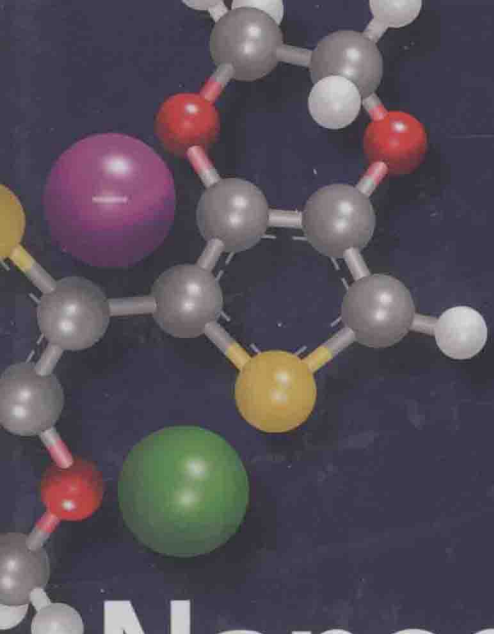
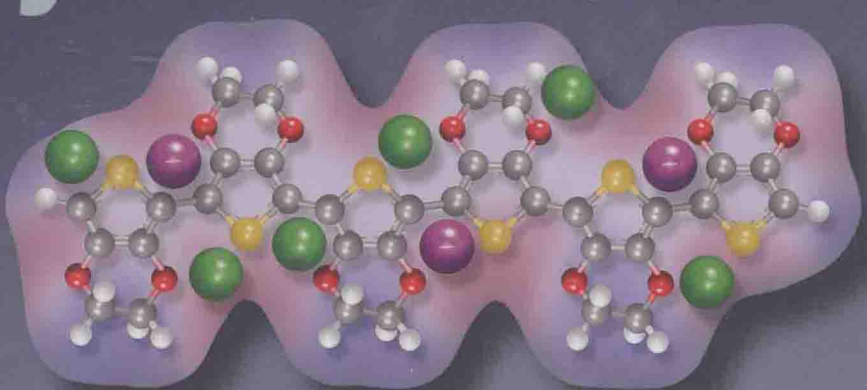


Editor

Ali Eftekhari

Nanostructured Conductive Polymers



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Nanostructured Conductive Polymers

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Nanostructured Conductive Polymers

Preface

In October 2000 when the winners of Nobel Prize in Chemistry were announced, I sent a greeting card to Alan J. Heeger for congratulating him on this honor and his pioneering works on conductive polymers. Professor Heeger replied me by the following note "This Prize was awarded to the field of semconducting and metallic polymers. You, as one with direct research experience in this field, have a right to be proud." A few months later I was in a position to defend a research proposal, and in reply to the question of one of the panelists "Is it a well-established subject with practical potentials or just fancy subject for academic projects", I had a convincing answer, and felt the glory of that award.

Nanotechnology and conductive polymers approximately have the same age, but contrary to the field of conductive polymers, which was abruptly introduced in a Short Communication, nanotechnology was emerged gradually through journey from micro-technology to smaller scales. There are two distinguishable aspects about nanotechnology, but this distinction is usually ignored: advancing our technology by taking control at smaller scales (an advanced form of microtechnology), or entering a new world at nanoscale because its scale is comparable with the molecular size. The fame of nanotechnology belongs to the latter one, but most of research studies are restricted to the first aspect.

Due to the interdisciplinary nature of nanotechnology, researchers from various disciplines have been involved in the rapid growth of nanotechnology as a promising field of study. One of the most active areas is polymer nanotechnology owing to the size of polymer chains. Advancement of nanotechnology tools has provided a rare opportunity to investigate individual chains of polymers. On the other hand, polymers as a member of soft matter family have incredible flexibility for the preparation of various nanostructures, particularly for nano-devices.

The emerging field of conductive polymers itself is indeed an interdisciplinary field, as the essential conductivity has well connected this field to other disciplines (which were not usually associated with polymer materials) from electrochemistry to electrical engineering. Now the emerging field at the interface of nanotechnology and conductive polymers covers a vast variety of quite different disciplines; which calls for more collaboration between researchers with different professions and knowledge. The present book and similar volumes aim to introduce new opportunities by linking different topics involved in this emerging field.

