

Working Group on Polymers, Biomaterials, and Soft Matter

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1. Introduction

Polymers and soft condensed matter encompass the world around us. Their applications range from the nanoscopic (e.g., biomolecular material and copolymeric mesophases) to the microscopic (microelectronics) to the macroscopic (high performance structural composites) world. Synthetic polymers have now begun to mimic the biological world of macromolecules, such as DNA and proteins, as well as viruses and cells.

At present, our synthetic capabilities limit us to simple well-defined copolymers of the AB, ABA, BAB, or ABC type blocks where the polymer chains are covalently linked at the end. These polymers form well-ordered, nanoscale morphologies and can exist as liquids, semicrystalline solids, gels, and glasses. They represent ideal model systems for investigating the fundamental chemical and physical principles related to supramolecular formation, folding, and phase transitions. The ability to study hierarchical structures composed of nanoscopic organic/inorganic materials and dynamics on nanoscopic, microscopic, and macroscopic scales, as well as the kinetic processes of self-assembly, have made synchrotron radiation an invaluable tool.

Polymers, biomaterials, and soft-matter science, as subdisciplines of materials science, are of ever increasing importance, both from the fundamental and applied viewpoints. Can the ALS impact these area of

science? The answer is self evident. The soft and intermediate x-ray regime is well matched to the spatial and temporal scales relevant to structure and dynamics of polymers, biomaterials, and soft matter. New insights can be achieved by studying the kinetics and thermodynamics of phase transitions involving long chain molecules in bulk, solution, or environments of reduced dimensionality.

2. Opportunities in Polymers, Biomaterials, and Soft Matter

2.1 Miniaturized Advanced Materials for the New Millennium

2.1.1 Biomolecular Materials

An emerging area of science and engineering is miniaturization of materials and structures. The twenty-first century will witness the development of micromachines (e.g., robots tens of microns in size) able to explore extremely hostile environments. One example is micromachine exploration of deep-ocean floors under extreme pressures and temperatures. A second example is biomedical micromachines with molecular-level chemical sensing that will be injected into the body (a truly hostile environment) for non-invasive *in-vivo* diagnostic, as well as chemical and electrochemical treatments.

Self-assembly leads to a highly controlled method of producing nanoscale components for micromachines. Microchannels (Figure 1) can be used to self-assemble biomolecules (e.g., lipids, polypeptides, DNA, and biopolymers) on micro- and nanostructured surfaces. The highly oriented and variable dimension self-assemblies are used as templates for the processing of nano- and microscale inorganic/organic structures; for example, nanowires and nanoconduits.

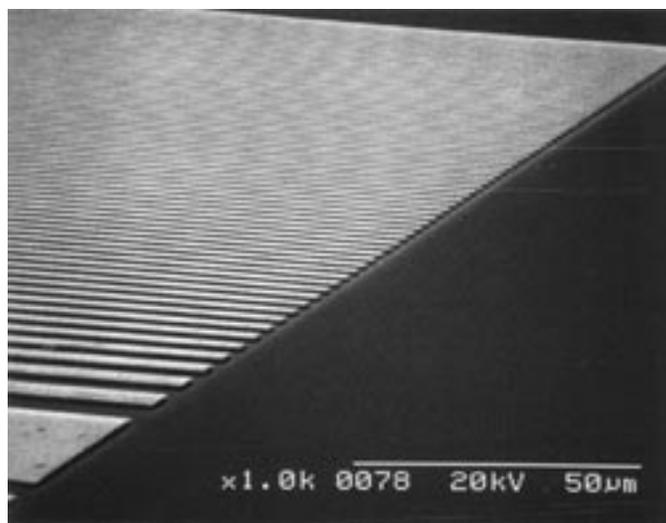


Figure 1. An example of variable-width (5000 nm to 500 nm) microchannels (silicon) used for directing the growth of variable-dimension biomolecular self-assemblies. Self-assemblies form templates for nanoscale inorganic/organic structures, e.g., to produce ultrathin wires or nanoconduits to serve as components of micromachines. [Figure courtesy of C. R. Safinya, University of California, Santa Barbara; see also "Structural Studies of DNA-Cationic Lipid Complexes Confined in Lithographically Patterned Microchannel Arrays," Y. Li, G. C. L. Wong, E. J. Caine, E. L. Hu, and C. R. Safinya, *International Journal of Thermophysics* (in press).]

