Focused Interest Groups Propel Innovation in the Emerging Data-Driven Hardware Ecosystem

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Over the past several decades, the science of electron microscopy (EM) has risen to become one of the cornerstone approaches to understanding material structure, chemistry, and defects at exceptional spatial resolution. This rise can be attributed to the hard work of researchers and companies who have pushed the bounds of instrumentation and analysis, but it is also the result of advocacy by members of professional societies. Such advocacy is exemplified by the Aberration Corrected EM (ACEM) focused interest group (FIG) of the Microscopy Society of America (MSA), which has played an important role in facilitating new hardware developments, promoting the exchange of ideas to catalyze discovery, and building the next generation of leaders in electron microscopy. From the early 2000s to the present, aberration correction has moved from proof-of-concept instrumentation to an established technique, providing unprecedented improvements in spatial and chemical resolution for breakthroughs in chemistry, physics, and materials science.

Originally founded as the Materials Research in an Aberration-Free Environment (MRAFE) FIG in 2002, MRAFE hosted several pre-meeting congresses (PMCs) as part of the Microscopy & Microanalysis (M&M) meeting (Figure 1). The FIG serves as a home for researchers in this area, helping them to get feedback and support from like-minded colleagues. The first chairman was Christian Kisielowski, with subsequent officers including other early proponents of the technique, such as Ian Anderson, Chris Kiely, and Larry Allard. The PMC regularly featured invited talks from developers of aberration correctors and electron microscopes, along with experts in applying these new instruments and techniques to materials problems. Reflecting this set of interests, after the 2010 meeting, the name of the FIG was changed to the ACEM. The founding and growth of the FIG spread awareness that aberration correction was the future of microscopy and that sustained development of hardware and techniques was necessary to bring it into the mainstream.

When asked to comment on the history of the FIG, Larry Allard said, "The Materials Research in an Aberration-Free Environment Focused Interest Group of the Microscopy Society of America (more generally called the "aberration-corrected FIG" by members), has been an important contributor to the growth and development of the field of aberration-corrected electron microscopy, through its well-attended Pre-Meeting Congress events and in-week symposia during M&M meetings over the past 2 decades. As an early adopter of aberration-correction technology nearly 20 years ago, I have enjoyed playing a role in the growth of the FIG from a group where only a few members had access to corrected instruments, to one in which a large number of members were users of the technology and am looking forward to seeing what the future holds for the field!"

Today aberration correction is common in many laboratories around the world, and perhaps the pace of development has slowed with more emphasis now on associated techniques. For example, new monochromator designs offer improved energy resolution while maintaining high spatial resolution, and new detectors produce faster and more sensitive streams of data. As a result, the FIG is now broadening its horizons to encompass other exciting emerging hardware developments. Following the M&M 2022 meeting in Portland, the FIG membership started a still-ongoing debate about changing its name to better recognize that, although high-resolution analysis continues to be a mainstay of electron microscopy, today such analysis takes many forms. The membership recognizes the continued need for a forum to discuss hardware, particularly new advanced sources, detectors, methodologies, and controllers. This refocusing of the FIG's objectives aims to bring it into complementary alignment with other FIGs, such as the newly formed EM Data Analysis and Management (EM-DAM) FIG, which aims to harness vast data from modern instrumentation. At its core, the ACEM FIG will remain focused on hardware developments, providing a welcoming environment in which both senior and junior researchers can connect. Some of the FIG's planned activities include hosting topical PMCs and developing tutorial materials for students on best practices. The ACEM FIG has also recently elected new leadership, including Dr. Andrew Lupini (ORNL) and Dr. David Bell (Harvard), who will take over for the existing chair, Dr. Steven R. Spurgeon (PNNL/UW), and secretary Dr. Shize Yang (ASU), respectively, in 2023.

The other big story in electron microscopy over the past decade has been the increasingly closer integration between microscopy and computation. Firstly, microscope operation and tuning are almost entirely computer-based in the modern era. Secondly, the availability of faster computing architectures, such as general-purpose GPUs, FPGAs, and massively parallel systems, has now allowed microscope simulations to reach increasing sophistication and scale. Thirdly, the availability of faster detectors has made the entire field of big-data

