

Organic Electronics

By JAY LEWIS

Guest Editor

JEREMY BURROUGHES

Guest Editor

YUTAKA OHMORI, *Fellow IEEE*

Guest Editor

K. S. NARAYAN, *Senior Member IEEE*

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Organic electronics is now entering its second decade as a commercial technology but in many ways is a relatively recent and emerging field. As such, significant advances are being made across a broad range of activities, from improving the understanding of very fundamental phenomena to improving manufacturing technologies.

Much of the interest in organic electronics stems from the chemical tunability of electronic states and the high efficiency of optical absorption and/or emission in many organic semiconductors. These properties have been utilized in organic dyes for millennia in a “passive” or all-optical role. Since the 1960s, the electrical and optical properties of organic semiconductors have been studied. A broad renewal of interest in the field owes largely to the demonstration of efficient light-emitting diodes based on either molecular structures by Tang and Van Slyke in 1987 [1] or conjugated polymers by Burroughes *et al.* in 1990 [2]. It is the demonstration of efficient injection or extraction of charge carriers to or from optical processes using organic semiconductors that enables functionality traditionally reserved for inorganic, epitaxially grown, compound semiconductors.

Around the same time, there was increasing interest in the use of organic semiconductors in all-electrical processes for diodes and field-effect transistors [3]. Like their inorganic analogs, charge transport and storage

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can be used in switching or memory applications. In a sense, it may not seem to be a worthy pursuit to develop semiconductors that perform the same function as silicon, yet do not provide a next generation to follow the end of Moore’s law. But when one considers the added advantages of many organic semiconductors, the value becomes apparent. In particular, it is the ability to process organic semiconductors over large areas and at low temperatures, e.g., on a wide variety of substrates, that provides opportunities for organoelectronics, where inorganic materials fall short. As with optoelectronic devices, the ability to fabricate highly efficient and tunable devices over large areas and to integrate dissimilar materials using relatively simple processing makes organic electronics very attractive for applications, including displays, e-readers, lighting, photovoltaics, radio-frequency identification (RFID), and optical communications.

As it is impossible to cover all aspects of organic electronics, the current Special Issue attempts to cover a representative sampling of activities. Organic electronics, for the purpose of this issue, are those in which active

electronic or optoelectronic components are composed partly or entirely of organic semiconducting materials. There are numerous technologies where organic materials are used as conducting or insulating components, but for the sake of limiting scope, these are not included in this issue.

The first papers deal primarily with electronic processes in organic semiconductors. The next section addresses organic light-emitting devices, and the final two papers deal with two examples of emerging photonic devices: organic emitters and detectors for photonics and optical amplifiers based on conjugated polymers.

In the first paper, Narayan *et al.* give an overview of the basic mechanisms involved in charge transport in disordered polymers. These basic processes apply to each of the devices covered in the rest of this issue, and this understanding is fundamental to achieving the potential of the technology. The authors start by describing the various techniques used to characterize charge transport, and discuss the behavior of charge carriers and excitons under applied fields. They also discuss charge carrier behavior near electrode boundaries, which particularly impacts such devices as light-emitting diodes and photovoltaics. They also describe the novel use of photoexcitation to study lateral transport in polymers and polymer-fullerene blends that have practical use in photovoltaic devices.

In the second paper, Sirringhaus describes the practical application of organic semiconductors as the active channel layer in field-effect transistors (FETs). The paper presents an overview of progress in the development of materials and device architectures that now provide channel mobilities on par with amorphous silicon-based devices. In particular, the paper describes the different approaches that have been taken to achieve high mobilities from solution-processed organics, which includes not just the development of new channel materials but also a detailed

understanding of the interface between the channel and the gate dielectric. Lastly, the paper includes a discussion of the status of near- and medium-term applications for organic FETs, which include display technologies, RFID, and multifunctional devices.

In the third paper, Rath and Pal describe the use of organic complexes in memory applications. An overview describes the various approaches and mechanisms for conductance switching. This is followed by the experimental demonstration of conductance switching based on charge-transfer complexes, in both a sandwich and planar configuration.

The remainder of this issue deals primarily with optoelectronic applications of organic devices. The fourth and fifth papers in particular address fundamental questions in organic devices through theory and modeling. In the fourth paper, Walker addresses the challenging field of modeling charge and excitonic transport in light emitting and photovoltaic devices. This effort integrates Monte Carlo simulations at the mesoscale with continuum models at the macroscopic scale. The focus is primarily on polymers for light-emitting and photovoltaic applications, but much of the same theory applies to molecular devices. In the fifth paper, Monkman *et al.* address the issue of singlet-triplet spin statistics and the experimental deviation from a 1 : 3 ratio in certain polymer devices. The paper covers the experimental methods used to make such measurements, then addresses the different models that would account for increased singlet formation in polymers, but not in small molecules.

The sixth paper, by Meerheim *et al.*, introduces a relatively recent development in organic light emitting devices, known as the p-i-n organic LED (OLED). Similar to inorganic devices that go by the same name, p-i-n OLEDs used doped injection layers to improve the efficiency of charge injection. This approach has yielded the highest reported OLED

efficiencies to date, and the lowest operating voltages, and is therefore very attractive for display technologies and, particularly, for lighting applications. The paper addresses the operating principles of p-i-n devices in comparison to a standard OLED, reviews the application of the approach to single- and multicolor structures, and discusses different architectures such as bottom- and top-emitting devices, as well as device stability.

