanced the field of nanotechnology. In the introduction, Friedersdorf and Spadola give a brief overview and use examples of contributions of women in a variety of technical areas impacted by nanotechnology. LeBlanc discusses how nanotechnology can be used to improve science and scientific literacy, differentiated by whether directed at a lay or technical audience. Some of the strategies used for incorporating nanotechnology in K–12 education are presented by Schmidt, with specific demonstrations and lessons for teachers and students.

The next few chapters take a more technical look at various aspects and applications of nanotechnology. Sayes makes a case for considering the environmental, health, and safety aspects of nanomaterials and gives the current state of understanding of nanotoxicology. Wen, Lee, and Steinmetz show how plant virus-based nanotechnologies are being developed for use in medicine, including for molecular imaging and drug delivery.

The impact of the nanoscale on thermoelectric transport properties of materials for applications such as waste heat recovery and solar power generation is discussed by Zebarjadi. Wang, Zhu, Mutha, and Zhao consider how nanostructured surfaces can control the manipulation of water for thermal management, energy production, and desalination. Norris and Larkin review developments in the understanding of thermal boundary resistance with a view toward the future when the ability to engineer the interface in order to optimize thermal performance will be possible.

Finally, Merzbacher provides a historical perspective on the US National Nanotechnology Initiative and provides her perspective on future prospects for nanotechnology.

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About the Authors

Lisa E. Friedersdorf A piece of advice I often give my students is to build a strong foundation so they can take advantage of opportunities as they arise, and I have been fortunate to be able to do so myself. I never could have foreseen the professional path I've taken nor charted a course to the position I now hold.

I graduated summa cum laude with a bachelor's degree in mechanical engineering from the University of Central Florida. While there, I had the opportunity to conduct independent materials science research, an experience which was pivotal to everything that followed. Not only did I learn laboratory skills, but I also assisted with the finances and writing reports and proposals. The research group of graduate and undergraduate students was dynamic and collaborative. Some of my favorite memories are the all-nighters making posters in the days leading up to major conferences. My research focused on electrochemistry, to study the environmental degradation of high-temperature superconductors and stress corrosion cracking of stainless steel alloys. For graduate school, I wanted to study surface oxidation with scanning probe techniques, tools that were just becoming commercially available. I wrote a proposal to NSF on this topic and was awarded a 3-year graduate fellowship. I joined a group at the Johns Hopkins University to pursue a PhD in materials science and engineering. That fall, I married a doctoral student also in materials science. The delivery of the scanning probe system was delayed so I worked on a side project to fabricate and characterize photoluminescent porous silicon which became the topic of my master's thesis. As I was finishing the required coursework and ramping up my doctoral research, several unexpected events took place. I had a difficult pregnancy that required months of bed rest, my advisor left the university, and my husband took a job on the other side of the country at the US Bureau of Mines in Albany, Oregon. I knew I wanted to teach at the university level which required a PhD, so after relocating with a newborn, I worked to find a way to finish my degree. Having completed my coursework, the first few months were focused on studying for the graduate board exam which gave me time to look for the resources to do my research. The Bureau of Mines let me use a small concrete building where I could control vibration, Hopkins let me borrow the scanning probe system, Linfield College gave me access to equipment in the physics department to make samples, and I used the library at Oregon State University. The lessons learned in building partnerships were perhaps even more valuable than the advancements I made in understanding of the initial stages of copper oxidation using scanning tunneling and atomic force microscopy. Meanwhile, congressional initiatives called for the elimination of the Bureau of Mines, so my husband accepted a position at Bethlehem Steel's Homer Research Labs in Pennsylvania. Since this was before the widespread use of email, my advisor and I spent hours on the phone reviewing drafts of my dissertation sent by FedEx. I remember clearly pulling the final page of my dissertation off the printer, dropping keys on my supervisor's desk, pulling the gate shut, and jumping in the car on our son's second birthday for the trip back East.