There is a rapidly increasing demand for biocompatible materials including medical implants and *in-vivo* drug-delivery systems. Companies have reached market capitalizations of over a billion dollars on the strength of simple stent devices. However, it is clear that future development of more sophisticated biomaterials must be based on a precise knowledge of the interactions of organic-polymer surfaces, both with device substrates and with the biological environments in which they operate. Properly designed organic films bonded to silicon, metals, and other substrates may be extremely valuable in preventing immune and inflammatory responses to *in vivo* devices. This applies to products ranging from drug delivery microcapsules to dental implants or more generally, to any material that forms specific boundaries to living surfaces. Conversely, films can be designed that include molecular receptors that promote cell destruction by eliciting strong immune responses at localized sites such as tumors.

Biological systems operate at cell and subcellular dimensions; therefore, material properties including polymer uniformity, thickness, mechanical deformability, permeability, state of hydration, and surface charge must be characterized to dimensions below 100 nm. In a related context, newly developed imprinted polymers are being created with specific features, such as metal ion selectivity, that have tremendous potential use in remediation and sensor technology. At present, these materials lack structural characterization, and thus a better understanding is needed of the metal-ion binding sites within the polymer matrix. What is unique about these materials is that, rather than the local molecular configuration, the long-range polymer structures are the likely key to their behavior. X-ray spectromicroscopy is very well suited to such studies, though enhanced spatial resolution is crucial. Characterization of these advanced miniaturized materials will require the development of an anomalous high-resolution small-angle x-ray diffractometer (5-keV to 10-keV range) with 0.1- μm beam-size capability. It will also require the development of a microdiffraction capability (5-keV to 10-keV range) with spatial resolution of 0.1 μm .

2.1.2 Nanoscopic Structures

Slight, nonfavorable, segmental interactions coupled with small entropic gains render dissimilar polymers immiscible. Covalently coupling two polymer chains restricts the separation of the chains to size scales commensurate with the size of the polymer coil. Depending upon the volume fraction of the dissimilar segments in the chain, periodic arrays of nanoscopic structures ranging from spheres to cylinders to lamellae form spontaneously. Controlling the orientation and spatial arrangement of these nanoscopic arrays with electric and magnetic fields and interfacial interactions is key for the incisive use of these structures in applications ranging from electronic devices to membranes to sensors. As an example, consider the diffusion of synthetic or natural macromolecules in solution through a nanoporous membrane comprised of cylinders 2 nm to 3 nm in diameter and tens of nanometers in length. Small-angle-scattering methods, both anomalous and high-resolution scattering, are essential for characterization of the configuration and conformation of the macromolecules in solution and as they penetrate through the membrane. Spectroscopic methods, such as near-edge x-ray absorption fine-structure spectroscopy (NEXAFS) will be key for the *ex-situ* and potential *in-situ* determination of the specific interactions that the macromolecule or associated ions experience at the surface of the membrane and as the macromolecule penetrates through the membrane.

2.2 Thin Films

Thin-film polymers have considerable technological importance and have numerous applications (adhesives, low-dielectric insulators in microelectronic circuits, multicolor printing, optical coatings, etc.). As compared to bulk properties, relatively little is known about the properties of polymers when they are processed into thin films. A detailed understanding of thin film properties, such as composition, morphology, viscosity, chain mobility, stability, and possible deviations from bulk properties, is essential for optimization.

Two specific examples are presented. Blends of immiscible and partially miscible polymers can be spun cast from solution onto various surfaces with controlled surface energies. Both the solvent and surface energy will influence the initially formed morphologies during solvent evaporation. Upon annealing, phase separation can occur. In contrast to the bulk, polymer-substrate and polymer-air interfacial energies or kinetic barriers play dominant roles. Experimental and theoretical work on thin films of binary polymer blends suggest large changes in both the phase behavior and dynamics relative to the bulk properties of these blends. A true three-dimensional, quantitative composition-analysis tool would be ideal to study the static and dynamic properties of the films providing a critical test for theories of polymer dynamics. Currently used techniques, such as atomic force microscopy (AFM) can only sense the surface topography and morphology but not the composition. Neutron and x-ray scattering can measure concentration gradients, but they are unable to determine the topography of the polymer-polymer interface unambiguously. Quantitative NEXAFS microscopy (transmission and surface-sensitive modes) provides an excellent complement to more traditional microscopy and reciprocal-space techniques for the elucidation of the properties of thin films.

