MARTIN P. HARMER

PROFESSIONAL BACKGROUND:

Current position: Senior Faculty Advisor for Research Initiatives, P.C. Rossin College of Engineering and Applied Science, Lehigh University, Alcoa Foundation Distinguished Professor of Material Science and Engineering, Lehigh University.

Appointments held:

2003- 2014: Director, Center for Advanced Materials and Nanotechnology (CAMN), Lehigh University.
1992-2003: Director, Materials Research Center (MRC), Lehigh University.
1988-1992: Director, Ceramics Research Laboratory, Lehigh University.
1988-present: Full Professor, Material Science and Engineering, Lehigh University.
1984-1988: Associate Professor, Material Science and Engineering, Lehigh University.
1980-1984: Assistant Professor, Material Science and Engineering, Lehigh University.

Education and Degrees:

1995 Doctor of Science (higher doctorate), Ceramics, University of Leeds, England (Awarded to individuals that have distinguished themselves by their original contributions to scholarship by means of a substantial and sustained contribution which has led to international recognition).
1980 Doctor of Philosophy, Ceramics, University of Leeds, England
1977-1978 Visiting Scholar, University of California Berkeley, graduate training in electron microscopy with Professor Gareth Thomas
1976 Bachelor of Science, 1st Class Honors, Ceramics, University of Leeds, England

International and National Awards and Recognition:

2015 Distinguished Life Member, American Ceramic Society, for “preeminent members who have made great advances in ceramic science and technology, given significant contributions to the benefit of the Society, and who have helped mentor and inspire our younger leaders through their research and teaching.”
2014 1992,1986,1984 Rowland B. Snow Award, American Ceramic Society
2014 TechConnect National Innovation Award
2011 Institute of Material Science Distinguished Lecture Award, previous recipients include six Nobel laureates, University of Connecticut.
2010 W. David Kingery Lifetime Achievement Award, American Ceramic Society, in recognition of using systematic experiments to resolve longstanding questions in ceramic science
2008 Robert B. Sosman Memorial Award, Highest Honor for Basic Science Achievement, American Ceramic Society. A Symposium on Kinetic Engineering of Interfacial Transport Processes was organized in honor of the awardee

2007 Member, World Academy of Ceramics
2007-2016 Editor, Acta Materialia
2006 Humboldt Award for Senior Scientists, Alexander von Humboldt Foundation
2002 Member, European Academy of Sciences
2002 ISI Most Highly Cited Researcher
1998 G. C. Kuczynski Prize, International Institute for the Science of Sintering
1998 Ross Coffin Purdy Award for Best Paper, American Ceramic Society
1998 Richard M. Fulrath Award, American Ceramic Society
1996 Creativity Award, National Science Foundation
1995 Doctor of Science, Leeds University, England
1993 Fellow, American Ceramic Society
1991 Chair, Gordon Research Conference on Solid State Studies in Ceramics
1989 Member, International Institute for the Science of Sintering
1989 DuPont Faculty Award
1985 Alcoa Foundation Award
1984-2010 International Ceramographic Contest Winners (~60 total)
1984 NSF Presidential Young Investigator Award, The President of the United States of America, Ronald Reagan.
1984 IBM Faculty Development Award.
1980-present Approximately 100 Ceramographic Contest Awards

Other Significant Awards

2007 Ben Franklin Technology Partners Innovation Award
2006 Teaching Excellence Award, College of Engineering, Lehigh University
2004 Hillman Faculty Award for outstanding faculty service and accomplishment, Lehigh University
2003 Engineering Ingenuity Award, College of Engineering, Lehigh University
1999, 2005, 2006 Gilbert E. Doan '19 Award to the Professor who "has best served them as mentor, in the Technical, Civic, Moral, and Spiritual dimensions of their education."
1990 Eleanor and Joseph F. Libsch Outstanding Researcher Award, Lehigh University

PROFESSIONAL ACHIEVEMENTS:

1. **Notable Technical and Professional Accomplishments:**

Professor Harmer is internationally recognized for his fundamental and groundbreaking work in the science and engineering of ceramic materials, which has had a significant impact on three important topics of the field. The following sections provide descriptive highlights of his accomplishments for each of the topical areas.

