Arthur R. von Hippel, In Memoriam (1898–2003): A Tribute to the Interdisciplinary Materials Research He Spawned

M.S. Dresselhaus and P. Chaudhari,
Guest Editors

Abstract

This article introduces the November 2005 issue of *MRS Bulletin* on the life and works of Arthur Robert von Hippel, who pioneered the interdisciplinary approach to materials research. This issue of *MRS Bulletin* celebrates his long life, his large volume of work, and the overall impact he had on materials research as practiced today. This introductory article summarizes the start and progression of the various fields presented in this issue, and how many were inspired directly by von Hippel's work and ways, and how new fields continue to emerge based on the same foundations of interdisciplinarity. The articles in this issue cover research areas in which von Hippel was involved, namely, ferroelectrics and magnetism; fields that thrived on an interdisciplinary approach that von Hippel represented, such as semiconductors; and areas that reflect his own vision about materials research and interests later in life, including molecular design and biomaterials. Before the scientific work is presented, the issue begins with a personal sketch of von Hippel, contributed by his son Frank N. von Hippel.

Keywords: *Arthur von Hippel, biomaterials, ferroelectrics, insulation research, interdisciplinary, magnetism, Massachusetts Institute of Technology, materials research, MIT, molecular design, semiconductors.*

It can be said that when Arthur Robert von Hippel joined the faculty of the Massachusetts Institute of Technology in 1936, the era of interdisciplinary materials research was born. Karl Taylor Compton, then president of MIT, was a visionary, and he attracted people who could "think big" and be leaders. At the time of his appointment, von Hippel had experience in several areas of applied physics, dating from his PhD thesis completion in 1924, including the sputtering of metals, the ionization characteristics of mercury atoms caused by electron impact, electric breakdown of gases, and high-voltage phenomena. He had also worked in many settings around the world, including Göttingen and Jena in his native Germany; Berkeley, California; Istanbul; and Copenhagen. Many of these moves were the result of the turbulent times in Germany early in his career.

Coming from a strong academic background, with a father and grandfather who had been successful university professors—and a Nobel Laureate father-in-law, James Franck—von Hippel had a passion, a vision, and an opportunity to do something important upon his arrival at MIT in 1936. His experiences in fleeing his home to escape from Nazi Germany and the outbreak of the Second World War in Europe triggered von Hippel to do important scientific work to curtail and counteract the technological strength of the Nazis. The United States was just beginning to ramp up its military strength, and von Hippel was eager to participate personally and through his laboratory in the science and technology explosion of that time. The environment of MIT during the war years turned researchers toward goal-oriented, large programs. It was also a time when relatively young and capable people could assume large responsibilities. Von Hippel flourished in this environment.

To do insulation research at the cutting edge in the 1930s required expertise spanning several academic fields, including materials preparation, characterization, properties measurements, and device applications. The strong emphasis on fundamental science as a scaffold for building an interdisciplinary program came both from von Hippel's early training and from the realization during World War II that many of the innovative and high-impact, large programs involved the development of much fundamental science to allow breakthrough technological advances—like radar and the Manhattan Project—to occur. The MIT setting of highly capable personnel (students and staff) further reinforced this approach. Von Hippel's vehicle was the Laboratory for Insulation Research (LIR), which he established in 1937.

Not only was the interdisciplinary aspect of the LIR a novel vision of the future, but von Hippel's interest in studying a large variety of different kinds of materials also became part of his vision. Coming from the Department of Electrical Engineering, von Hippel applied his knowledge of this type of interdisciplinary engineering to a variety of materials, such as conductors of electricity, insulators, and magnetic materials. His colleagues watched his interest in different categories of materials grow over the years; toward the end of his career, he became enamored with water (which he considered the basis of life) and biological materials, which fascinated him as he asked the recurring question

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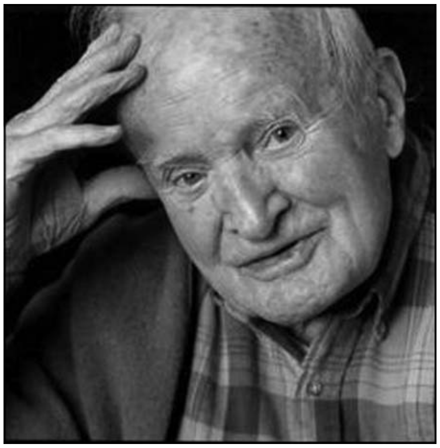


Arthur von Hippel at age 100; photo taken by his grandson, photographer Jonas A. Kahn (www.jonaskahn.com).

