Women in Engineering and Science

Mary E. Kinsella *Editor*

Women in Aerospace Materials

Advancements and Perspectives of Emerging Technologies

Springer

Women in Engineering and Science

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Jill S. Tietjen
Greenwood Village, CO, USA

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Preface

This book provides scholarly chapters detailing the research and development of key aerospace materials that have enabled some of the most exciting air and space technologies in recent years. These scientific and engineering successes are shared by the women who accomplished them, those who were in the labs, on the shop floors, or on the design teams contributing to the realization of these technologies. Their work contributes to the world in the challenging and vital field of aerospace materials, and their stories seethe with pride and passion for the opportunity to make these important contributions.

Materials are the basis of new advancements in technology. They play an especially important role in aerospace by providing properties that enable performance in the extreme environments of air and space. From high-strength, high-temperature materials for engines to stiff and lightweight materials for structures or from radiation-hardened materials for electronics to advanced biomaterials, the world of challenge in aerospace materials is vast. Materials themselves include metals, ceramics, polymers, and composites. Aerospace applications include jets, helicopters, and other air vehicles; rockets, satellites, and other space vehicles; all their associated support and subsystems; and interactions with humans and the environment.

The intention of this book is to benefit a number of audiences, including:

- Young women thinking about careers in materials science or engineering or related fields, working in research or aerospace industry
- Women in these fields interested in learning about and connecting with women doing similar work
- Teachers, professors, advisors, and mentors looking for exemplars (i.e., women engineers and scientists in aerospace materials) to bring to the attention of their students and protégés
- People everywhere interested in learning about
  - Leading-edge aerospace materials research
  - Talented researchers dedicated to advancing materials technology for aerospace missions and for the greater good

- The roles of women in aerospace engineering and science and specifically in materials research

The book begins with a summary of pioneering women in aerospace materials and follows up with chapters describing the work of each individual author and her collaborators. A separate section of biographies is also included, highlighting the backgrounds of the authors, their motivations, and their inspirations.

The materials topics featured in this book represent a small sampling of ongoing research in aerospace materials. Effort has been made to present details of selected materials work and describe the relevant potential aerospace applications. Examples from electronics, optical, biological, metal, and composite materials are all included. Various perspectives are represented, such as processing, testing, characterizing, and manufacturing. The reader will be exposed to the breadth of materials disciplines, the depth of ongoing research therein, and the expanse of potential applications in the realm of aerospace.

All of the contributing authors work in aerospace research and development on projects that include an emphasis on materials. Authors were primarily selected on the basis of this work, their interest in the project, and their enthusiasm for contributing to this volume. Invitations to contribute had to be limited due to the far-reaching scope of the topic; therefore, this book is not representative of all women in the field of aerospace materials, nor was it intended to be.

As the editor of this volume, I am pleased to have had the opportunity to contribute to this series publication, to showcase some of the work that has major impact in the materials and aerospace communities, and to work with several outstanding women who are among the most talented engineers and scientists in research and development.

Centerville, OH, USA Mary E. Kinsella

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Chapter 1
Aerospace Trailblazers

Jill S. Tietjen

1.1 Introduction

Women's contributions to aerospace materials ensure aircraft and rockets that survive the rigors of air and space travel. A woman invented the molecular density switch monitoring the artificial atmospheres that protect electronic equipment and then alerting humans of the need for remedial action. Another woman invented the propulsion system that keeps communication satellites on orbit after she recognized the efficiencies and other benefits of using only one fuel. The "Queen of Carbon Science" made crucial advances in the understanding of the thermal and electrical properties of carbon nanomaterials. A woman in academia has researched advanced structural alloys used in the aerospace, energy, and automotive industries. Women astronauts have worked on the ceramic tiles that form the heat shield for the space shuttle and served as research chemists investigating organic polymers. The women briefly described in this chapter helped pave the way for the chapter authors that follow in this volume.

1.2 Beatrice Hicks (1919–1979)

Beatrice A. Hicks broke new ground for women as an engineer, inventor, and engineering executive. Because of her interest in mathematics, physics, chemistry, and mechanical drawing in high school, she decided to become an engineer. In fact, her interest had been sparked at age 13 when her engineer father had taken her to see the Empire State Building and the George Washington Bridge, and she learned that it was engineers who built such structures. Although her high school classmates and

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some of her teachers tried to discourage her, pointing out that engineering was not a proper field for women, her parents did not stand in her way.