Another thin-film example is the influence of spatial confinement on the mobility and orientation of polymer chains. In the bulk, the transition from long-range mobility to essentially frozen chains is described by the glass-transition temperature. In small spaces, such as thin films, the chains can “sense” the presence of confining interfaces. Understanding the mobility and dynamics of polymer chains in these situations, as well as the possible influence on material properties, is a considerable challenge that provides great opportunities in polymers, biomaterials, and nanotechnology/nanocomposites involving polymers. NEXAFS, NEXAFS microscopy, and high-resolution scattering and reflectivity can play an instrumental role in these areas.

2.3 Surfaces and Interfaces

2.3.1 Pattern Recognition

Natural-selection processes rely on intermolecular recognition between molecules that consist, at first glance, of a random sequence of different amino acids. However, an intriguing possibility is that the random sequencing of units actually comprises a statistical patterning of units in the macromolecules. In terms of recognition or interactions between chains or chains and substrate, theory predicts that first-order transitions occur as a function of the composition of the macromolecules and of the probabilities of matching specific sequencing. Synthetic random copolymers in contact with randomly patterned surfaces offer a simple, unique, and quantitative means of understanding rather complex recognition processes. In particular, consider a random copolymer containing only two units where the composition and chain statistics can be varied in the synthesis. Consider, also, a surface that contains complementary interaction sites that are also randomly arrayed on a surface. Maximization of the interactions between the random copolymer and the surface requires optimization of the relative spatial distribution of interacting sites. Elucidation of the kinetics, dynamics, and

thermodynamics of this recognition process requires quantitative characterization of the sequencing along the chain and on the surface. The former can be addressed by nuclear magnetic resonance (NMR) methods, whereas the latter requires techniques with the ability to spatially resolve chemically distinct units on a size scale that ranges from one to tens of nanometers. It is also necessary to characterize the specific orientation of chemical units on the surface prior to and subsequent to the chain adsorption. At present, no technique can satisfy these demands. However, x-ray microscopy represents a truly unique means by which these goals can be achieved. The current spatial resolution of x-ray microscopy is on the order of 40 nm. While this resolution is insufficient to address pattern recognition on the molecular level, improving this resolution further will have significant consequences. Even with the current resolution, renormalization of the pattern recognition problem to larger size scales suggests that x-ray microscopy can have immediate impact. The ability to perform site specific spectroscopy with polarized x rays gives x-ray microscopy a significant advantage over any other technique.

2.3.2 Polymer Surface Relaxation

The relationship between nanoscopic and microscopic mechanisms and macroscopic spatial- and temporal-frequency-dependent viscoelastic properties of a polymeric material continues to provide an enduring research focus for polymer chemical physicists. To establish and understand this relationship in detail will help to forge a crucial link between polymer structure and properties, thereby facilitating progress in an important array of problems:

- Production of new and useful polymeric materials.
- Understanding the often dramatic ways in which a free polymer surface responds to its environment.
- Optimization of the interfacial mechanical properties of polymer mixtures and ordered copolymer phases.

To formulate this connection requires development of experimental tools having sensitivity over a broad range of both spatial and temporal scales. The primary goal is to determine the microscopic modes of polymer relaxation, such as those that conspire to produce the diverse kinetic and thermodynamic properties often observed. Many such techniques have been successfully developed. Quasi-elastic neutron scattering, for example, has been applied incisively at the length and time scales relevant to entanglement of polymer chains. Dynamic laser light scattering can probe slower phenomena at longer length scales associated with polymer diffusion. Various electron and photon microscopies have been enormously successful in probing polymer morphology over a very large range of length scales but with relatively limited temporal dynamic range. However, no experimental probes have been developed to measure the dynamics of complex fluids on a nanometer length scale at times longer than about 0.1 microsecond. Many interesting and important polymer relaxations (those noted above, for example) occur in this range.