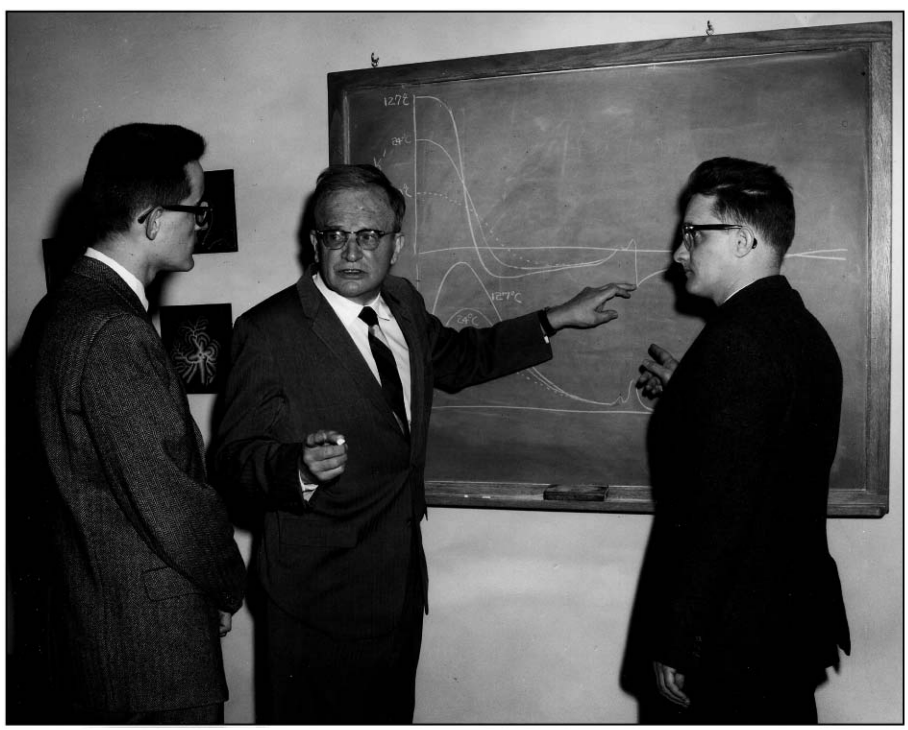
about what was different between a "living" material and an inanimate material.

With this issue of *MRS Bulletin*, we celebrate the long life, the large volume of work, and the overall impact of Arthur von Hippel on materials research. Because of the many similarities in the vision of von Hippel and the goals of the Materials Research Society as embodied and expressed in *MRS Bulletin,* we also celebrate the 30th anniversary of the *Bulletin* this year. In choosing the content of the issue to celebrate the life and work of von Hippel, we selected articles and authors in a special way. First, we have a short biography written by his third son, Frank N. von Hippel, that is intended to acquaint readers with the warmth and motivation of the man behind the science and the technology.

We selected the personal sketch to come first because Arthur von Hippel approached his scientific collaborators first with a cup of tea and cookies. Before starting serious work, he liked to strengthen personal relations and to discuss the big picture in a gracious atmosphere. He also wanted to be sure that his colleagues were enjoying music and art and getting enough exercise. His concern for people went far beyond his MIT collaborators, and all who knew Arthur knew about the many care packages he and his wife Dagmar sent to people abroad who were recovering from the ravages of the war years or simply to those in need. These personal aspects of von Hippel strongly affected the mutual and long-term dedication he developed with his collaborators. Frank N. von Hippel focuses on the warm surroundings of the von Hippel family, but also conveys the spill-over of this ambiance to the von Hippel laboratory and to the interdisciplinary research practiced there.