After her high school graduation in 1935, she entered the Newark (New Jersey) College of Engineering. In 1939, she received a B.S. in chemical engineering and took a position as a research assistant at the College. In 1942, she got a job with the Western Electric Company, becoming the first woman to be employed by the firm as an engineer. She worked first in the test set design department and later in the quartz crystal department. An early award citation stated "the quality of her work became legend." She studied at night while employed and, in 1949, earned an M.S. in physics from Stevens Institute of Technology. Subsequently, she undertook further graduate work at Columbia University. Hicks pioneered the theoretical study, analysis, development, and manufacture of sensing devices, patented a molecular density scanner, and developed an industry model for quality control procedures.

She joined Newark Controls Company, the company her father had founded, as chief engineer in 1945. When her father died in 1946, she became vice president as well. Newark Controls Company specialized in environmental sensing devices. In 1955, she bought control of the company and became president. One of the major products of the company at that time was low-water cutoffs and other devices to protect people from their own forgetfulness, often sold through mail-order companies. During her years with the Company, it manufactured specialized electromechanical devices such as liquid level controls, pressure controls, and altitude switches for aircraft and space vehicles where extreme reliability under severe environmental conditions was required.

At Newark Controls Company, Hicks was also involved in the design, development, and manufacture of pressure and gas density controls for aircraft and missiles. In 1959, she was awarded patent 3,046,369 for a molecular density scanner or gas density switch (Fig. 1.1). This type of switch is a key component in systems using artificial atmospheres. The gas density switch (today called a gas density sensor or gas density control or gas density monitor) was designed to monitor gas leakage, particularly for artificial atmospheres around electronic equipment. The artificial atmospheres include dry air, nitrogen, sulfur hexafluoride (SF_6), and fluorochemicals. These gases are suitable as insulators and heat dissipators for a broad range of applications including sealed electronic equipment (non-airborne), sealed airborne electronic equipment, power transformers, switchgear, X-ray units, pressurized power cables, waveguides, and coaxial cables.

At the time of her invention, no mechanism existed to monitor the gas leakage and then signal to the equipment operator that action was warranted. Her gas density switch monitors the number of molecules per unit volume and was capable of indicating leakage at a pressure value that varied with temperature. Density, not pressure or temperature, is the important variable in a sealed-in atmosphere, because it determines arc resistance and heat transfer.

Her switch was a unique bellow-type switch. It could be calibrated to protect throughout the entire temperature range. In addition to its function of signaling critical density, the switch could also be used to activate control circuits of systems, e.g., opening a valve or starting a pump.