The wavelength range of soft x rays is well matched to the relevant length scales, and the photon energy range of soft x rays is particularly well suited to studies of light elements that are the primary constituents of most polymers. The application of soft x rays to these problems has already started. For example, relaxations near an oriented polymer surface have been probed as a function of temperature and depth using dichroism in polarized NEXAFS spectroscopy. This technique should be further developed and more broadly applied, possibly in a microscopic mode using a focused soft x-ray beam. Another somewhat more exotic experimental approach entails development of dynamic x-ray scattering using a transversely coherent soft x-ray beam. The wavelength dependence of the volume of coherent phase space indicates that, in principle, orders of magnitude more coherent flux

is available in the soft than in the hard x-ray regime. In some cases, this translates into an ability to probe dynamical phenomena on much shorter time scales by using dynamic soft x-ray scattering rather than dynamic hard x-ray scattering. Moreover, the possibility of doing dynamic scattering near a threshold for core-electron excitation, the dynamic version of anomalous scattering, will allow selective sensitivity to particular light-atom species and possibly also to particular functionalities. By virtue of its high brightness, the ALS is uniquely suited to develop this new technique.

2.4 Engineering Polymers

Engineering polymers have myriad applications: parts for automobiles, dashboards, computer cases, suitcases, etc. The macroscopic properties of these materials are controlled by the nanoscopic structure and chemistry. Key issues in engineering polymers include understanding the microscopic phase structure in blends, compatibilization of multiple phases, fracture mechanics, segregation of additives, adhesion of paints, and adhesion of polymers to other materials. For example, to enhance the adhesion between different polymer phases, a third component is added to strengthen the interface and reduce interfacial tension between the two phases. Soft x-ray microscopy is an excellent method to determine the fate of the compatibilizer. Polymers under tensile stress can be examined *in situ*, allowing the simultaneous tracking of chemistry and microstructure. The kinetics and thermodynamics of the intermixing of phases in polymer blends is also an important phenomena to understand. Other areas include interfacial adhesion in composites and nanocomposites and determining the microscopic structure of these materials. Synchrotron-based analysis techniques can make an important contribution to understanding many of these phenomena.

Scanning transmission x-ray microscopy (STXM) has already made inroads into the quantitative analysis and chemical basis of microscopic phase structure in polyurethane foams used in furniture and car seats. These materials are very complicated, consisting of several different phases. STXM has been applied to spectromicroscopic quantification of polyol, urea, and urethane content in different phases that are sub-micron in size. Currently this technique can be carried out at about 50-nm spatial resolution, whereas many of the interesting phenomena are below 10 nm in size. Achieving 10-nm spatial resolution is based largely on the availability of suitable zone plates. Those currently available do not yet provide the requisite resolution. Advancing the state of the art in zone plate manufacturing is a key technology for advancing STXM and scanning photoemission microscopy (SPEM) at the ALS.

Another area of interest is understanding the spatial variation of crosslink density in gels and other elastomeric materials. Spatial variation in crosslink density may be built into a product, as in the case of super-absorbent polymers. In these materials, a semi-rigid, highly crosslinked shell around the polymer particles helps them to maintain their shape when they are hydrated during use. STXM can be used to determine the variation in the polymer density after swelling the polymer in water. The polymer density, the degree of swelling, and, thus, the crosslink density can be inferred. Studying hydrated polymers is particularly suited to STXM using x-rays in the “water window,” the energy between the K absorption edges of carbon and oxygen atoms (285 eV to 540 eV).

2.5 Organic Earth Materials

Chemical characterization of the organic matter included in sediments and sedimentary rocks is of paramount importance to understanding the generation of oil and gas, refining our understanding of the geologic component of the global carbon cycle, and deriving effective strategies for improved technological utilization of solid phase fossil energy resources, e.g. coals. There are currently a number of powerful techniques capable of providing molecular and functional group information on solid-phase organics. However, the chemical structural information obtained is integrated over the entire sample; these methods are incapable of revealing the chemistry within compositionally discrete subdomains. Herein lies the problem, solid-phase organics in earth materials exhibit a high degree of chemical heterogeneity on length scales from tens of nanometers to microns. Understanding the chemistry of these materials requires the ability to obtain molecular structural information at very short length scales. Soft x-ray microscopy and spectromicroscopy provides such a microprobe. Micro-carbon, oxygen, and nitrogen NEXAFS reveals functional group specific information on the appropriate length scales [currently down to 50 nm at Beamline X1A at the National Synchrotron Light Source (NSLS) and 100 nm at Beamline 7.0.1 at the ALS]. The spectroscopic requirements are high energy resolution (0.1 eV or less) transmission NEXAFS on the nitrogen, carbon, and oxygen K edges. Ideally, NEXAFS on either the sulfur K or L edges would also be desirable.