A. *Processing, interfaces and microstructure control*

The early work:

Professor Harmer's career began at Leeds where he pioneered the principles and practice of "fast-firing" as an effective means to improve sintered ceramic microstructures. Fast firing has subsequently become an established fabrication route in the industry. His early career at Lehigh focused on conducting critical model experiments combined with kinetic analytical approaches to elucidate the role of additives (notably MgO) in the sintering and grain growth of alumina. His group was the first to demonstrate unambiguously that MgO decreases grain boundary mobility in alumina, which had been a highly contentious issue for several decades. He devised a new form of microstructure development map, which is useful for illustrating the competing effects of dopants on microstructure development, which is now featured in many textbooks. His work on model tailored final-stage microstructures was instrumental in testing prevailing theories concerning the interplay between the kinetics and thermodynamics of sintering, and in establishing acceptance of grain boundary diffusion as a dominant transport mechanism in sintering. His fundamental work on the effect of second phase particles on pinning of grain boundary motion challenged the established preconceived thinking, which was recognized by the granting of two prestigious best-paper awards - the Ross Coffin Purdy Award and the G. C. Kuczynski Prize. He and his colleagues also developed models and engineering principles in order to understand and control the reaction bonded aluminum oxide (RBAO) process, which has enabled the near net-shape fabrication of some of the largest components ever produced by this method.

The contemporary work:

Professor Harmer's contemporary work is on the concept of grain boundary "complexions" and has attracted a considerable amount of international attention, and has been featured prominently in numerous recent articles including Science, a 48 page commissioned overview article published in January 2014 Acta Materialia and a 2012 Feature article in the Journal of the American Ceramic Society entitled "Challenges in Ceramic Science: A Report from the Workshop on Emerging Research Areas in Ceramic Science" by Rohrer et al, which identified Harmers work as a grand challenge in the field of ceramics.

The complexions concept pioneered by Harmer's group has the potential to transform the way scientists and engineers view and treat interfaces in materials, which control the performance and reliability of most materials. Grain boundary complexions (GBC's) were theoretically predicted to exist by thermodynamic modeling, but his group's work represents the most comprehensive characterization and proof of their existence in a real material system. The concept has general applicability to both ceramic and metallic systems. Grain boundary complexions are distinct thermodynamically stable states at grain boundaries, which show phase-like behavior in that they can transform to different complexions as a function of temperature, interfacial chemistry, stress, and grain misorientation. Harmer's group has identified six distinct types of complexions in alumina under different conditions of temperature and doping, using the technique of high-resolution aberration corrected scanning transmission electron microscopy. Different interface complexions exhibit drastically different transport kinetics (parallel and perpendicular) and different physical properties, opening up the prospect for mechanism-informed property tailoring.

Dr. Harmer's work on complexions has led to new explanations for the origin of abnormal grain growth in polycrystalline material and the cause of liquid metal embrittlement in metal alloys such as Bi-containing nickel, problems that leading researchers in the field have struggled to explain for the past 50 years. Using this new fundamental knowledge he has been able to control the abnormal grain growth process to engineering advantage and reproducibly convert tubes of polycrystalline alumina into single crystal sapphire. Most recently he and his collaborators at Carnegie Mellon University have demonstrated that grain boundary complexions exhibit time-temperature-transformations (TTT's) analogous to bulk phase transformations paving the way for a new approach to engineer microstructure and properties of polycrystalline materials. These discoveries have also led to him becoming the co-founder of a new spin-off company, Materials Complexions Inc., in Bethlehem PA, which works with larger companies to understand how to control materials properties by controlling the grain boundary complexions.