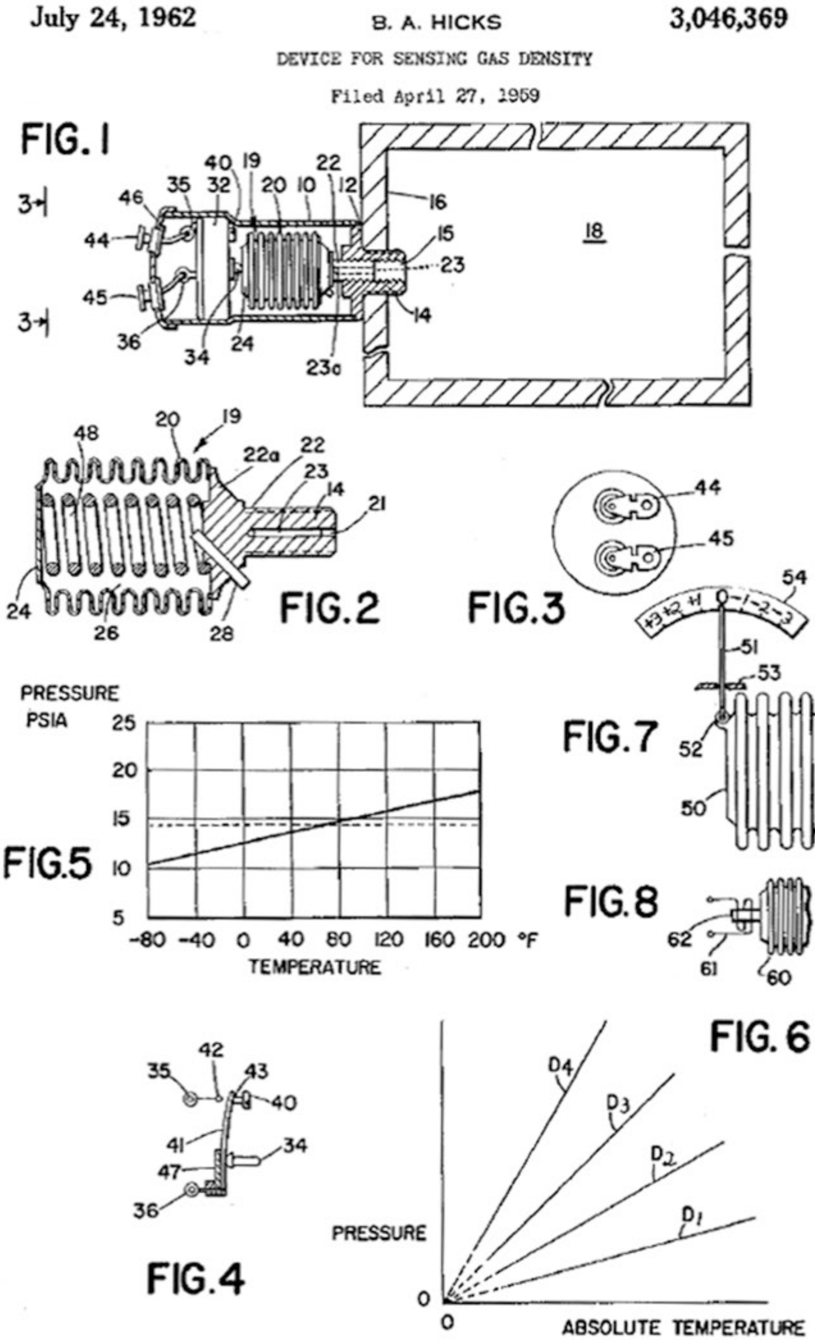

Fig. 1.1 Beatrice Hicks' patent 3,046,369 – gas density sensor. Source: U.S. Patent and Trademark Office

The sub-miniature gas density switch was in use in a number of applications particularly in aircraft and missiles and also in the space program including the Saturn and Apollo missions. The Boeing 707 used a gas density switch to monitor the nitrogen atmosphere around the high voltages in a sealed communications antenna coupler. On both the Boeing 707 and the Hustler B-58, the antenna couplers handle very high voltages and would arc-over in the upper atmospheres. A gas density switch mounted in each antenna coupler indicated remotely at the pilot's panel board if a problem developed.

Fire extinguishers use gas density switches to indicate which units are ready for recharging. Power transformers using gas and vapor cooling are monitored by gas density switches. At the time the switch was developed, it allowed early detection of leakage with an associated remote indicator that prevented critical loss of the gases and permanent damage to the transformers. Gas density switches are of value when power transformers are in shipment or storage, at the time they are put in service, as well as when they are in operation.

Bellow-type gas density switches are still manufactured, in use, and marketed today. One of the most significant applications for these types of gas density switches today is for high-voltage SF_6 breakers. The monitors ensure that the breaker will adequately perform its function of properly interrupting faults. The monitor alarms and then trips the breaker when there is no longer adequate SF_6 to extinguish a fault. Monitors are manufactured in the USA and abroad.

One of the founders of the Society of Women Engineers (SWE), Hicks was elected to serve as its first president in 1950. She was committed to the organization because of her belief that there was a great future for women in engineering. Hicks (Fig. 1.2) received SWE's Achievement Award in 1963 "In recognition of her

Fig. 1.2 Beatrice Hicks – SWE archives, Walter P. Reuther Library, Wayne State University https://reuther.wayne.edu/node/1622

significant contributions to the theoretical study and analysis of sensing devices under extreme environmental conditions, and her substantial achievements in international technical understanding, professional guidance, and engineering education."

Hicks received many other honors and awards over her lifetime. In 1952, she was named "Woman of the Year in Business" by *Mademoiselle* magazine. In 1961, she was the first woman engineer appointed by the US Secretary of Defense to the Defense Advisory Committee on Women in the Sciences. She was the first woman to receive an honorary doctorate from Rensselaer Polytechnic Institute (1965). She also received honorary degrees from Hobart and William Smith Colleges, Stevens Institute of Technology, and Worcester Polytechnic Institute. In 1978, she was elected to the National Academy of Engineering, the sixth woman to be elected. In 2001, she was inducted into the National Women's Hall of Fame. In 2013, Hicks received the Advancement of Invention Award from the New Jersey Inventors Hall of Fame [1–4].