The intrinsic polarization of the synchrotron x-ray beam is also extremely useful in study of progressive graphitization of organic matter in thermally metamorphosed rocks. A related question involves the elucidation of the mechanisms and phase chemistry of nematic phase transitions in organic glasses and heavy liquids (a major technological issue in the fabrication of carbon electrodes and metallurgical cokes). Suppression of nematic phase development is crucially important in petroleum refining. X-ray linear-dichroism studies have the potential to resolve long standing problems in both organic geochemistry and fuel chemistry.

The ability to interrogate the organic structure within carbonaceous chondritic meteorites has become a very important issue in cosmochemistry. It is now well established that a broad range of molecular and macromolecular organic matter was synthesized in the pre-solar nebula. It has been speculated by some that this organic matter may have seeded the primordial earth, leading to the genesis of life. What is poorly understood is the organosynthesis mechanisms. It will be crucially important to characterize the organic matter in these meteorites *in situ*; issues related to spatial chemical heterogeneity and organic-inorganic associations will require the capabilities of x-ray microscopy.

The current instrumental capabilities (e.g., STXMs at Beamline X1A at NSLS and Beamline 7.0.1 at ALS) have already shown the potential to revolutionize the field of organic geochemistry and fuel chemistry. The only limitation is experiment time. The present x-ray microscope facilities are over subscribed—a situation that is guaranteed to become substantially worse. The proposed ALS bend-magnet beamline and STXM, to be dedicated to natural and synthetic polymer research, is designed to address these needs. Even this facility, however, will rapidly become over subscribed. The ALS has the potential to become the home of the premier soft x-ray microscopic and spectromicroscopy facilities in the world. This would ensure the ALS's participation in the rapidly evolving fields of organic geochemistry and fuel chemistry.