Once settled in Bethlehem, I took a part-time research position in the Materials Research Center at Lehigh University working on functionally graded thermal barrier coatings for turbine blades until I had my second son. Although mostly at home for the next year, I worked with Lehigh faculty to write proposals and papers, and then I got a call from the center director. He offered me an industrial liaison position with the promise of flexible hours; it was the perfect fit. I found I was well suited to promoting and managing the complex interactions between academia and industry. Over the next 5 years, I grew the program, worked closely with Ben Franklin to support entrepreneurs and local start-ups, and established a multimillion dollar public–private partnership in microelectronic packaging. I also built my own research group, funded by the Office of Naval Research, and taught corrosion and electrochemistry classes for the materials science department. The steel industry, however, was not doing well and we decided to do a nationwide job search shortly before Bethlehem Steel declared bankruptcy.

Finding positions for two professionals is always a challenge, but especially so when you have the same technical specialty. I was offered two faculty positions and my husband had offers from a small company and a research institute. Although I loved teaching and research, at that time I decided that a tenure-track faculty position would not allow me the flexibility I still wanted with my small children, which was certainly a deviation from my original professional plan. We moved to Charlottesville, Virginia, where my husband joined a small company. For the first year, I continued to work for Lehigh managing the public–private partnership and helping to revise the university's intellectual property policy. I became actively engaged in the tech community and began consulting for the Virginia Center for Innovative Technology as my responsibilities at Lehigh wound down. I also took a position teaching physics and advanced placement chemistry at a local private high school. My role at CIT grew and I was promoted to director of the Virginia Nanotechnology Initiative where I led an alliance of academic institutions, industry, and government laboratories. I worked closely with the legislative and executive branches of the state government and the Virginia congressional delegation. I compiled an inventory of nanotechnology assets; facilitated research and commercialization collaboration; prepared and presented reports, strategic plans, competitive analyses, and investment proposals; reviewed legislation; provided technical support and briefings; and conducted outreach to build community. During this time, I was also building connections to the Office of the Vice President for Research at the University of Virginia and they created a new part-time research program manager position. In this role, I was responsible for building cross-school teams and leading proposal development for large programs. I also supported statewide efforts including the Virginia Research and Technology Advisory Commission (VRTAC) and served on Joint Commission on Technology and Science (JCOTS) citizen advisory committees. Although I was juggling family and several part-time jobs, I had the flexibility to work around the clock. As funding for the VNI was declining, I moved into a full-time position at UVA with an equal split between the program management role and as managing director of the Institute for Nanoscale and Quantum Scientific and Technological Advanced Research (nanoSTAR). At nanoSTAR, I oversaw institute operations including research program development, budget management, marketing, communications, and outreach. I established and administered funding programs for faculty seed projects, undergraduate summer research, and graduate student travel. I also designed and established an industry collaborative research program and facilitated the formation of a multimillion dollar public–private partnership in nanoelectronics. My passion for mentoring students continued and I taught materials science and corrosion classes, advised numerous senior projects, served on graduate committees, and was the advisor to Tau Beta Pi and the Nano and Emerging Technologies (NExT) club.

Shown an advertisement clipped from "The Hill" for a policy analyst, I reached out to colleagues at the National Nanotechnology Coordination Office (NNCO) to learn more. With one son in college and the other finishing up high school, I became a consultant at the NNCO while maintaining a visiting position in materials science at UVA. My primary responsibility was to support the Nanotechnology Signature Initiatives and after a couple of years I was asked to join the leadership as deputy director. I returned to UVA as a principal scientist and under the intergovernmental personnel act (IPA) joined the National Science Technology Council of the White House Office of Science and Technology Policy, and was later promoted to Director. In this role, I now lead the office that provides technical and administrative support for the National Nanotechnology Initiative and coordinates collaboration among the 20 federal agencies that invest approximately $1.5 billion annually in nanotechnology research and development. I also serve as the spokesperson for the NNI nationally and internationally. In addition to facilitating interagency coordination, I have strengthened communication with the research community through collaboration with technical societies, associations, and major conferences; initiated and expanded mechanisms for public outreach and STEM education including podcasts, contests, videos, animations, and student and teacher networks; and expanded the use of communities of interest including the US-EU communities of research.

My technical knowledge is of course an asset that enables me to advance major R&D initiatives, but my experience communicating across sectors and building collaborations has been equally important throughout my career. And it's a lot of fun.