The first technical article, by Robert E. Newnham and L. Eric Cross, is on ferroelectrics—insulators with strong and permanent electric polarizations—a field that von Hippel influenced strongly at the very early stage of its development. Von Hippel's entry into the field stemmed from his strong commitment to developing more effective insulating materials. Therefore, materials with the potential of achieving very high dielectric constants would hold great interest for him. Von Hippel's ground-breaking work on the ceramic ferroelectric $BaTiO_3$ brought him international fame and led to the golden years of the LIR, corresponding roughly to the decade before von Hippel's retirement in 1964. Through his research efforts on $BaTiO_3$, we see his scholarship and his vision for understanding the behavior of materials at the molecular level, his interdisciplinary approach to carrying out the research itself, gaining detailed control of the materials synthesis process, characterizing the materials from several complementary standpoints, and then using all this knowledge to make devices that would have some impact on society. The authors chosen to write the article are both long-term experts in the field, and Newnham himself was a member of the LIR in his youth, thereby providing personal insights into the discovery process in von Hippel's laboratory. In this article, the authors trace the evolution of the ferroelectric $BaTiO_3$ into a broader class of dielectric and piezoelectric materials and their use in a variety of applications ranging from capacitors to transducers. We note the interplay between fundamental science and applications in von Hippel's laboratory, so characteristic of materials science as we see it today.

The second technical article is written by John B. Goodenough, a luminary in the magnetism field who got to know von Hippel at an early stage of Goodenough's own career, with interactions between the two men continuing long after von Hippel's retirement. The article focuses on the structural and magnetic properties of ferrospinels and to some extent on garnets, which saw significant activity at the LIR during the 1950s. In this work, we get a glimpse of the importance of the quality of materials, typified by a single crystal of Fe_3O_4, in establishing the underlying mechanism of a variety of magnetic phenomena. But beyond that, we see the breadth of interest of von Hippel and of his colleagues and how they worked together at his laboratory. The ferrospinels von Hippel studied were insulating, and in that sense fit into the framework of his



"The Prof": Arthur von Hippel with students at the Massachusetts Institute of Technology, circa late 1950s.

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laboratory, but the science and applications of the programs took him far afield from dielectric breakdown phenomena and into a totally unexplored realm. Attracted by the possibility of using magnetic materials to store information in a computer, and encouraged by the similarities of cooperative phenomena in ferroelectricity and ferromagnetism, von Hippel was ready to dive into new intellectual areas, using a very similar interdisciplinary research approach involving materials synthesis, study by multiple characterization techniques, and finally involvement in device development stemming from the basic science. When entering a new field with uncertain outcomes, he would often say to his colleagues, "We will not be intimidated!"

The field of magnetism, driven by the electrical and computer industries, has grown exponentially; magnetic storage, radiation-hard magnetic bubble memories, and high-field and high-coercivity magnets are a few of the examples requiring a strong interdisciplinary program for their success. Our understanding and control of materials and properties, typified by the brief description given in Goodenough's article, can trace their roots to the work done in von Hippel's laboratory.

Semiconductors was selected as the subject of the third technical article, because when we look back to the timeframe of post–World War II materials research, we tend to focus on the semiconductor revolution. We chose a long-term expert in the semiconductor field, Alan B. Fowler, to tell us why this field has been so important to materials research and to give us insights into both why von Hippel was not himself working in this field and why

The MRS Von Hippel Award

Arthur R. von Hippel was "a pioneer in the study of dielectrics, semiconductors, ferromagnetics, and ferroelectrics." So reads the citation on the Materials Research Society's first Von Hippel Award, which was presented to von Hippel himself in 1976 and in whose honor the premier award of MRS was named. With this award, MRS recognized von Hippel as an early advocate of the interdisciplinary approach to materials research, stating that "his example substantially furthered the science of materials." Up until 1984, von Hippel participated in the Von Hippel Award presentations at MRS's Fall Meetings, in which he gave a short address (Figure 1), often reflecting on the interdisciplinary nature of materials research. This year, Robert Langer, Institute Professor at MIT, will receive the 2005 Von Hippel Award, the 29th scientist to be so honored (see list of recipients).