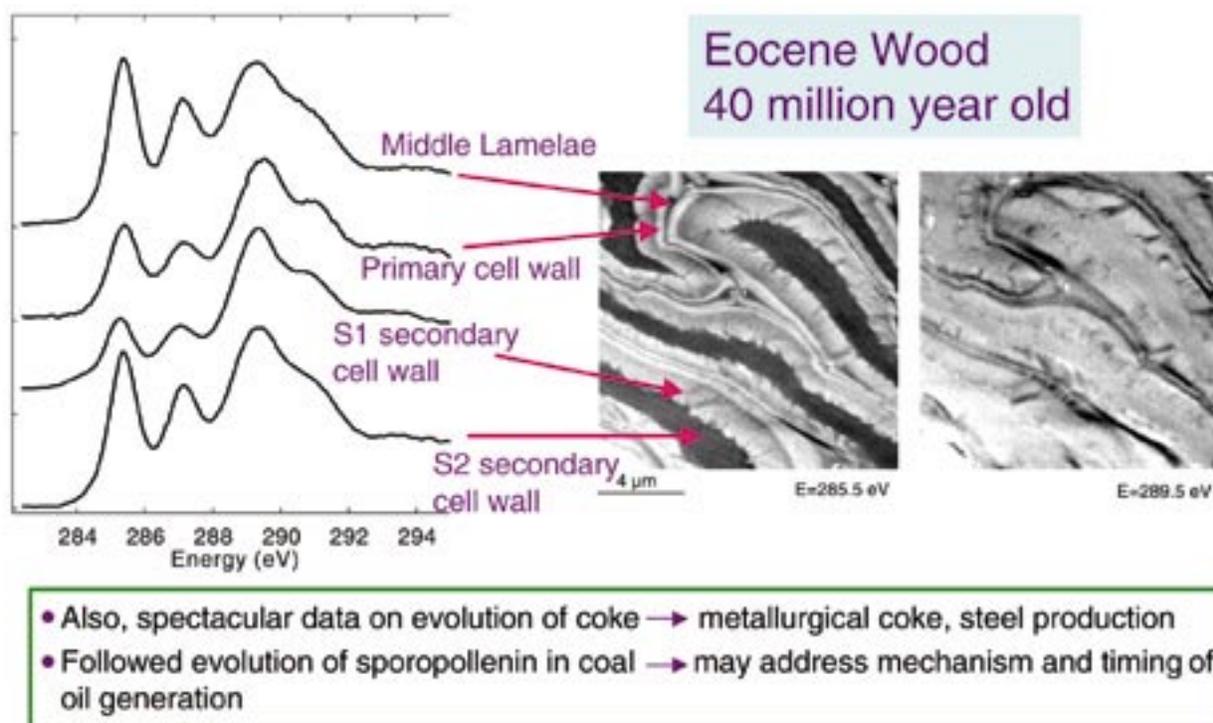


Figure 2. The data shown are from wood 40 million years old that was recovered from a remarkable “preserved” deposit of ancient wood in the eastern arctic region of Canada. Although the wood has evolved chemically into a coal-like material, the spectacular chemical differentiation intrinsic to the original cell-wall structure persists. The image on the left was acquired with 285.5-eV photons. Absorption at this energy corresponds to aromatic $1s \rightarrow \pi^*$ transitions, thus the image contrast maps out the distribution of the biopolymer lignin. The image on the right is of the same region acquired with 289.5-eV photons. Absorption in this energy region is largely due to the $1s \rightarrow 3p/\sigma^*$ transitions associated with secondary alcohols in carbohydrates. Carbon NEXAFS spectra of the various chemically differentiated regions reveal the large differences in the chemistry of organic functional groups from region to region. [Data acquired by G. Cody et al. of the Carnegie Institution Geophysics Laboratory on the STXM at Beamline X1A at NSLS.]

3. Requirements for Success

3.1 ALS/Industry Partnership: Key Elements for Sustainable Success

The construction and utilization of the x-ray microscopy capability at the ALS has, within a relatively short time frame, enjoyed an outstanding level of success in extending the reach of technologies for the microanalytical characterization of materials. In particular, the spectromicroscopic (< 100 nm) characterization of soft materials (biological and synthetic polymers) has opened the door for exciting value-added research that will most certainly benefit society in many ways. However, before value generation/capture can be optimized, several issues must be addressed that relate to the involvement of industry in the visioning, development, implementation, and sustainability of these x-ray microscopy technologies.

Considering the pressures that industry faces to maximize shareholder value, it should come as no surprise that industry, in general, has aggressively reduced its structural costs, shortened its product-development time horizon, and decreased its tolerance toward higher risk/lower potential-return

opportunities. In other words, businesses want it faster, cheaper, and more often—all with increased odds for success. In spite of this, the importance of industry in influencing scientific discovery and in developing value-contributing technologies has never been so high.

With these factors as a backdrop, it behooves the ALS to form multiple and substantive partnerships with a diverse industrial partner base. To this end, it is necessary to:

- Identify key industrial partners early on (i.e., while still in the concept phase of a technology) and work toward cultivating mutually beneficial relations.
- Minimize industry's risk through the “seeding” of key technologies that are jointly identified with potential industrial partners.
- Increase industrial-partner access to ALS facilities. It is not only important to obtain beam time but also to receive it in “packets” that are useful to the industrial investigator, e.g., contiguous shifts rather than singular shifts.
- Increase the quantity of beamline support personnel that can help in the experiment set-up and breakdown, the collection of data, and the maintenance/development of instrumentation
- Encourage the formation of participating research teams (PRTs) between academia, industry, and the ALS, including minimizing hurdles (e.g., cost, bureaucracy, and paperwork).
- Provide rapid access to facilities (i.e., in many cases, the problem needs to be solved rapidly and cannot wait several weeks or months for future access).

3.2 Dedicated Science-Driven Beamline for Users

A specialized, dedicated beamline has proven to be more effective for less-experienced users and can save substantial time for instrumentation set-ups where change-overs often require expertise in alignment of x-ray optics and other components. Such is the case, for example, for small-angle x-ray scattering. Thus, beamlines for polymers and soft-condensed-matter research should be dedicated ones which are designed to be user friendly and well supported by staff. A well-run beamline will permit the users to concentrate all of their beam time on science instead of on solving instrumentation problems, thereby improving the effectiveness of the facility. As stated previously, this point is particularly relevant to industrial users, who often have limited time and support personnel to carry out the assignment.

Interesting and unique materials are prepared by scientists and engineers whose expertise is inclined towards chemical and biological disciplines. It is very important to have better communication and to provide educational opportunities for the participants of multidisciplinary experiments so each participant can appreciate the capabilities and the limitations of what the others can do. Aside from workshops, one approach is to provide financial support for user experiments, especially the beginners. In particular, adequate support and encouragement should be made available to those who have good ideas to do important science. By doing so, synchrotron utilization can be expanded to a broader scientific community and more effective use of synchrotron radiation to society will be achieved.