1.3 Yvonne Brill (1924–2013)

Yvonne C. Brill expanded the frontiers of space through innovations in rocket and jet propulsion. Her accomplishments and service had major technical and programmatic impacts on a very broad range of national space programs. Her most important contributions were in advancements in rocket propulsion systems for geosynchronous communication satellites. She invented an innovative satellite propulsion system that solved complex operational problems of acquiring and maintaining station (keeping the satellite in orbit and in position once it is aloft).

Her patented hydrazine/hydrazine resistojet propulsion system (patent no. 3,807,657 – granted April 30, 1974) provided integrated propulsion capability for geostationary satellites and became the standard in the communication satellite industry (Fig. 1.3). Two aspects of Brill's invention are of special significance: she developed the concept for a new rocket engine, the hydrazine resistojet, and she foresaw the inherent value and simplicity of using a simple propellant. Her invention resulted in not only higher engine performance but also increased reliability of the propulsion system and, because of the reduction in propellant weight requirements, either increased payload capability or extended mission life. As a result of her innovative concepts for satellite propulsion systems and her breakthrough solutions, Brill earned an international reputation as a pioneer in space exploration and utilization.

Through her personal and dedicated efforts, the resistojet system was then developed and first applied on an RCA spacecraft in 1983. Subsequently, the system concept became a satellite industry standard. It has been used by RCA, GE, and Lockheed Martin in their communication satellites. The thruster has stood the test of time; more than 200 have been flown. Satellites using her invention form the backbone of the worldwide communication network – 77 of them form the Iridium mobile telephony constellation of satellites, and 54 are geosynchronous

United States Patent [19] [11] **3,807,657**

Brill [45] **Apr. 30, 1974**

[54] **DUAL THRUST LEVEL MONOPROPELLANT SPACECRAFT PROPULSION SYSTEM**

[75] Inventor: **Yvonne Claeys Brill**, Skillman, N.J.

[73] Assignee: **RCA Corporation**, New York, N.Y.

[22] Filed: **Jan. 31, 1972**

[21] Appl. No.: **221,955**

[52] **U.S. Cl.** .... **244/1 SB**
[51] **Int. Cl.** **B64d 3/00**
[58] **Field of Search** 244/1; 60/200–204, 206–207, 218–220, 224–225, 229, 242

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[57] **ABSTRACT**

A flight auxiliary propulsion system for velocity trim, station keeping, momentum adjustment for a spacecraft comprising rocket or reaction motors, also designated thrusters, utilizing thermally decomposable monopropellants such as hydrazine and other derivatives, thereof hydrogen peroxide, and isopropyl nitrate. The thrusters are arranged in a distribution or manifold system so that one set of thrusters provides for relatively large thrusts of force in the order of 1 to 5 pounds and another set of thrusters develop low thrusts in the millipound range. The large thrusts are developed by the catalytic decomposition of the monopropellant into a thrust chamber and through a throat and expansion nozzle to the ambient externally of the spacecraft. The low level thrusts are developed by heating catalytically or thermally decomposed monopropellant by electrical heating elements more commonly known as resisto-jet elements. Dual thrust levels may also be achieved by a common motor with a controllable resisto-jet and variable throat-area control.

10 Claims, 5 Drawing Figures

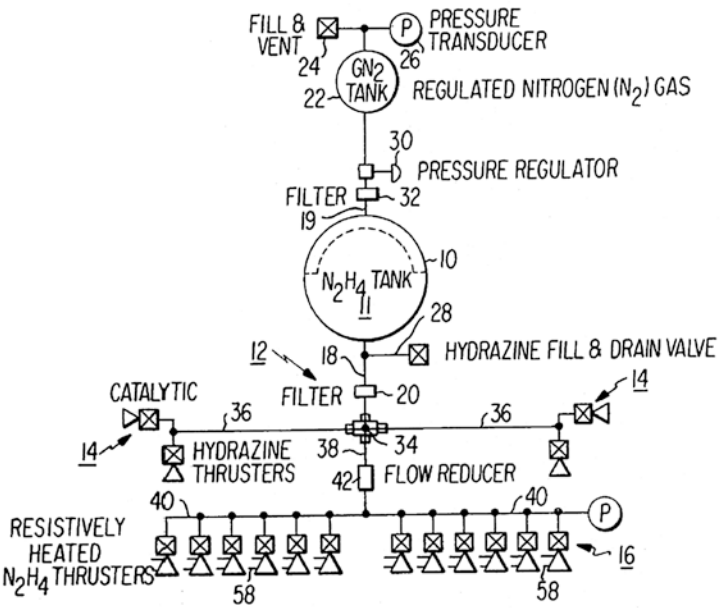

Fig. 1.3 Yvonne Brill patent 3,807,657. (Source: U.S. Patent and Trademark Office)

