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EDITORIAL

Molecular Materials in Electronic and Optoelectronic Devices

The effects of the electronics and photonics revolutions, enabled by the silicon-based transistor (and its incorporation into integrated circuits), fiber optics, and solid-state lasers, are evident in almost every aspect of modern commerce. Yet, far from saturating the market, these devices are predicted to proliferate far beyond anything we have imagined so far: whereas roughly 50% of households in the developed countries own one personal computer, industry leaders today predict that in the next decade or so we will all own dozens or even hundreds of computers (most of them embedded in information appliances), all of which will communicate with each other on a network similar to the Internet. We will not know where these computers are, nor will we care, as long as they carry out their functions.

In this new world of "pervasive computing" (a term originated by Joel Birnbaum of Hewlett-Packard Laboratories), in which most computing is carried out by distributed resources connected by a utility-like network, the user's awareness of a "computer" lies only in what he or she sees at the interface: the display and input devices. Displays, now considered a "peripheral", will be the central object from the user's perspective, while the processor becomes peripheral. This vision, however, requires displays which are far different from the current cathode ray tubes and expensive (and slow) liquid crystals, since they must be numerous, compact, and portable.

While the current display market is many billions of dollars by any estimate, it is this emerging new paradigm that really drives the effort to produce displays that are vastly smaller, lighter, and cheaper than today's displays. Organic electroluminescence, a phenomenon first observed and extensively studied in the 1960s, forms the basis for the most likely candidate to serve this role. Because crystalline order is not required, organic materials, both molecular and polymeric, can be deposited far more cheaply than the inorganic III−V semiconductors of conventional LEDs. Patterning is also easier, and may even be accomplished by techniques borrowed from the printing industry. Displays can be prepared on flexible, transparent substrates such as plastic. These characteristics form the basis for a display technology that can eventually replace even paper, providing the same resolution and reading comfort in a long-lived, fully reusable digital medium.

The interplay of basic science and applied development in this field has been quite close ever since activity began to dramatically accelerate with the discovery of electroluminescence in conjugated polymers in 1991. Today there are close to a hundred research groups around the world engaged in OLED research and development. Universities, large corporations, government labs, and start-ups are all represented; in several cases new companies have been formed on the basis of university research, and one or more faculty members retain close ties (as for example chief technology officer) to the start-up.

The ability to transport charge is clearly a necessary component of an electroluminescent device, but charge transport is useful for other reasons. While not specifically covered in this issue of *Accounts of Chemical Research*, there is also extensive activity in the area of organic transistors. While unlikely to ever compete with polycrystalline silicon field effect transistors in the important parameter of charge mobility, the potential of organics to be substantially cheaper enables applications not otherwise accessible. Other arenas for organic materials to occupy an active role (as distinct from passive behavior, such as waveguides) are memory and non-transistor-based switching. (Electrooptic effects comprise a rather different set of issues, in which nonlinear optical response is the key parameter, but conductivity is not required since the effects are obtained solely from an applied field.)

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This special issue provides an overview of the state of basic research in this field. The primary themes that characterize the articles are those of electronic structure calculations, surface chemistry, morphology, nanoscale structural properties, and chemical behavior under electrical stress. Underlying these specific themes are the general ones relevant to any solid-state electronic/photonic system: how does charge get injected into the material, how is it transported, and how (for a light-emitting device) does it generate excited states? The commercial interest described above has sparked an explosion of activity focused on these fundamental issues.

Much difficulty stems from the fact that charge-transporting organic materials possess intermolecular interactions that are not easily described by any simple approximation. In solution electrochemistry the molecules have localized wave functions which interact by well-known dipolar and exchange processes, while in perfect crystals the atoms or molecules form highly delocalized bands, the theory of which is of course very highly developed for inorganic semiconductors. The systems described in this issue fit well in neither of these models, and consequently even the very language used to describe them is often the basis of intense debate (and confusion). To achieve the degree of acceptance of a unified framework for discussion of charge injection that exists for semiconductor−liquid electrolyte systems (as in, for example, "Surface Electron Transfer Processes", by R. J. D. Miller et al.) would be a major achievement that the work described here is moving toward, but has certainly not yet reached.

We have carefully chosen the title "Molecular Materials in Electronic and Optoelectronic Devices" rather than the simpler "Molecular Electronics" because realistically feasible applications do not, at this time, depend on single molecules or even small assemblies of molecules to perform useful operations. Exactly that is a goal on many agendas, however, and it seems highly probable that it can be achieved in some form. The article by Fox in this issue discusses some of the issues that must be addressed at the synthetic and morphology levels. A fundamental problem at the systems level is how to address individual molecules from the external (inevitably macroscopic) world. Clearly the subjects of interfaces and the length scale over which one controls properties comprise vital elements of future research.

Several threads of research activity feed into this process, including self-assembly techniques and principles, techniques for the study of single molecules (scanning probe as well as optical), and the ever-crucial synthetic process. Recent developments in the use of biopolymers such as DNA and proteins as templates to control the assembly of electrically functional elements (both organic and inorganic) are especially exciting in this regard, and are among the many relevant topics that could not be addressed in the limited space of one journal issue. All together, however, we hope we have succeeded in capturing some of the scientific excitement in a field that has been revitalized by its commercial potential.

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