Electrochemical Concepts in Functional Materials

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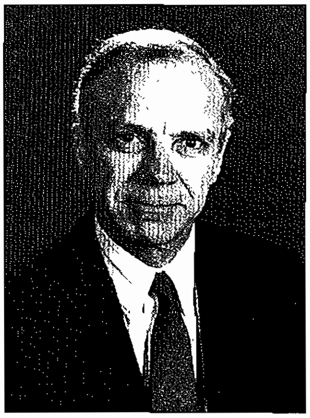
I am pleased to write a preface to this special issue on "New developments in electrochemical fabrication of functional materials", and I sincerely thank the editors for the opportunity. As all electrochemists know, electrochemistry has been at the heart of many disparate fields of materials research for more than a century, notably energy conversion and storage, industrial electrosynthesis, chemical analysis, and corrosion, which together comprise a huge economic value. The recent advent of nanotechnology in general and molecular electronics in particular has emphasized the importance of interfaces, and the ability to control materials synthesis and characterization at the atomic and monolayer scales. Today's electrochemistry routinely involves fabrication of monolayers by self-assembly, covalent modification of electrode surfaces, vacuum deposition, and surface attachment of biologically active enzymes and recognition sites in order to tailor an electrode to perform particular functions. Throughout the historical and modern manifestations of electrochemistry is the fundamental process of exchanging electronic current with chemical reactions, of course, and the scientifically and commercially important applications of this exchange show no sign of being exhausted.

My own field of Molecular Electronics provides excellent examples of the importance of electrochemistry to fabricating new functional devices and to understanding their behavior. The prospect of using single molecules or oriented monolayers of molecules as circuit elements generated tremendous excitement starting in the late 1990's, mainly due to the wide variety of molecules available with presumably a wide range of potential electronic functions. Although the initial excitement has been tempered somewhat by experimental and conceptual difficulties, the great scientific and economic promise of augmenting silicon-based microelectronics with molecular components remains. Electrochemistry brings valuable tools and concepts to molecular electronics, in addition to the experience with electrode modification and monolayer chemistry already mentioned. First, resonant electron transport between orbitals of equal energy is the most efficient means to move electrons, and best exploited by molecules with orbitals near in energy to the contact Fermi level. Second, activated electron transfer resulting in oxidation or reduction underlies all of Marcus-Levich kinetics and redox exchange, and is operative in many molecular electronic devices which exhibit "conductance switching". Third, the motion of ions and electrons in both inorganic and organic electronic devices depends on the same physics of electric fields, mobility, and migration familiar to electrochemists, and has fostered the new area of "nanoionics". In many respects, the molecular electronic devices which have generated so much notoriety in recent years are electrochemical in nature, ranging from relatively simple transport of electrons by tunneling or through orbitals to more complex structures resembling an electrochemical cell, with redox components and mobile ions.

In addition to fabricating and understanding molecular electronic devices, electrochemists can play an important role in device characterization. Since electrochemistry is inherently interfacial, the battery of techniques developed for electrochemical investigations are equally useful for studying molecular electronics. Surface characterization with scanning probe microscopy and photoelectron spectroscopy, spectroelectrochemistry based on Raman, Infrared, and UV-Vis spectroscopy, quartz crystal microbalances, ellipsometry, and related methods have all been used on solid state molecular electronic devices, albeit with the requirement of monolayer sensitivity. Taken as a whole, the concepts of electrochemistry combined with monolayer fabrication and characterization techniques promise a bright future for electrochemistry applied to molecular electronic and functional materials. The dominant lesson from my own excursion into a new field is the eminence of electrochemical principles in a wide variety of scientifically and economically important phenomena, ranging from the familiar areas of energy conversion, chemical analysis, and electrosynthesis, to new applications in molecular electronics, chemical and biological sensing, and novel, "intelligent" interfaces.



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