B. Ferroelectric ceramics

Professor Harmer's early pioneering work on the control of microchemical ordering and domain structures in lead-based relaxor ferroelectrics is widely appreciated and highly cited. Dr. Harmer became engaged in research on relaxor ferroelectrics after spending a short sabbatical leave working with Professor L. Eric Cross at The Pennsylvania State University in the early eighties. He published the first direct observations of thermally-induced microchemically ordered domain structures in the model relaxor material lead scandium tantalate (PST). His most highly cited work (500 citations currently) is the paper that he published with his colleague Dr. Chan and his graduate student Jie Chen on the control of microchemical ordering in the classic prototypical relaxor ferroelectric system lead magnesium niobate (PMN). This fundamental work demonstrated for the first time how the degree of microchemical domain ordering in PMN could be controlled (promoted or suppressed) in a highly systematic manner, by controlled doping with either Na and/or La on the A-sites, with corresponding adjustments in the Mg/Nb ratio. This classic work also confirmed that the ordered arrangement of the nanodomains in PMN represented a doubling of the unit cell (so-called 1:1 ordering), which could be explained by two alternative models of 1:1 ordering sequences (the so-called space charge and stoichiometric ordering models). The same ideas were extended to barium based perovskite materials (such as BZN) important for microwave communications. These fundamental ordering studies have helped to lay the foundation for understanding how to engineer cation ordering in perovskites in general, which has had a major impact on the ability to engineer new electroceramic materials with superior performance.

Professor Harmer and his group pioneered the technique of single crystal conversion in polycrystalline PMN:PT as a novel alternative to the traditional melt processing methods such as the Czokralski method. The viability of using the so-called solid-state conversion method to fabricate single crystal PMN:PT has been proven and patented by Harmer's group. The most promising near term application of the PMN:PT single crystals is for the next generation of medical ultrasound transducers. Professor Harmer's former graduate student Jie Chen has played a leading role as corporate staff scientist for Philips Medical Systems in the commercialization of ultrasound transducers utilizing single crystals. The new transducers show dramatic improvements in efficiency, sensitivity and bandwidth.

Professor Harmer is also highly regarded for his scientific contributions in working with Professor Don Smyth on the defect chemistry and microstructure of barium titanate based ceramics, where his individual role was to apply advanced techniques of electron microscopy to validate models of defect compensation mechanisms. He was one of the first to apply the technique of ALCHEMI (atom location by channeling enhanced microanalysis) in perovskites, which he exploited to verify that Ca could be forced to occupy Ti sites in barium titanate, which had an important implication to the development of multilayer capacitor dielectrics with base metal electrodes. His group also made the fundamental discovery of a new type of 90-degree ferroelectric domain configuration in Ca-doped barium titanate through a combination of carefully correlated SEM and TEM investigations.

C. Structural ceramics

Professor Harmer and his colleagues including Professor Chan and Professor Rickman have been at the forefront of research on the mechanisms and control of creep resistance of alumina and associated transport processes, such as grain boundary diffusion and oxidation through alumina scales on metal alloys. Their group was the first to discover that doping of alumina with the rare-earth oxide Y_2O_3 reduced the creep rate by up to two orders of magnitude. Subsequently, there has been a worldwide effort to understand the mechanism and exploit the effect, which his team has made a significant contribution towards through a comprehensive series of carefully controlled systematic studies correlating transport kinetic measurements with detailed microstructural and atomistic characterization by HRTEM and EXAFS. The group's work has highlighted the importance of the role of solute segregation of oversized ions to the grain boundaries in inhibiting grain boundary transport (diffusion and sliding). They have developed co-doping strategies in order to maximize creep resistance, and shown for example that co-doping of alumina with Nd_20_3 and $Zr0_2$ can lower the creep rate by approximately three orders of magnitude, which suppresses grain boundary diffusion and sliding transport processes so dramatically that lattice diffusion becomes rate limiting. Work on the creep of rare-earth doped alumina's has had an impact on the development of creep resistant alumina fibers in engineering ceramics. It motivated the 3M corporation to introduce a new generation of Y_2O_3-doped alumina creep resistant fibers under the trade name of Nextel 650. It has also contributed to the understanding of the "reactive element effect" for oxidation suppression in high temperature super alloys.

