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INTRODUCTION

This book is focused on organic light-emitting transistors and on their characteristics, which make them a potentially disruptive technology in a variety of application fields, including display and sensing. The distinguishing feature of this class of devices is the use of a planar field-effect architecture to combine in a single-structure electrical switching, electroluminescence generation, and photon management in organic materials.

Organic semiconductors are carbon-rich compounds with a structure tailored to optimize functions, such as charge mobility or luminescent properties. A distinguishing factor resides in the multiple functionalities that organic materials can sustain contemporarily when properly tailored in their chemical structure. This may allow the fabrication of multifunctional organic devices using extremely simple device structures and, in principle, a single active material. Indeed, in a molecular solid in which the constituting units are molecules held together by weak van der Waals forces, the optical properties are dominated by excitons, which are molecular excited states that are mobile within the solid. Excitons can hop from molecule to molecule or, in the case of polymers, from chain to chain as well as along the polymer backbone, until it recombines generating light in a radiative process. Similarly, charge carrier (electron or hole) transport can occur via hopping between molecular sites or from chain to chain. In this case, the carrier mobilities are quite low compared with inorganic semiconductors, whose room temperature values

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typically range from 100 to 10^4 cm^2/Vs. In contrast, in highly ordered molecular materials where charges hop between closely spaced molecules forming a crystalline stack, mobilities of less than 1 cm^2/Vs have been observed at room temperature. This is an approximate upper bound, with the mobility ultimately limited by thermal motion between neighboring molecules. Low mobility leads to low electrical conductivity and also results in a very low charge carrier velocity, which one has to consider as an intrinsic factor when evaluating the practical applications of organic semiconducting materials.

The weak van der Waals forces typical of molecular solids decrease as $1/R^6$, where R is the intermolecular spacing. This is in contrast to inorganic semiconductors that are covalently bonded, whose strength falls off as $1/R^2$. Hence, organic electronic materials are soft and flexible, whereas inorganic semiconductors are hard, brittle, and relatively robust when exposed to adverse environmental agents, such as moisture, corrosive reagents, and plasmas, commonly used in device fabrication. The apparent fragility of organic materials has also opened the door to a suite of innovative fabrication methods that are simpler to implement on a large scale than has been thought possible in the world of inorganic semiconductors.

The most appealing property of organic materials for electronic and photonic applications is that they can be deposited on virtually any substrates, including silicon backplanes and low-cost ones such as plastic, metal foils, and glass. Organic materials are compatible with low-cost fabrication methods that can be implemented on a large scale, such as vacuum sublimations and solution-based processes. This fundamental advantage and the low amount of material used in thin-film devices position them favorably to fill the application markets where cost is a key factor and the requirements on performances do not impose the use of high-performing inorganic semiconductors.

Organic electronics are beginning to make significant inroads into the commercial world, and if the field continues to progress at its current pace, electronics based on organic thin-film materials will soon become a mainstream of our technological existence. Already products based on active thin-film organic devices are in the marketplace, most notably the displays of several mobile electronic appliances. Yet, to unravel the greater promise of this technology with an entirely new generation of ultralow-cost, lightweight, and even flexible electronic devices, new and alternative solutions must be identified to overcome the limitations currently faced with the existing device architectures.

Indeed, the vertical-type structure of organic light-emitting diodes (OLEDs) is very well known and has been extremely successful for developing low-voltage-driven light-emitting devices, eventually fabricated on large-area flexible substrates. However, since OLED is a current-driven device, its application, for example, in display technology, requires high-quality TFT backplanes such as those based on LTPS—Low-Temperature Polysilicon—which increase, on the one hand, the production costs and, on the other hand, hinder the development of a truly flexible platform. On the contrary, OLET is a voltage-driven device that can be switched on and off exclusively by applying a potential, with no constrains on the current density of the switching device. This has the profound implication that lower quality TFT backplanes can be used to drive OLET frontplanes in a radically new approach toward low-cost and flexible display technology. In addition, the combination of electrical switching and light generation in a single device structure simplifies the driving circuit of the display, and therefore the manufacturing processing, ultimately leading to decreased production costs. It is also worth mentioning that OLETs offer an ideal structure for improving the lifetime and efficiency of organic light-emitting materials due to the different driving conditions with respect to standard OLED architectures and to optimized charge carrier balances.

This book aims at providing the scientific fundamentals and the key technological figures of organic light-emitting transistors (OLETs) by putting them in the context of organic electronics and benchmarking their characteristics with respect to OLEDs for applications in display and sensing technology.

In chapter 2, the OLED device features and its state-of-the-art performances are reviewed and the display technology applications are discussed. A comparative analysis of the OLED with respect to the OLET is provided to highlight the fundamental differences in terms of device architecture and working principles.

In chapter 3, the basic optoelectronic characteristics of OLETs are reported and the different structures of the active layer are correlated to the device properties.

In chapter 4, the constituting building blocks of the OLET device are discussed and their role in determining the ultimate device performance is highlighted.

In chapter 5, the charge transport and photophysical properties of OLET are analyzed, with particular emphasis on the excitonic properties and the spatial emitting characteristics.

In chapter 6, the photonic properties of OLETs are presented, focusing on the external quantum efficiency, the brightness, and the light outcoupling and emission directionality and reviewing the opportunity offered by the OLET structure for the long-searched organic injection lasing.

In chapter 7, the key applications of OLETs are discussed, driving the attention to the potential impact on display technology and sensing.