Kenneth A. Jackson recalls that back in 1975, when he was vice president of the MRS Council and thus in charge of the conference program, he had a conversation with Rudy Voorhoeve over lunch in the dining room of Bell Telephone Laboratories where they both worked. Jackson said that MRS should have an award named after a prominent materials scientist, and Voorhoeve suggested Arthur von Hippel. Being unfamiliar with von Hippel's work, Jackson did some research and immediately agreed. He then took the suggestion to the MRS leadership, which then established the award.

Rustum Roy of the Pennsylvania State University, who was serving as president of the MRS Council in 1975 and as vice president of MRS, also remembers the desire within the Society to name an award after someone who embodied what MRS stood for, mainly, interdisciplinarity. Roy said that the interdisciplinary nature of materials research is what distinguishes it from other sciences and what distinguishes MRS from other professional scientific societies.

"The choice of von Hippel was explicitly made for one reason alone," Roy said. "He was certainly the outstanding pioneer of interdisciplinarity in all of American academia, and it was in the area of materials, which made materials the model for all interdisciplinarity in intellectual research."

Jackson had connections with a scientist at Union Carbide, where ruby laser crystals were grown. The ruby laser crystal (Figure 2) was chosen for the Von Hippel Award trophy to symbolize the many-faceted nature of materials research, and von Hippel himself liked beautiful crystals. While the details are somewhat sketchy after so many years, it seems that a skilled polisher, Bill McGill, cut and polished discarded material on his own time to create the ruby crystals for the awards. The crystals, ~5 cm long and ~2 cm in diameter, were sent to MRS Headquarters in small batches, and each year a crystal was used in the Von Hippel Award trophy. Initially, the crystals were mounted on wooden plaques; in 1983, the Society began embedding the crystals in a Lucite pillar (Figure 3). McGill continued to provide the trophy crystals for MRS—about three a year—for close to 30 years.

Figure 1. Arthur von Hippel in 1983, addressing the audience during the presentation of the Von Hippel Award at the MRS Fall Meeting in Boston. Von Hippel attended the annual presentation of the award that bears his name until 1984.

Jackson recalls that when the Von Hippel Award was established, the crystals were a novelty—and are still not all that common.

"The crystals themselves are the result of a fine example of materials work, and they make a very nice presentation gift," Jackson said. "Von Hippel was a pioneer in materials research, although

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his own interdisciplinary approach to materials research is so strongly intertwined in developments in this field over the past 50 years. Fowler provides a succinct summary of the history of semiconductors and discusses how the lessons learned from von Hippel's work on multidisciplinary research were essential to the development of this all-pervasive technology. The integrated circuit and the multilayer package, light-emitting diodes, solid-state lasers, and flat-panel displays (whether plasma or liquid-crystal-based) could never have been developed without an interdisciplinary effort. High-purity silicon and other semiconductors with controlled doping and a precisely controlled silicon dioxide interface are the basis of today's semiconductor technology.

Although von Hippel was not personally involved in research in the semiconductor field, he was strongly attracted by the beautiful science emanating from this research area and by the power of the electronic devices that resulted. In the 1970s, when low-dimensional phenomena in semiconductors and intercalation compounds were first emerging, he took great delight in learning about what he called "the wonders of modern materials science." He was always ready to listen to the research innovations of advanced graduate students, young faculty members, and colleagues, especially if the work involved concepts that were new to him and if the research had potential for beneficial societal applications. He was fascinated by semiconductor nanosystems, such as quantum wells, even in the 1970s, for he foresaw in the future of the field a deep understanding of materials at the molecular level.

Figure 2. Ruby laser crystal prepared for the MRS Von Hippel Award trophy. Length, ~5 cm. Photo by Kristin Wilson.

Figure 3. The MRS Von Hippel Award trophy, showing a ruby laser crystal embedded in a Lucite pillar.