communication satellites. The impact of global satellite communications extends to all walks of life, from national security to commercial telephone, from remote medicine and education to international trade. Brill's innovation, by enabling a dramatic improvement in satellite capability, has directly improved all of these endeavors. Every time one of our soldiers uses his/her Iridium satellite telephone, that solider is directly benefiting from Brill's innovation.

The invention of the hydrazine/hydrazine resistojet and its extensive use on current communications is just one of the many contributions Brill made to expanding space horizons. Her other significant technical achievements include work on propellant management feed systems, electric propulsion, and an innovative propulsion system for the Atmosphere Explorer, which, in 1973, allowed scientists to gather extensive data of the earth's thermosphere for the first time. Brill defined, successfully advocated, and conducted a program to evaluate capillary propellant management for three-axis stabilized spacecraft. Capillary propellant management is now routinely used on a significant fraction of US space systems. Her system has led to major improvements in the capabilities and competitiveness of very large numbers of US spacecraft.

Brill managed the fabrication, assembly, integration, and test of a complex Teflon solid propellant pulsed plasma propulsion system (TSPPS), also called pulsed plasma thrusters (PPTs). She resolved many technical and design problems in the process of bringing TSPPS from experimental to operational use in satellites, including the NOVA I spacecraft launched in May 1981, which formed part of the US Navy's Navigational Satellite System. Her efforts both provided the solution for an unprecedented navigational capability and opened the way for the now routine use of electric propulsion on commercial Western space systems. In addition, PPTs, which are direct descendants of her design, are now being developed for propulsion functions on small/micro-government spacecraft for many applications.

Brill brought to society the benefits of her bountiful knowledge and wisdom by consulting with governments and space agencies throughout the world. She was instrumental in the success of several satellite system developments for the International Maritime Satellite (INMARSAT) organization and for Telenor, the Norwegian telecommunications organization. She served as one of nine members of NASA's Aerospace Safety Advisory Panel (ASAP) which was created in 1968 after the Apollo 204 Command Module spacecraft fire in 1967 to focus on safety issues. During her period of service, ASAP defined and recommended many technical and programmatic changes to enhance Orbiter safety that were subsequently implemented by NASA. Specific examples of such impacts include a modified Space Shuttle Main Engine (SSME) heat exchanger design that eliminated a catastrophic failure mode, a SSME design change that enabled lowered turbine inlet temperatures with increased safety margins, and increased staffing at NASA space flight centers in support of Orbiter flows.

During her long and stellar career, Brill was a pioneer in the field of space technology. Throughout most of that time, she was the sole technical woman working in rocket propulsion systems. As she excelled in her career, Brill worked tirelessly to nominate women for awards and to boards and served as a role model for several generations of women engineers, including her daughter.

Brill became a member of the National Academy of Engineering in 1987 and was a fellow of SWE and the American Institute of Aeronautics and Astronautics. Among her many awards were the 1986 SWE Achievement Award "for important contributions in advanced auxiliary propulsion of spacecraft and devoted service to the growing professionalism of women in engineering," the 1993 SWE Resnik Challenger Medal for expanding space horizons through innovations in rocket propulsion systems, and induction into the Women in Technology International Hall of Fame in 1999. After her induction into the New Jersey Inventors Hall of Fame (the first woman) in 2009 and the National Inventors Hall of Fame in 2010, Brill received the nation's highest honor, the National Medal of Technology and Innovation, from President Obama in 2011 (Fig. 1.4) "For innovation in rocket propulsion systems for geosynchronous and low earth orbit communication satellites, which greatly improved the effectiveness of space propulsion systems" [4–7].