The present book does not claim to provide an ultimately comprehensive resource on the field, and it is almost impossible; but as far as possible, I tried to collect most active areas of research. More than 80 referees assisted me to assure the scientific quality of this book. Although all chapters were solicited in advance, some of contributions were rejected as they did not meet the required standard, and there was insufficient time to call for a replacement by another author. In addition, some authors agreed to deliver their manuscripts by the given deadline but simply declined to submit their contributions in due time. Thus, the audience may feel that some topics have been missed.

As a matter of fact, we are still far from ultimate control at nanoscale as claimed by the mission of nanotechnology; thus, the subjects discussed here are mainly at the interface of transition from micro- to nano-world. This is indeed a transition from the first to second decade of third millennium. This book builds a bridge to the forthcoming decade in which we expect to witness incredible advancement in the realms of nanotechnology. The present book aims to lead researchers from different disciplines in this direction and somehow unite them to think about emerging problems from quite different perspectives.

The book starts with an introductory chapter about conductive polymers. For those who are familiar with nanotechnology, this chapter is a guiding star; and for polymer scientists, it is a reminder that from where we have started. The two next chapters are typical ones to introduce the realms of nanostructured conductive polymers. Polyaniline is considered as a prototype and among most popular conductive polymers. Chapter 3 discusses some interesting features in surface studies of conductive polymer, while surface analysis is always a key concept in the realm of nanotechnology.

The second part of the book commences with a series of papers devoted to a variety of nanomaterials made of conductive polymers, and later introduces some important properties of conductive polymers and methodology of the field. Electrospining is an effective method for the preparation of a variety of nanomaterials, and it has been widely utilized for the fabrication of conductive polymers. Carbon nanotubes are indeed the most dominant prototype of nanomaterials, as they are among the first prototypes of nanomaterial which were introduced to the market in abundance; thus, nanocomposites based on carbon nanotubes have attracted a considerable attention, particularly due to the special conductivity of carbon nanotubes and conductive polymers. Due to the intrinsic difference between inorganic and polymer materials (soft matter vs. rigid structure), this type of composites has long attracted a noticeable attention. Now structural entanglement at nanoscale has provided rare opportunities for the formation of interesting nanocomposites. This is of particular interest when dealing with inorganic materials and conductive polymers which both have ionic properties and conductivity, and the resulting nanocomposites have a wide variety of applications. Metallic nanoparticles are usually too small, leading to severe difficulties in handling the nanomaterials, and soft structure of polymers is an appropriate medium to host such tiny nanoparticles. Again electrical conductivities of both ingredients of this class of nanocomposites lead to potential applications.

Like all types of polymers, conductive polymers are first characterised by spectroscopic techniques, and this is of particular importance for nanostructured materials too. Atomic force microscopy (AFM) is a powerful (and relatively inexpensive) microscopic technique for surface studies at nanoscale, and sometimes this is essential for the investigation of conductive polymers. Despite available limitations, progress in nanodevices has provided

new opportunities for the study of single molecules. Study of single wires of polymers is quite easy due to the size of the polymer chains. An interesting feature recently reported is the possibility of preparation of micro- and nano-containers of conductive polymers which can have potential applications. Magnetic properties and electron transfer in nanocomposites made of conductive polymers are complicated which need profound investigations. An important application of conductive polymers is in solar cells, but to reach effective performances, it is necessary to inspect charge transfer theoretically.

The last part of the book reviews some important applications of conductive polymers which have been evolved by the birth of nanotechnology. Chemical and electrochemical sensors based on conductive polymers have been effectively fabricated during the past decades, and now nanomaterials have significantly improved the sensor performances. In recent years a noticeable attention has been paid to polymer-based actuators, and according to potential applications at smaller scales, nanostructured-based polymers play key roles in this case. From the first electrochemical synthesis of conductive polymers, they have been propounded for the protection of metal surfaces against corrosion as a thin layer could be simply electrodeposited. Possibility for the coating of uniform with small thickness has made this idea more practical. Electrochemically prepared conductive polymers show excellent electrocatalytic properties (and particularly in electroactive composites) and due to the enhanced electrochemical properties of nanostructured materials, this is an open issue in the realms of nanotechnology. Polymers are generally a dominant category in biomaterials, and due to the fictional prospective of nanotechnology to make a revolution in medicine, it is always interesting to inspect biomedical applications of polymer nanomaterials. Taking control at nanoscale provides golden opportunities; for instance, conductive polymers are not limited to polymers which are originally conductive, but it is possible to make conductive polymer-based nanocomposites by nanofillers.