The final two papers cover less developed aspects of organic optoelectronics. In the seventh paper, Ohmori and Kajii discuss the application of organic devices to integrated photonics. The authors describe the concept of organic emitters and detectors that are directly integrated with optical fibers to provide short-distance local-area network interconnections. Both small-molecule and polymeric materials are used to fabricate high-speed light emitters as well as to fabricate photodiode detectors. Speeds of 100 MHz are demonstrated for emitters and 80 MHz for detectors, which is sufficient for video transmission.

The final paper, by Amarasinghe *et al.*, describes the use of organic semiconductors as optical amplifiers. Conjugated polymer-based amplifiers are shown to significantly outperform comparable dye-doped or rare earth metal-doped amplifiers. All-optical switching is also demonstrated using a relatively simple approach, and the future prospects for optically and electrically pumped amplifiers are discussed. ■

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ABOUT THE GUEST EDITORS

Jay Lewis received the bachelor's degree in materials science and engineering from the Georgia Institute of Technology, Atlanta, in 1996. He received the M.S. degree in materials science and engineering and the Ph.D. degree from the University of Florida, Gainesville, in 1998 and 2000, respectively.

He joined MCNC, Research Triangle Park, NC, in 2001. He joined the Center for Materials and Electronic Technologies, RTI International, with the acquisition of MCNC in March 2005. With MCNC and RTI, he has conducted research and managed programs primarily in the areas of optoelectronics, organic electronics, and flexible electronics technologies. His current interests also include photovoltaics, novel sensor technologies, and printing approaches for flexible electronics. He has published more than 20 peer-reviewed papers, including three invited review papers.



Jeremy Burroughes received the Ph.D. degree from the Cavendish Laboratory, University of Cambridge, U.K.

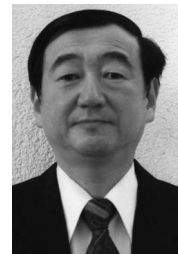
He is joint Founder of Cambridge Display Technology Ltd. (CDT), which is developing light-emitting polymers for display and lighting applications. His thesis was on "The Physical Processes in Organic Semiconductor Polymer Devices." He discovered that conjugated polymers could electroluminesce. This resulted in a patent being filed, which led to the formation of CDT a few years later. In 1989, he joined the Opto-electronics Division, IBM T. J. Watson Research Center, Yorktown Heights, NY, working on III/V semiconductor high-speed metal-semiconductor-metal photodetectors for low-cost infrared communication systems. In 1991, after three months with Cavendish working on a simple 3×5 pixel light-emitting polymer display, he joined Toshiba, where he worked on quantum electronic and optoelectronic devices. He has been Chief Technology Officer with CDT since 2001.

In 1988, he became a Fellow of St. John's College, Cambridge.



Yutaka Ohmori (Fellow, IEEE) received the Dr.Eng. degree from the Department of Electrical Engineering, Faculty of Engineering, Osaka University, Osaka, Japan, in 1972. In 1977, he joined Nippon Telegraph Telephone Public Corporation (now NTT Corporation), where he worked mainly on research on optical semiconductor devices. In 1989, he became an Associate Professor in the Department of Electronic Engineering, Faculty of Engineering, Osaka University. In 2000, he became a Professor with the Collaborative Research Center for Advanced Science and Technology (since 2004, the Center for Advanced Science and Innovation), Electronic Materials and Systems Engineering Department, Osaka University, where he worked on optical and electrical devices utilizing organic materials, including conducting polymers.

Prof. Ohmori is a Fellow of the Institute of Electronics, Information and Communication Engineers of Japan and a member of the Japan Society of Applied Physics, American Physical Society, and Materials Research Society.



K. S. Narayan (Senior Member, IEEE) received the M.Sc. degree in physics from IIT, Bombay, and the Ph.D. degree from The Ohio State University, Columbus, in 1991 in the area of low-dimensional molecular magnetism.

Subsequently, he was a Scientist with Wright Patterson Air Force Base, Dayton, OH. Since 1994, he has been with JNCASR, Bangalore, India, where he is a Professor and heads the molecular electronics laboratory. He has been actively involved in studying electronic, optical, and magnetic phenomena and exploring device structures in synthetic polymeric/organic/nanoparticle-based systems. His current research activities is focused on i) device physics of soft-electronic materials, which involves fabrication of field-effect transistors, solar cells, and large-area imaging structures; ii) photophysical and transport studies of conjugated polymers and carbon nanotube systems using quasi-near-field scanning and spectroscopic techniques; iii) electric field induced instabilities in soft elastic films; and iv) photoinduced charge transport processes in membrane proteins and functional biological molecules such as bacteriorhodopsin systems. He has held visiting positions at the University of Illinois, University of Michigan, and Motorola Labs. He has more than 70 publications and received a U.S. patent on optical control of polymer field-effect transistors. He is an Editorial Board Member of the *Pramana Journal of Physics*, *Synthetic Metals*, and *Journal of Sensors*. He is actively involved in community efforts related to usage, implementation, and information dissemination of alternative energy resources.