Von Hippel Award Recipients

1976 **Arthur R. von Hippel**, *Massachusetts Institute of Technology*
1978 **William O. Baker**, *Bell Laboratories*
1979 **David Turnbull**, *Harvard University*
1980 **W. Conyers Herring**, *Stanford University*
1981 **James W. Mayer**, *Cornell University*
1982 **Clarence M. Zener**, *Carnegie Mellon University*
1983 **Sir Peter B. Hirsch**, *University of Oxford*
1984 **Walter L. Brown**, *AT&T Bell Laboratories*
1985 **John W. Cahn**, *National Bureau of Standards*
1986 **Minko Balkanski**, *Université Pierre et Marie Curie*
1987 **Sir Charles Frank**, *University of Bristol*
1988 **Jacques Friedel**, *Université de Paris-Sud*
1989 **John B. Goodenough**, *University of Texas at Austin*
1990 **Robert W. Balluffi**, *Massachusetts Institute of Technology*
1991 **Theodore H. Geballe**, *Stanford University*
1992 **Michael F. Ashby**, *University of Cambridge*
1993 **Frederick Seitz**, *Rockefeller University*
1994 **Alfred Y. Cho**, *AT&T Bell Laboratories*
1995 **William W. Mullins**, *Carnegie Mellon University*
1996 **Sir Alan H. Cottrell**, *University of Cambridge*
1997 **Gabor A. Somorjai**, *University of California, Berkeley*
1998 **Larry L. Hench**, *Imperial College of Science, Technology, and Medicine*
1999 **Richard S. Stein**, *University of Massachusetts Amherst*
2000 **George M. Whitesides**, *Harvard University*
2001 **Simon C. Moss**, *University of Houston*
2002 **Howard K. Birnbaum**, *University of Illinois at Urbana-Champaign*
2003 **Julia R. Weertman**, *Northwestern University*
2004 **Nick Holonyak Jr.**, *University of Illinois at Urbana-Champaign*
2005 **Robert Langer**, *Massachusetts Institute of Technology*

it was not called that then. He did most of his work on dielectrics and especially oxide materials.

"Sapphire is undoped aluminum oxide, and ruby is chromium-doped aluminum oxide. Sapphire and ruby are very hard, durable, and of course, natural ruby is very expensive. Sapphire and ruby crystals are very difficult to grow. The crystals are grown from molten aluminum oxide, which is held in an iridium crucible. Aluminum oxide melts at 2072°C. The process requires very careful control so as not to melt the iridium."

The color in natural ruby comes from small amounts of elements such as chromium, iron, titanium, or vanadium. Laser ruby contains just a small amount of chromium, which is necessary for the lasing action, and it is much paler in color than natural ruby. Ruby lasers are high-powered lasers, and are still used extensively. □

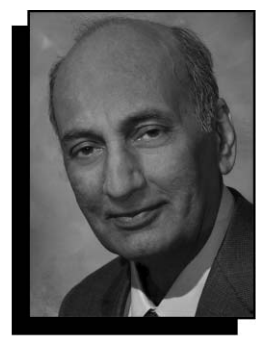
The topic of the fourth technical article, "Molecular Designing of Materials and Devices," by Morrel H. Cohen, was chosen to reflect von Hippel's own vision about materials research. Von Hippel saw a future where fundamental understanding at the molecular level would open an endless frontier of new discovery and applications. In his later years, when industrial business models were questioning the concept of the endless frontier, von Hippel remained convinced of the value of heavy investment in basic research. He further felt that the field of materials research was a model system for demonstrating the validity of his faith in basic research. To convey this enthusiasm, vision, and documented achievement, Cohen gives a summary of advances in theoretical and computational materials research over the past 50 years and portrays how one breakthrough after another has brought us closer to the ability to design materials at the molecular level so that they could provide the desired device applications requested by society. The pedagogic and inspirational approach of the Cohen article is reminiscent of von Hippel and his legacy as a classroom teacher and a pedagogic author.