4. What Role Can the ALS Play?

4.1 Key Techniques for Polymers, Biomaterials, and Soft Matter

The following list gives the key techniques and their current characteristics, along with projected performance improvements:

- **STXM** (Scanning Transmission X-Ray Microscopy)
Zone-plate focusing at 50 nm, improving to 10 nm. C, N, and O edges. Many applications also exist for STXM in the intermediate energy region (1 keV to 5 keV).
- **PEEM** (Photoelectron Emission Microscopy)
100-nm spatial resolution, improving to 2 nm at the most critical C, N, and O edges.
- **XPS and SPEM** (X-Ray Photoelectron Spectroscopy and Scanning Photoelectron Microscopy)
High resolution XPS analytical capability and SPEM at 100-nm spatial resolution improving to 10-nm.
- **SAXS and ASAXS** (Small Angle X-Ray Scattering and Anomalous SAXS)
SAXS and ASAXS in photon-energy range from 2 keV to 10 keV.
- **Microdiffraction**
Microdiffraction at 1- μm spatial resolution, improving to 10-nm in photon-energy range from 2 keV to 10 keV.
- **Dynamic Scattering**
Dynamic scattering facility at grazing incidence using coherent soft x-ray illumination.
- **TXM** (Transmission X-Ray Microscopy)
TXM in short term at 50-nm resolution until high-resolution STXM is available.

4.2 Soft X-Ray Spectromicroscopy

As stated in the Birgeneau panel report, “For any polymer that has been processed, x-ray microscopy comes to the fore as an ideal tool for characterization.” Soft x-ray spectromicroscopy is one of the most promising ways in which the ALS can have an impact on the scientific issues in polymer science and soft matter that were discussed in the previous sections. Many areas of impact exist based on the chemical and orientational sensitivity at high spatial resolution afforded by transmission NEXAFS microscopy of thin films and microtomed sections. The excellent surface sensitivity and high spatial resolution provided in a PEEM and SPEM, and possibly in STXM operated in total electron yield mode, also hold much promise. Already, there is a strong PEEM project at the ALS; a STXM and SPEM exist at Beamline 7.0.1; a microXPS and microdiffraction facility is coming on-line; and a dedicated Polymer STXM is going to be installed at Beamline 5.3. This will be the most complementary and complete set of instrumentation available for x-ray microscopy of polymers world wide, and the ALS should fully capitalize on this leadership.

However, only the polymer STXM is intended as a facility dedicated to polymer science. The Beamline 7.0.1 STXM and SPEM are available at best for a combined one-fifth of operation time for all subfields of science and the Beamline 8.0 PEEM for about one-third for all subfields of science. Synchrotron-radiation facilities are underutilized by polymer scientists despite their great potential for polymer characterization. While there are several reasons for this, complex multi-user

and multi-experiment facilities can be singled out as the major deterrent for a polymer scientist to become a user. It is thus important that sufficient attention and support be provided to the planned dedicated polymer STXM to make it a user-friendly dedicated facility, while microscopy improvements are further pursued at the Beamline 7.0 microscopes and on the proposed Beamline 6.0 STXM. Instrument development and user operation have to be decoupled if the present potential barrier to new users from the field of polymer science and related fields is to be overcome.

Only the ALS is bright enough to use a bend magnet as a source for a microscope based on diffractive optics such as STXM. It is, therefore, the only facility in the nation that will be able to provide much needed STXM capacity. Since a bend magnet beamline is relatively cheap, it is conceivable that several STXM might be operated at the ALS in the future.

It is also desirable that the currently proposed STXM at ALS undulator Beamline 6.0 be co-developed by the various communities at the ALS, including the polymer-science community. A bend-magnet STXM will provide capacity, while only the Beamline 6.0 STXM will provide ultimate performance. Both are necessary and complementary developments.

4.3 Microdiffraction, SAXS, and ASAXS

The availability of an anomalous-microbeam-small-angle x-ray scattering and diffraction spectrometer is also critical for research on polymer, biomaterials, and soft matter. The instrument should be capable of probing self-assembling structures on scales spanning 0.1 nm to 1000 nm.