Professor Harmer and his colleagues group conducted the first rigorous scientific investigation into the cause of the strengthening mechanism in alumina-silicon carbide ceramic nanocomposite materials popularized by Niihara, which was published in a highly cited paper by Zhao et al. in 1993 (217 citations). This classic study (supported by subsequent detailed scientific investigations conducted by his group and by others from around the world) established that the strengthening effect was in fact caused by a reduction in the flaw size due to a combination of apparent toughening from machining-induced residual stress and crack healing from thermal annealing. They also demonstrated that these materials exhibited a 2-3 orders increase in tensile creep resistance over conventional alumina.

Professor Harmer and co-workers are also recognized for the substantial body of work that they have conducted on microstructural engineering with duplex (two-phase) and laminar oxide ceramic composites, in order to improve the room-temperature mechanical reliability (e.g. flaw tolerance) and high-temperature microstructural stability (e.g. resistance to grain growth) of structural ceramic materials. Dramatic property improvements have resulted from the designed incorporation of spray-dried agglomerates into two-phase ceramic matrices, which is a simple and cost effective fabrication route. They have also demonstrated that it is possible to design trilayer-laminated composites having high toughness and flaw tolerance properties, without sacrificing strength. AFOSR has highlighted Lehigh's research on the effective use of dual phase mixing to promote high coarsening resistance and associated microstructural stability at high temperatures in oxide structural ceramics.

2. Leadership and Outreach

Professor Harmer has been responsible for leading three major multi-institutional multi-million dollar research programs, in addition to his leadership as Director of the Center for Advanced Materials and Nanotechnology, which is one of the largest research centers on campus at Lehigh. Individually, he has been one of the most productive researchers at Lehigh University raising over a million dollars annually for most of his academic career.

The first major program is a Department of Defense Multidisciplinary University Research Initiative (MURI) program funded by the Office of Naval Research. The project started in June 2011 and received $7.5 million in funding for a 5-year program entitled "Tailoring of Atomic-scale Interphase Complexions for Mechanism-Informed Material Design". Harmer leads a team of scientists from Lehigh, Carnegie-Mellon, UC San Diego, Illinois and Kutztown universities to determine how the atomic structure of grain boundary complexions affect the mechanical, electrical and thermal properties of a wide range of strategic engineering materials.

The second program is the Pennsylvania Materials Research Science and Engineering Center (PA MRSEC), which is funded by the Commonwealth of Pennsylvania Department of Community and Economic Development ($7.2M since 2001), which was created and led by Professor Harmer. Under this program and Professor Harmer's leadership Lehigh University and Carnegie Mellon University have collaborated together, with many industrial partners as well as other universities and schools in Pennsylvania, in order to provide unique, accessible engineering equipment and expertise for universities and industry, opportunities for graduate research and engineering advancement, multi-institutional education and outreach programs, and student experience with PA technology companies. Since its conception the program has had 380 company interactions, leading to the creation of many new technologies and engineering products. The granting of the 2007 prestigious Technology Partners Innovation award to Professor Harmer's team by the Ben Franklin Technology Partners of PA recognized this. Through the PA MRSEC program Professor Harmer also established and developed a new organization called the Lehigh Nanotechnology Network (LNN), which has been recognized as a model organization, which connects the university with 90 government, and technology organizations around and outside the region.

Dr. Harmer also created an innovative educational program called the MatPAC - the Materials Pennsylvania Coalition. The MatPAC enables the sharing of graduate level courses in engineering amongst the six major universities across the State of Pennsylvania (Penn State, CMU, Lehigh, Drexel, Pitt and UPenn) via live videoconferencing, and also coordinates an Outstanding Graduate Student Award and Seminar series across the Commonwealth. The PA MRSEC also incorporates various outreach activities such as the *Imaginations* program, which enables middle school teachers and their students to remotely access and operate electron microscopes at the university to study real world solutions to engineering problems.