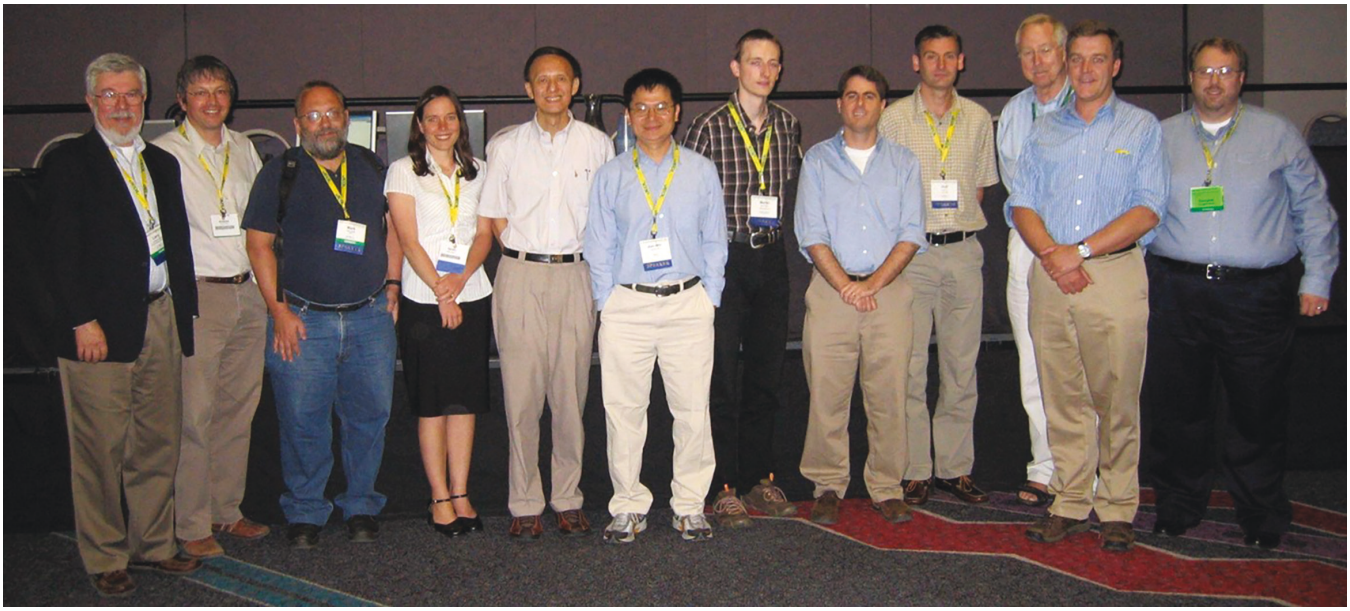

Figure 1: The invited speakers from the 2008 PMC. (Courtesy of Larry Allard, standing on the far left.)

electron microscopy possible, such as ultrafast diffraction, 4D-STEM, and time-resolved *in situ* studies. In many cases, approaches that were not feasible a few decades ago, such as software correction of microscope aberrations through electron ptychography or strain mapping through scanning nanobeam electron diffraction, have become routine. Looking to the future, these trends will only accelerate as machine learning integrates more tightly with electron microscopy operation and data analysis.

While the pace of developments in the field has been rapid and breathtaking, this situation also presents multiple challenges to a microscopist. Not only do they need to understand the microscope, but they also must be able to implement, or at least be aware of, analysis algorithms to extract the most information from their hard-gotten data. Analysis, reconstruction, and automation programs have consistently increased in their sophistication and complexity, making this area sometimes confusing to enter for an electron microscopist who probably comes from the experimental side of the field. To address these challenges, Dr. Colin Ophus and Dr. Alexander Rakowski of Lawrence Berkeley National Laboratory (LBNL) started the Electron Microscopy - Data Analysis and Management (EM-DAM) FIG in 2021. The EM-DAM aims to facilitate the integration of cutting-edge analysis programs, data management resources, and best practices by the general microscopy community. Since 2022, Dr. Debangshu Mukherjee from Oak Ridge National Laboratory (ORNL) and Wyeth Gibson from the University of California, Irvine have been chairing the EM-DAM FIG.

Along with providing a forum for computational electron microscopy, the EM-DAM FIG also aims to bridge the gap between transmission electron microscopy's physical and biological wings. The cryo-EM community has long faced many of the same challenges, including microscope automation, massive datasets from modern high-speed detectors, and sophisticated data analysis algorithms. For example, the Electron Microscopy Public Image Archive (EMPIAR) in the United Kingdom has functioned as a centralized data storage repository for cryo-EM datasets for over a decade. EMPIAR hosts over a petabyte of annotated open-access microscopy datasets, one of the largest such repositories in any scientific area. Such setups do not yet exist for materials microscopy, and we at the FIG aim to foster communication between these two disciplines of microscopy such that best practices can be learned and pitfalls avoided.

Overall, we believe that the most exciting story for the coming years in microscopy will probably be written by combining advances in *both* software and hardware. Recognizing the intertwined nature of the hardware and software developments, joint PMC (X64) between the ACEM and EM-DAM FIGs is taking place at M&M 2023, with speakers drawn from developers pushing forward in both of these often-complementary fields.

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