The last technical article, which addresses biomaterials, was contributed by Samuel I. Stupp and his co-authors Jack J.J.M. Donners, Liang-shi Li, and Alvaro Mata. This topic was chosen to demonstrate von Hippel's vision toward the end of his career of the direction materials discovery would take. Von Hippel spoke a great deal about biomaterials in his later years and pursued his own research interests in this area with great enthusiasm. The objective of the article is to show biomaterials to be a very promising new direction for materials research where much future discovery can be expected. Biomaterials have two characteristics which often set them apart from other materials; one is the preponderance of hierarchical structures and the other is of emergent phenomena. Stupp and coauthors weave these themes into five research directions: materials to repair human biology, materials that imitate biology, materials to monitor biology, materials to learn biology, and use of biology to make materials. No doubt all of these themes would have inspired von Hippel, but it was the use of materials to learn biology that actually attracted him to the field.

Von Hippel was motivated by "grand challenges," and the origin of life was one that was central to his thinking as a mature scientist, in part stimulated by his father-in-law James Franck's intense interest in the mechanism behind photosynthesis. Because of von Hippel's knowledge and experience with a wide variety of materials, it was natural for him to think of biomaterials as a mechanism for addressing some of the grand challenges of biology. The article by Stupp et al. vividly brings these concepts to life and ably captures von Hippel's visionary approach to materials research.

There is no doubt that Arthur von Hippel changed the way we think about materials and the way we carry out materials research investigations. The founders of the Materials Research Society were in strong agreement with von Hippel's vision about the importance of interdisciplinary research. It is for this reason that we celebrate the von Hippel vision every year as we recognize him and his legacy at the time of presenting the Von Hippel Award, the most prestigious honor of the Materials Research Society. To further commemorate the achievements and contributions of Arthur von Hippel, the Society has launched a Web site as a tribute to the man and the scientist behind the award: http://vonhippel.mrs.org. It is with great pleasure that we present the following articles celebrating von Hippel's life and works. □

Mildred S. Dresselhaus



Praveen Chaudhari

Mildred S. Dresselhaus, Guest Editor for this issue of *MRS Bulletin,* has been an Institute Professor at the Massachusetts Institute of Technology since 1985. She received her undergraduate education at Hunter College in New York City. After a year of study at the University of Cambridge and another year at Harvard University, she completed her PhD degree at the University of Chicago in 1958. Following her doctoral studies, she spent two years at Cornell University as a National Science Foundation postdoctoral fellow, and then seven years as a staff member of the MIT Lincoln Laboratory in the Solid State Physics Division. She joined the MIT faculty in the Department of Electrical Engineering and Computer Science in 1967, followed by the Department of Physics in 1983, and finally her current position. She also served as director of the Office of Science at the U.S. Department of Energy in 2000–2001 and currently chairs the governing board of the American Institute of Physics. Her research interests are in experimental solid-state physics, particularly in carbon-related materials and novel forms of carbon, including fullerenes, carbon nanotubes, porous carbons, activated carbons, and carbon aerogels, as well as other nanostructures such as bismuth nanowires and the use of nanostructures in low-dimensional thermoelectricity.

Dresselhaus is a member of the National Academy of Sciences, the National Academy of Engineering, and the American Philosophical Society. She is a fellow of the American Academy of Arts and Sciences, the American Physical Society, IEEE, the Materials Research Society, the Society of Women Engineers, the American Association for the Advancement of Science, and the American Carbon Society. She has served as president of the American Physical Society, treasurer of the National Academy of Sciences, president of the American Association for the Advancement of Science (AAAS), and a member of numerous advisory committees and councils. She has received numerous awards, including the National Medal of Science and 21 honorary doctorates, and is the co-author of four books on carbon science.

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Praveen Chaudhari, Guest Editor for this issue of *MRS Bulletin,* has been the director of Brookhaven National Laboratory since 2003. He received his doctoral degree from the Massachusetts Institute of Technology in 1966. He joined IBM Research the same year and over the years carried out research in materials while advancing to an appointment as director in

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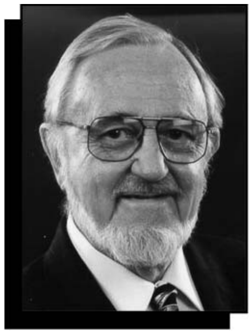
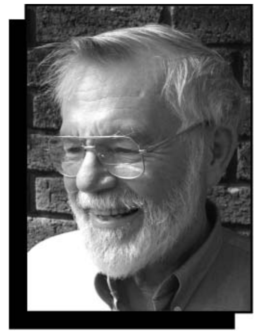
Morrel H. Cohen



L. Eric Cross

Jack J.J.M. Donners



Alan B. Fowler

John Bannister Goodenough

1981 and then vice president of science in 1982.