Fig. 1.4 Yvonne Brill with her National Medal of Technology and Innovation poster and medal. (Source: Author)

1.4 Mildred Dresselhaus (1930–2017)

At the Massachusetts Institute of Technology for nearly 60 years, Dr. Mildred Dresselhaus was the first female recipient of the National Medal of Science in the engineering category, the first woman to receive the Institute of Electrical and Electronics Engineers (IEEE) Medal of Honor, and was known as the "Queen of Carbon Science." She was the first woman tenured in the School of Engineering at MIT. In August 2000, she became the Director of the Office of Science in the Department of Energy, having been nominated by President Clinton and confirmed by the US Senate.

Dresselhaus was a solid-state physicist and materials scientist whose research areas included superconductivity; the electronic and optical properties of semimetals, semiconductors, and metals; and, particularly, carbon-based materials. She made crucial advances in the understanding of the thermal and electrical properties of carbon nanomaterials. She was the first female institute professor at MIT, an honor that recognizes distinguished accomplishments in scholarship, education, service, and leadership. Her professorship was in electrical engineering and physics.

Her other honors demonstrate the recognition she received for her significant accomplishments. The citation for her 1990 National Medal of Science reads "For her studies of the electronic properties of metals and semimetals, and for her service to the Nation in establishing a prominent place for women in physics and engineering." Her 2014 US Presidential Medal of Freedom (the highest honor for civilians) citation reads for "deepening our understanding of condensed matter systems and the atomic properties of carbon – which has contributed to major advances in electronics and materials research." On presenting her the award, President Obama said "Her influence is all around us, in the cars we drive, the energy we generate, the electronic devices that power our lives."

In 2017, she received the Benjamin Franklin Medal "For her fundamental contributions to the understanding and exploitation of carbon nanomaterials, such as the spheres known as Buckminsterfullerenes, the cylindrical pipes called nanotubes, and the single-atom-thick sheets of carbon known as graphene, and for launching the field of low-dimensional thermoelectricity, the direct conversion of heat to electricity." She was the first solo recipient of the Kavli Prize for her pioneering contributions to the study of phonons, electron-phonon interactions, and thermal transport in nanostructures.

Growing up poor but with exceptional musical ability, Dresselhaus received a scholarship to music school. Determined to pursue every education opportunity she could, she applied to Hunter College High School for Girls. There, she received encouragement to study physics at Hunter from her advisor Rosalyn Yalow (later a Nobel Laureate) as opposed to becoming a schoolteacher. Dresselhaus received an A.B. from Hunter College in 1951 in physics and math. After a year in Cambridge, England, on a Fulbright scholarship in physics, she studied first at Harvard, completing her master's degree and then received her Ph.D. from the University of

Chicago in 1958 with a thesis on superconductors. She then served as National Science Foundation postdoctoral fellow at Cornell University.

In 1960, Dresselhaus joined the Lincoln Lab at MIT, where she studied the properties of graphite. Although her early results were not encouraging, she persevered to obtain data that provided the most accurate characterization of carbon's electronic band structure that had ever been achieved. As a result, she was appointed as a visiting faculty member in the Electrical Engineering Department at MIT under the Abby Mauze Rockefeller Fund, established to promote the scholarship of women in science and engineering. Soon, she achieved tenured professorship. When this occurred in 1968, she became MIT's first tenured female faculty member in engineering.

During the 1970s, Dresselhaus studied graphene intercalation compounds and built her reputation. Her work resulted in a better understanding of fundamental quantum concepts which Dresselhaus used to update theoretical equations as they apply to nonmaterial systems.

A decade later, Dresselhaus's group pursued new carbon materials by blasting graphite with lasers. The ablation produced large carbon clusters of 60 or 70 atoms. Richard Smalley, who was independently performing similar experiments, identified the clusters as fullerenes, more commonly called buckyballs. Dresselhaus spent the remainder of her career calculating the intricacies of carbon nanotubes, which she determined could be formed by elongating the fullerene structure instead of terminating it into a buckyball. She showed that the electrical properties of the carbon nanotubes changed with the orientation of the hexagonal structure. Her calculations of these electrical properties revealed that carbon nanotubes could be applied as either metals or semiconductors.

The 1977 recipient of SWE's Achievement Award "for significant contributions in teaching and research in solid state electronics and materials engineering," Dresselhaus (Fig. 1.5) co-founded the MIT Women's Forum in 1970. The Forum

Fig. 1.5 Mildred S. Dresselhaus – SWE archives, Walter P. Reuther Library, Wayne State University http://reuther.wayne.edu/node/1527