LeighAnn S. Larkin Retrospectively, my path into science was predictable. I was a curious child, and in school I had always loved my math and science courses. However, it was not until my senior of high school that I made the conscious decision to begin my journey to becoming a scientist. At 17 years old, with the encouragement of my high school physics teacher, I participated in a research opportunity during which I was able to conduct my own research. I immersed myself in the sciences and solidified my goal to eventually become a scientist. I started my journey majoring in physics at a small liberal arts school in NY state, The College at Brockport. In my senior year of college, I took my first quantum mechanics course. The strange and complex laws governing the world of the very small intrigued me more than any topic I had previously studied. I was fascinated by how these quantum mechanical properties influenced the macro-world we live in. I observed as modern technologies were utilizing nanoscale phenomena to greatly improve our quality of life. I decided I wanted to pursue a PhD where I could study fundamental principles to improve our world's nanotechnology. Upon graduation, I immediately joined the Nanoscale Heat Transfer laboratory under the advisement of Dr. Pamela Norris at the University of Virginia. I began studying how to best optimize heat transport for a range of applications, such as thermoelectric, magnetic storage, and microelectronic devices. I am currently in the process of finishing my PhD in Engineering Physics and finishing a dissertation aimed at advancing our current understanding of thermal transport across metal/semiconductor interfaces. As I progress in my career, I hope to continue conducting research on the transport properties of materials and how these properties can be tailored to improve the technology ubiquitous in our everyday lives.

As a first-generation college student, I believe that without the encouragement and support of my mentors and peers, my journey may have evolved very differently. I have channeled these beliefs into a commitment to mentoring the next generation of scientists and improving the climate of the sciences within the academy. I joined UVA's NSF-sponsored Institutional Transformation ADVANCE program as a research assistant. The ADVANCE program is focused on methods to increase representation of women in the academy in the sciences. The UVA program, referred to as UVA Charge, has a special emphasis on Voices and Visibility, increasing the visibility and sense of belonging of STEM women at UVA. My research has been focused on collecting ethnographic data from UVA's staff and faculty on the diversity climate at UVA and how they have been influenced by institutional change programs and policies. In addition to following my own career path, I believe that it is equally important to create an environment that enables our next generation of scientists to be able to pursue their own passions and craft their own journey.

Saniya LeBlanc My engineering career path has been a windy road with detours down avenues in education and service. For most of that path, my identity has been one defined by exception. The first exception was my decision to be a mechanical engineer. Unlike most people, I chose my discipline when I was a young child, and I never changed my mind (or regretted the decision). My upbringing was a fortunate exception. From a family full of female STEM professionals, I never realized that my career choice might be atypical, my proficiency in math might defy a societal norm, or my gender might distinguish me. I passed most of my undergraduate career in happy oblivion, learning independently with my nose in a book, reveling in the beauty that is engineering, vaguely aware that about 80% of my peers were male and only one of my engineering classes was taught by a woman (a fact which held true for the duration of all four of my engineering degrees).

Some very determined professors nudged me towards graduate school and graduate fellowships, so, with a B.S. in mechanical engineering (and a minor in French) from the Georgia Institute of Technology, I went to the University of Cambridge as a Churchill Scholar to earn a research-based master's degree in engineering. I had deferred admission to Stanford University, and I was supposed to head to sunny Palo Alto to pursue a PhD after finishing my degree at Cambridge. My path seemed clear, but my heart was going in another direction. I felt a calling to serve society in a meaningful way, and it was not clear how graduate school fulfilled that calling. Maybe it was the many hours in a cleanroom bunny suit trying to fabricate my device to no avail, but research was not fulfilling my passion for engineering.

Skimming a bookshelf in a college bar (the college bars have libraries at Cambridge), I picked up *Savage Inequalities: Children in America's Schools* by Jonathan Kozol, and, for the first time, I stared my privilege in the face. The systemic inequity in our education system appalled me. I was humbled … and impassioned to become an educator. I passed up Stanford's graduate fellowship, deferred the National Science Foundation Graduate Research Fellowship, and joined Teach For America to teach math and physics in an urban high school—to the dismay of family, friends, and mentors who were concerned it was a career mistake.