The third major program led by Professor Harmer was the $4M Mid-Atlantic Partnership in Nanomaterials project between NASA Goddard Space Flight Center, Lehigh University and various industry partners. As the P.I. for this program Professor Harmer led a team of approximately 20 engineers and scientists from multiple academic disciplines at Lehigh to interact with engineers at NASA Goddard in order to develop solutions to important engineering problems relevant to space missions. Members of his engineering team studied the reliability of micro shutter MEMS devices used in the James Webb Telescope, enabled the testing and validation of a transparent polycrystalline ceramic of spinel for windows for the crew exploration vehicle, created a novel ceramic cooling device, and developed a prototype for a new gas sensor which tested successfully in a recent space mission. Professor Harmer also led a team of education professionals who engaged in important outreach programs with local NASA explorer schools, and who organized an exhibit for the public at the DaVinci Discovery Center in Allentown PA.

In addition to the above Dr. Harmer has established a highly successful series of international workshops on interfaces known as “International Workshop on Interfaces at Bear Creek”. The first workshop was held in October 2006 at Bear Creek Mountain Resort in Macungie PA and was co-organized with Rowland Cannon and Manfred Ruehle. Subsequent workshops were held in 2009, 2012 and 2016. The workshops are modeled after the highly acclaimed workshops organized by the Max Planck Institute in Germany, which bring together leading senior researchers as well as junior researchers and graduate students in a remote setting for a week of intensive discussion and scientific exchange.

SERVICE TO THE AMERICAN CERAMIC SOCIETY

Member since 1981
Division affiliation: Basic Science

Duties:

2015-2018 Member of Board of Directors
1984-2007 Associate Editor, Journal of the American Ceramic Society
2004-2009 Richard M. Fulrath Award Committee
2002-2004 Nominating Committee
1998-2001 Ross Coffin Purdy Award Committee
1995-1998 Sosman Memorial Lecturer Award Committee
1996-1997 Fellows Committee
1994-1995 Chair, Basic Science Division
1993-1994 Chair-elect, Basic Science Division
1992-1993 Program Chair for Basic Science Division for 1993 Annual Meeting
1991-1992 Symposium Organizer, Symposium on Interpenetrating Phase Ceramics
1992-1993 Vice-chair, Basic Science Division
1991-1992 Secretary, Basic Science Division
1990-1994 Executive officer, Lehigh Valley Section

PRODUCTIVE SCHOLARSHIP

Professor Harmer has published extensively in refereed journals including highly selective journals such as Science and Acta Materialia, holds 3 patents, and has trained 62 Ph.D. students and mentored 25 post-doctoral researchers. He has been identified as an ISI highly cited researcher. He has 8765 citations and an h-index of 52 from Google Scholar.

PUBLICATIONS

1. O. L. Krivanek, M. P. Harmer and R. Geiss, "Electron Microscopy and Grain Boundary Segregation in Al_2O_3," Proc. Ninth Intl. Conf. on Electron Microscopy, Toronto, 1, 414, Imperial Press, Ontario (1978).

2. M. P. Harmer, E. W. Roberts and R. J. Brook, "Rapid Sintering of Pure and Doped α-Al_2O_3," Trans. J. Br. Ceram. Soc. 78 [1], 22 (1979).

3. M. P. Harmer, E. W. Roberts and R. J. Brook, "Fast Firing of Alumina Ceramics," in Energy and Ceramics, Mat. Sci. Mono. 6, 155, Elsevier Science Publishers (1980).

4. M. P. Harmer and R. J. Brook, "The Effect of MgO Additions on the Kinetics of Hot Pressing in Al_2O_3," J. Mat. Sci. 15, 3017 (1980).

5. R. J. Brook and M. P. Harmer, "Densification Data and Defect Types in Al_2O_3," in Computer Simulation in the Chemistry and Physics of Solids, ed. C.R.A. Catlow, W. C. Mackrodt, V. R. Saunders, SRC, Dewsbury, pp. 80-81 (1980).

6. M. P. Harmer and D. Hind, "A Low Cost High Temperature Furnace System for Sintering Studies," Ceramics Int. News, 1, 22 (1981).

7. M. P. Harmer and R. J. Brook, "Fast Firing-Microstructural Benefits," Trans. J. Brit. Ceram. Soc. 80, 147 (1981).

8. M. P. Harmer, "Controlled Reduction of Electric Arc Furnace Dust," Final Report to Department of Commerce, NTIS No. PB82-182593, Section VI.D1 (1982).

