Liquid Cell Electron Microscopy

The first book on the topic, with each chapter written by pioneers in the field, this essential resource details the fundamental concepts, applications, and future developments of liquid cell electron microscopy.

This book describes the techniques that have been developed to image liquids in both transmission and scanning electron microscopes, including general strategies for examining liquids, closed and open cell electron microscopy, experimental design, resolution, and electron beam effects. A wealth of practical guidance is provided, and applications are described in areas such as electrochemistry, corrosion and batteries, nanocrystal growth, biomineralization, biomaterials and biological processes, beam-induced processing, and fluid physics. The book also looks ahead to the future development of the technique, discussing technical advances that will enable higher resolution, analytical microscopy, and even holography of liquid samples.

This is essential reading for researchers and practitioners alike.

Frances M. Ross is based at the IBM Thomas J. Watson Research Center, where she has built a program around a microscope with deposition and focused ion beam capabilities and developed closed liquid cell microscopy to image electrochemical processes. Previously she worked at the National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, and she has also been a Visiting Scientist at Lund University and an Adjunct Professor at Arizona State University. She received the UK Institute of Physics Boys Medal, the MRS Outstanding Young Investigator Award, and the MSA Burton Medal, holds an Honorary Doctorate from Lund University, and is a Fellow of APS, AAAS, MRS, MSA, and AVS.

Advances in Microscopy and Microanalysis

Microscopic visualization techniques range from atomic imaging to visualization of living cells at near nanometer spatial resolution, and advances in the field are fueled by developments in computation, image detection devices, labeling, and sample preparation strategies. Microscopy has proven to be one of the most attractive and progressive research tools available to the scientific community, and remains at the forefront of research in many disciplines, from nanotechnology to live cell molecular imaging.

This series reflects the diverse role of microscopy, defining it as any method of imaging objects of micrometer scale or less, and includes both introductory texts and highly technical and focused monographs for researchers and practitioners in materials and the life sciences.

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Preface and Acknowledgements

Electron microscopy amazes and educates us with its images of atomic level structure, measurements of nanoscale chemistry, and movies showing otherwise invisible phenomena. However, electron microscopy is generally used only on solid samples, since liquids, particularly those with low vapor pressure such as water, are challenging to image within the microscope vacuum. The difficulty of dealing with water and other liquids was recognized early on in the development of electron microscopy, but practical solutions to the engineering challenges appeared only recently with the advent of microfabrication and micromanipulation techniques. We can now build liquid cells that allow us to apply the powerful capabilities of the electron microscope to imaging and analysis of liquid specimens. This has opened up wonderful opportunities ranging from nanoscale materials and processes in liquids to biological structures imaged at high resolution without freezing or drying. Physical and chemical changes taking place within batteries during operation, the attachment of atoms during the self-assembly of nanocrystals, and protein structures within whole cells in liquid water are examples in which a microscopic view is providing unique insights.

This book describes the practical aspects of liquid cell electron microscopy. We start with a historical perspective, then consider several different strategies for experimental design as well as resolution and electron beam effects. We next describe research results in fields as diverse as energy storage, biomineralization, fluid physics, and the structure of different types of biomaterials in their native, hydrated state. We finally look forward to future experiments with improved spatial and temporal resolution or analytical capabilities that probe increasingly complex materials and processes.

The motivation for bringing these discussions together is the exciting current state of liquid cell electron microscopy. Since the equipment is not too expensive and generally works in existing electron microscopes, many programs involving electron microscopy of liquids have developed around the world. These projects have provided unique, high quality scientific information that frequently appears in high impact journals. Within just the last few years, electron microscopy experiments involving liquids have become a regular component of materials science and microscopy conferences, generating lively and occasionally confrontational discussions. Liquid cell electron microscopy in all its different variations is well positioned to improve its reach still further. The ease of use of the equipment is improving continuously, our understanding is becoming more quantitative, and new capabilities are appearing that allow further exploration of frontiers in materials, environmental science, life sciences, and beyond.

Combining the expertise of many materials scientists, physicists, biologists, and microscopists in this edited volume enables us to address two aims. One is to help electron microscopists by providing guidance on how to obtain meaningful data from experiments on liquid samples. This is addressed through the chapters on experimental design, artifacts, and quantification. The other aim is to provide information that will help scientists who are not microscopists to decide for themselves the value of adopting or collaborating on electron microscopy techniques for imaging and analysis of liquids. This is addressed through the descriptions of scientific questions that have already been answered, as well as the discussions of the current status and future capabilities for obtaining information on liquid samples. By drawing on the experience of many of the leaders in this field we hope this book will fulfill these two objectives. While we cover a broad range of topics, our intention is that not too much specialized knowledge is required in any one of them.

I am grateful for all the help I have received during this project. I would especially like to thank my family for their patience and enthusiastic support and my colleagues at IBM and Cambridge University Press for their understanding and help as this book came together. It has been a great pleasure and a powerful learning experience to collaborate with colleagues around the world. Although there are omissions – a field moving this quickly cannot be captured in a book – I hope that we can nevertheless give a snapshot of the evolution, current position, and future of liquid cell electron microscopy, and preview the remarkable opportunities that I believe will be realized in the future.

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