Teaching in a diverse, high-needs community fundamentally altered my understanding of society. With graduate classes in education, professional development, and many, many hours of exhausting practice, I started to learn how to be a teacher. More importantly, I started to understand how policy, paradigms, culture, and social injustice form a tangled web in which so many people get caught. I was no longer able to wrap myself in a cocoon of science and engineering, and my career path as an educator, engineer, or something else entirely was unclear. Although I was deeply fulfilled by my role as a teacher, I missed engineering. I longed for that hard engineering that makes you feel exhausted but energized when you finally conquer a technical challenge. I even missed the clean room (sort of). Maybe those mentors were right, and I should be an engineering professor—an engineer and an educator.

After a 3-year detour, I finally made it to Stanford University where I felt very much like an exception. I had never heard of Stanford before an undergraduate professor told me to apply there, so maybe it is no surprise I was out of place. Perhaps out of a sense of survival, I focused on what I knew best—learning. I relished the cornucopia of engineering topics—nanomaterials, energy systems, thermal transport, and microsystems—until I found the theme which united it all: energy. It links the nanoscale to the macroscale and provides invaluable services to society. The materials, manufacturing techniques, devices, and even economics of energy systems fascinate me. I also used the time at Stanford to learn about engineering education, especially the education research which drives better teaching and learning.

After obtaining my PhD, my passion for energy technologies led me to join Alphabet Energy, an energy technology startup company, as a research scientist. I created research, development, and manufacturing characterization solutions for thermoelectric technologies and evaluated the potential of new power generation materials. It was an outstanding industry experience, but the educator in me missed working with students.

In 2014, I joined the Department of Mechanical and Aerospace Engineering at the George Washington University. With a grant from the National Science Foundation, I created an undergraduate Nanotechnology Fellows Program which allowed me to combine my research and education expertise to influence future generations of scientists and engineers. The experience prompted the discussion presented in this chapter. My research is also an enjoyable exception since it spans many disciplines: thermal sciences, materials science, mechanical engineering, engineering economics, and engineering education to name a few. I have the privilege of conducting exciting, interdisciplinary research in advanced materials and manufacturing techniques for energy systems. I hope to push the boundaries of how we think about the link between materials, manufacturing, and systems for energy technologies.

As I continue on my path, I hope to use my experience as the exception to serve others and offer a perspective that deepens discussions between scientists, engineers, and educators. Many people do not have the luxury of learning independently, immune to societal pressures, identities, and stereotypes. They are not handed the privilege of unabated educational opportunity with the chance to pursue a career about which they are passionate. I aim to recruit and guide future engineers through the perilous journey of finding their own exceptional paths.

Karin L. Lee My interest in pursuing biomedical research started at a young age. As long as I can remember, I was interested in science; biology and chemistry were my favorite classes throughout grade school. Toward the end of high school I decided that I wanted to pursue a career in biomedical research after attending an engineering summer camp and participating in a summer internship in a biomedical engineering lab. I found the field appealing because the research done was directly able to impact human health. However, as an undergraduate, I learned that the field of biomedical engineering was broader than I had imagined and encompassed a range of research interests, everything from prosthetics and implants to tissue engineering and nanoparticles. Luckily, I had the opportunity to work in multiple labs that had different research interests and found that I was most interested in using biomaterials for biomedical applications.

My specific interest in nanotechnology grew out of this interest in biomaterials. I was first introduced to nanotechnology as an undergraduate, and as I considered graduate schools, I aimed to find a lab that worked with nanoparticles. I ultimately joined Dr. Nicole Steinmetz's lab, where we focused on using plant viruses as nanoparticles. I was fascinated by this work because the concept of using natural carriers to better human health was unique and innovative. My thesis work focused on the development of potato virus X (PVX), a flexible, elongated plant virus, for use as a cancer therapy. My early projects with PVX utilized it as a traditional nanoparticle for drug delivery, while my later projects investigated its use for immunotherapy. I received my PhD from Case Western Reserve University in 2016 and soon after started my postdoctoral research.

I am now a postdoctoral research fellow at the National Cancer Institute within the National Institutes of Health. I am working on the development of cancer vaccines, to be used in combination with other immunotherapies, and have had the opportunity to learn many new techniques. I am lucky to have been able to take my interests in nanotechnology and biomedical engineering and apply the skills I learned toward preclinical research in new in vivo models, which will be used to guide clinical trials. As I move forward in my career, my hope is that the work I've done and continue to do will contribute to improving clinical options for cancer patients.