The subjects quoted above are among hot topics in the interfacial field between conductive polymers and nanotechnology, which have been elaborately discussed by leading scientists. Each chapter reviews the past by citing key references through a comprehensive review of the literature, discusses the present by reporting recent and forthcoming achievements, and draws the future by introducing a prospective of the topic under consideration. As emphasised before, the present book should play a role in transition from the present to future as we are just in the beginning of a new stage in the realms of nanotechnology. Until now we were engaged with the birth of nanotechnology, but now it is the time for maturing this rapidly growing field. We witnessed many incredible but random achievements in different disciplines associated with nanotechnology; however, now we need to conduct the scientific research in desirable ways to reach planned goals.

At last but not least, I need to thank those people whose names are not printed in this book, but the publication of this volume would not have been possible without their hard efforts. The list of people from scientific referees to technical staff is too long to be incorporated here; but I must send my special thanks to Alexandra Carrick, Emma Strickland, and Richard Davies. I could not forget how they have worked with me with patience on a daily basis. One may think it is just formalities and as a part of publication industry everyone does her/his duty; but the fact is that in such a complicated process, sincere collaborations and mutual understanding between all parties involved can lead to the publication of a brilliant volume. Definitely, it was the case for the present book, and

I hope we are successful in contributing to the scientific community. Although it was a team work, any failure returns to me as the coordinator of this book project; thus, I strongly appreciate any comment, which will be invaluable for me in editing prospective volumes.

Ali Eftekhari
January 2010

Foreword

In the recent decades, the field of conductive polymers has been one of the most exciting fields of science and technology. It has brought together scientists from many disciplines and countries. This great progress has involved synthesis of materials closely linked to physical characterisation. With the development of this field, a wide range of applications have been envisaged, presenting their own research challenges and stimulating further innovation. It discovery, provided new materials and frequently also reflected back on our understanding at a more fundamental level. Throughout, the interplay of structure and properties has been at the heart of the subject, and now this book reviews the field with particular emphasis on nanostructure. It elegantly captures the key features of the field outlined above: the quest to make materials, relate their properties to their structure, the favourable interplay of basic and applied research, and the realisation of materials that could only have been dreamt of in the past.

The opening chapter by Campbell Scott gives an eloquent, insightful and personal history of the subject by a leading researcher whose career has spanned, what he describes as, the modern age of materials. The subsequent chapters show an enormous range of ways of synthesising and preparing nanostructured conductive polymers in many different forms – nanofibres, nanorods, nanotubes, nanospheres and even "brain-like" morphologies. Besides covering chemical and electrochemical synthesis methods, the chapters are devoted to advanced processing techniques for nanostructure fabrication, such as electrospinning and soft lithography. Conductive polymers can be blended with a range of other materials such as nanoparticles and carbon nanotubes, leading to nanocomposite materials with additional properties. Many interesting examples discussed in this volume range from magnetic composite materials to conductive nanogreases.

The development of nanostructured conductive polymers also requires the development of advanced characterisation techniques, and this aspect of current research is captured in several chapters. A detailed review of Atomic Force Microscopy (AFM) covers the wide range of related scanning probe microscopes that are particularly relevant to soft materials. It also shows how techniques such as conductive AFM go beyond structural measurements to image the functional properties of materials relevant to applications such as solar cells. A wide range of spectroscopic techniques has also been reviewed, showing how they can be applied to learn about the interactions between conductive polymers and nanostructured

hosts. In addition, rheological measurements as well as the impact of nanostructure on electrical and optical properties have been described.

This book covers the remarkable range of applications emerging for nanostructured conductive polymers. These applications generally exploit the increased surface area of nanostructured materials, often to do something very new. One very important example is of polymer solar cells, where nanoscale phase separation lies at the heart of charge generation and extraction. Another exciting application domain is the use of nanostructured conductive polymers as biomaterials, including the development of neural interfaces. Other applications described include sensors, actuators, corrosion protection and electrocatalysis.

Each chapter provides a comprehensive review by a leading researcher. But a bigger picture emerges from reading all the chapters together – it reveals how we are now working with new classes of materials, new techniques and how the quest to link properties to structure is advancing at the nanoscale. The ensemble of all the chapters captures the excitement and potential of this field, whilst beautifully demonstrating the interdisciplinary and international nature of modern science.

Ifor Samuel, St Andrews,
May 2010

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