9. M. P. Harmer, "Characterization of Magnetically Separated Electric Arc Furnace Dust," Final Report to Department of Commerce, NTIS No. PB82-182593, Section II.D1 (1982).

10. M. P. Harmer, R. K. Mishra and G. Thomas, "Electron Microscopy Study of Annealed 7(Ni, Zn, Co) Fe_2O_4," J. Am. Ceram. Soc. 66, C44 (1983).

11. M. P. Harmer, S. J. Bennison and C. Narayan, "Microstructural Characterization of Abnormal Grain Growth Development in Al_2O_3," Mat. Sci. Res. 15, 309 (1983).

12. S. J. Bennison and M. P. Harmer, "Grain Growth and Cavity Formation in MgO-Doped Al_2O_3," Adv. in Ceramics 6, 177 (1983).

13. S. J. Bennison and M. P. Harmer, "Microstructural Studies of Abnormal Grain Growth Development in Al_2O_3," in Ceramic Powders, ed. P. Vincenzini, Elsevier Scientific, Amsterdam, The Netherlands, pp. 929-938 (1983).

14. N. H. Keyser, J. R. Porter, A. J. Valentino, M. P. Harmer and J. I. Goldstein, "Characterization, Recovery and Recycling of Electric Arc Furnace Dust," Proceedings of a Symposium on Iron and Steel Pollution Abatement Technology for 1981, Chicago, pp. 246-260 (1983).

15. S. J. Bennison and M. P. Harmer, "Effect of MgO Solute on the Kinetics of Grain Growth in Al_2O_3," J. Am. Ceram. Soc. 66 [5], C90 (1983).

16. M. P. Harmer, Y. H. Hu, M. Lal and D. M. Smyth, "The Effects of Composition and Microstructure on Electrical Degradation in $BaTiO_3$," Ferroelectrics, 49, 71 (1983).

17. N. Stenton and M.P. Harmer, "Electron Microscopy Studies of a $SrTiO_3$ Based-Boundary-Layer Material," Adv. in Ceramics 7, 156 (1984).

18. H. Chan, M. P. Harmer, M. Lal and D. M. Smyth, "Calcium Site Occupancy in $BaTiO_3$," Materials Research Society Symposium Proc., 31, 345 (1984).

19. M. P. Harmer, A. Bhalla, B. Fox and L. E. Cross, "Electron Microscopy of Ordered Domains in Lead Scandium Tantalate $Pb(Sc_{0.5}\,Ta_{0.5})O_3$," Materials Letters, 2 [4A], 278 (1984).

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21. M. P. Harmer, "The Use of Solid Solution Additives in Ceramic Processing," in Advances in Ceramics, 10, pp. 679-96, Ed. W.D. Kingery, The American Ceramic Society, Columbus, Ohio (1985).

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25. S. J. Bennison and M. P. Harmer, "Swelling of Hot Pressed Al_2O_3," J. Am. Ceram. Soc., 68 [11], 591 (1985).

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29. Y. H. Hu, H. M. Chan, X. Zhang and M. P. Harmer, "Scanning Electron Microscopy and Transmission Electron Microscopy of Ferroelectric Domains in Doped $BaTiO_3$," J. Am. Ceram. Soc., 69 [8], 594 (1986).

30. H. M. Chan, M. P. Harmer, and D. M. Smyth, "Compensating Defects in Highly Donor-Doped $BaTiO_3$," J. Am. Ceram. Soc., 69 [6], 507-510 (1986).

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35. Z. Q. Zhuang, M. P. Harmer, D. M. Smyth, and R. E. Newnham, "The Effect of Octahedrally-Coordinated Calcium on the Ferroelectric Transition in $BaTiO_3$," Proc. Sixth IEEE Int. Symp. on Application of Ferroelectrics, 122 (1986).

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49. M. P. Harmer, "Science of Sintering as Related to Ceramic Powder Processing," Ceramic Transactions, 1, Part B, 824-39, Ceramic Powder Science, Am. Ceram. Soc. (1988).

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