Chaudhari has served on numerous advisory committees to universities, professional societies, and institutions and is a member of the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences. He has won a number of awards, including the National Medal of Technology (1995), presented by President Clinton. He was executive secretary of President Reagan's Advisory Council on Superconductivity (1988) and a member of the National Commission on Superconductivity that reported its findings to President G.H.W. Bush (1989). He has served on the U.S. National Critical Technologies Panel (1992 and 1993).

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Morrel H. Cohen is a Distinguished Scientist and member of the graduate faculty in the Department of Physics and Astronomy at Rutgers University. He received a BSc degree and an honorary DSc degree from Worcester Polytechnic Institute in 1947 and 1973, respectively. He received an MA degree in 1948 from Dartmouth College and a PhD degree in physics in 1952 from the University of California, Berkeley. His current research interests include electronic structure theory, first-principles studies of enzyme activity mechanisms, the foundations of chemical reactivity theory in density functional theory, and analyzing economic phenomena with statistical physics methods. He is a fellow of the American Physical Society and the American Association for the Advancement of Science, as well as a member of the National Academy of Sciences.

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L. Eric Cross is an Evan Pugh Professor of electrical engineering at the Pennsylvania State University. He received BS and PhD degrees in physics from Leeds University, where he proceeded to become a University Scholar, assistant professor, and ICI fellow. He was also a senior scientist at the Electrical Research Association (ERA) in England. Cross joined the faculty at the Pennsylvania State University in 1961 as a research associate in ceramics, and later became a senior research associate and professor of solid state science in the Materials Research Laboratory. His research interests are in the field of ferroelectric materials and their applications as dielectrics in capacitors and as piezoelectric and electrostrictive transducers and actuators for medical ultrasound and undersea communication. His work on the phenomenology of ferroelectricity and specifically on the special group of materials known as relaxor ferroelectrics has received international recognition.

Cross is a member of the National Academy of Engineering and a fellow of the American Physical Society, ACerS, the IEEE, and the American Optical Society. He is a member of the Defense Sciences Research Council, which is the senior academic advisory group to the Defense Advanced Research Projects Agency (DARPA). He is also one of the two permanent members of the International Union of Pure and Applied Physics (IUPAP) advisory group on ferroelectricity. He has published more than 650 articles on topics in ferroelectricity and holds some 13 patents.

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Jack J.J.M. Donners is a postdoctoral fellow at the Institute for BioNanotechnology in Medicine at Northwestern University in Chicago. In 1998, he received his master's degree in chemistry (with R.J.M. Nolte) at the University of Nijmegen, the Netherlands; in 2002, he received his PhD degree in chemistry (with E.W. Meijer) from the Eindhoven University of Technology. His current research involves the application of self-assembling peptide amphiphile scaffolds capable of growth-factor binding to stem cell differentiation.

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Alan B. Fowler is now fully retired, having begun his career receiving BS and MS degrees in physics from Rensselaer Polytechnic Institute in 1951 and 1952, respectively. He served in the U.S. Army (1946–1948 and 1952–1953); when he was recalled to the Army, he was assigned to the Signal Corps Laboratory at Camp Evans, N.J. He then moved on to work part-time at Raytheon's Research Division while attending Harvard. After earning his PhD degree in applied physics from Harvard in 1958, he accepted a staff position in the IBM Research Division, where he worked until 1993, leaving as an IBM fellow and having served in various management positions over the years.

Fowler's best-known work was in 2D electron gases in MOSFETs. He has received medals from APS, IEEE, and the Franklin Institute, and he is a fellow of the National Academy of Sciences, the National Academy of Engineering, the American Academy of Arts and Sciences, the Royal Society of London, the IEEE, and APS.

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John Bannister Goodenough is the Virginia H. Cockrell Centennial Chair of Engineering and a professor in the departments of Mechanical Engineering and Electrical and Computer Engineering at the University of Texas at Austin. He studied mathematics at Yale University, meteorology in U.S. Army Air Force cadet training, and physics at the University of Chicago, receiving his PhD degree in 1952. In addition to consulting for various firms in both the United States and the United Kingdom,

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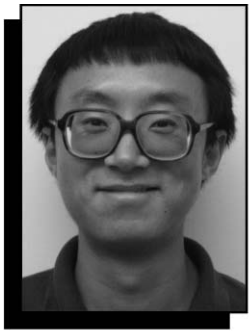

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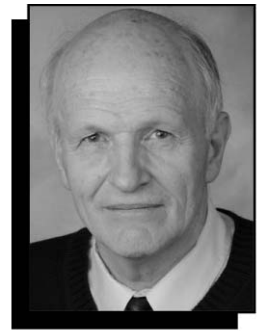

Frank N. von Hippel

Goodenough was a USAAF captain, a research engineer at the Westinghouse Research Corp., a research scientist and group leader at MIT's Lincoln Laboratory, and finally, a professor and head of the Inorganic Chemistry Laboratory at the University of Oxford, at which point he accepted his current position with UT. His principal areas of research are digital computer components, transition metal compounds, metals, and materials for alternate energy technologies.

Goodenough has received numerous awards and honors, including the MRS Von Hippel Award in 1989, and most recently, the Japan Prize. He is a member of numerous scientific societies and serves on the editorial boards for the *Indian Journal of Pure & Applied Physics* and *Comptes Rendus.* He is also currently an associate editor for six journals, including the *Materials Research Bulletin,* and an advisor to various scientific councils and boards around the world.

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Liang-shi Li has been a postdoctoral researcher in the group of Samuel I. Stupp at Northwestern University since 2003. He received a BS degree in chemical physics and an MS degree in physics from the University of Science and Technology of China; his PhD degree in chemistry was received under the guidance of A. Paul Alivisatos at the University of California, Berkeley. His PhD work involved synthesis, characterization, and self-assemblies of CdSe nanorods, and his current research focuses on one-dimensional organic self-assemblies.

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Alvaro Mata is a postdoctoral fellow working with Samuel I. Stupp at the Institute for BioNanotechnology in Medicine (IBNAM) at Northwestern University. He received his BS degree from the University of Kansas in 1998, his MS degree from the University of Strathclyde (Glasgow, U.K.) in 1999, and his DEng degree in biomedical engineering from Cleveland State University in 2005. Mata's research focuses on combining microfabrication technology with molecularly designed nanomaterials for tissue engineering applications.

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Robert E. Newnham is professor emeritus of solid-state science and a former associate director of the Materials Research Laboratory at the Pennsylvania State University. Prior to joining the Penn State faculty, he taught in the Electrical Engineering Department at the Massachusetts Institute of Technology and worked for Arthur von Hippel in the Laboratory for Insulation Research.

Among Newnham's recent awards are the Kingery Award from the American Ceramic Society, the Turnbull Lectureship of the Materials Research Society, the Third Millennium Medal of IEEE, and the Benjamin Franklin Medal in Electrical Engineering from the Franklin Institute. He is also active in several professional societies, having served as editor of the *Journal of the American Ceramic Society,* secretary of the Materials Research Society, president of the American Crystallographic Association, and Distinguished Lecturer for the IEEE. As a member of the National Academy of Engineering, Newnham has written more than 500 research papers and 20 patents on electroceramics and composite materials for electronic and acoustic applications. His most recent book is *Properties of Materials: Anisotropy, Symmetry and Structure,* published by Oxford University Press.

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Stupp's areas of research include supramolecular materials science and self-assembly, chemical synthesis of molecules programmed for self-organization into functional materials, biomaterials designed for interactions with cells and as scaffolds for tissue engineering, and templating processes for nanostructured inorganic materials including biominerals and semiconductors.

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