Preface

Nanocomposite organic/inorganic materials are a fast expanding area of research, part of the growing field of nanotechnology. The term "nanocomposite" encompasses a wide range of materials mixed at the nanometer scale, combining the best properties of each of the components or giving novel and unique properties, unknown in the constituent materials, with great expectations in terms of advanced applications. Significant effort is focused on the ability to control the nanoscale structures via innovative synthetic approaches. The properties of nanocomposite materials depend not only on the properties of their individual components but also on their morphology and interfacial characteristics.

Experimental work has shown that virtually all types and classes of nanocomposite materials lead to new and improved properties, when compared to their macrocomposite counterparts: they tend to drastically improve the electrical conductivity, specifically the ionic conductivity, and thermal conductivity of the original material as well as the mechanical properties, e. g., strength, modulus, and dimensional stability. Other properties that might undergo substantial improvements include decreased permeability to gases, water and hydrocarbons, thermal stability and chemical resistance, surface appearance and optical clarity. Therefore, nanocomposites promise new applications in many fields such as mechanically reinforced lightweight components, nonlinear optics, battery cathodes and solid state ionics, nanowires, sensors, and many others. Much effort is going on to develop more efficient combinations of materials and to impart multifunctionalities to the nanocomposites.

In previous volumes of this book series, we have reported on the properties and applications of materials with characteristic dimensions in the nanometer scale. These reports were however mainly devoted to inorganic single phase materials. Recent years have seen a widespread development of polymer and hybrid organic/inorganic systems, which improve the variability of the materials properties and give supplementary freedom for realization of hitherto unattainable combination of properties.

In this book, we want to review some recent advances in composite materials with domain sizes in the nanometer range, emphasizing polymeric and hybrid systems, which have advanced spectacularly. Given the scientific background of the editors, most of the chapters are devoted to ionic conducting materials; some emphasis is put on materials potentially useful in fuel cells and lithium ion batteries, including polymer nanocomposites with clay and other plate-shaped particles as second phase.

The first chapter sets the general frame for the investigation of composite polymeric electrolytes. This chapter is especially devoted to lithium ion conducting solid electrolytes for lithium batteries, with polyethylene-oxide-based systems playing a central role. But theoretical models of electrical properties and ionic conduction in polymers are discussed in depth and various scenarios for conductivity enhancement effects are outlined, including space charge and Lewis acid–base model. These concepts are useful for any kind of polymer electrolyte.

On the basis of these foundations, the second chapter addresses proton-conducting nanocomposite and hybrid polymers used as electrolyte membranes in proton exchange membrane fuel cells. An overview of recent literature in this domain is given: besides traditional Nafion, polyaromatic polymers play an increasingly prominent role in the field. Models used for description of the structure, stability, and transport properties of proton-conducting polymer nanocomposites are also outlined.

Thin-film metal–polymer and metal oxide–polymer nanocomposites are the subject of the third chapter: they are prepared by vacuum phase codeposition of metal and polymer, using *para*-xylylene as monomeric unit, and subsequent oxidation. The vacuum deposition technique might be applicable for related materials; relevant properties are reported, including adhesion and electrical resistance. These composite films can be used in different domains, such as microelectronics and Li-ion battery electrodes.

The mechanical properties of polymer nanocomposites with rod- and plate-shaped nanoparticles are described in the fourth chapter. The anisotropy plays a central role for improvement of mechanical properties. The materials preparation and analysis are described, including specific techniques such as dynamical mechanical analysis or moisture diffusion measurements. Modeling of mechanical properties is also treated.

The fifth chapter presents a small outlook on the vast and rapidly growing domain of computer simulation of materials. Relevant methods, quantum mechanics, Monte-Carlo simulations, and molecular dynamics, are briefly introduced. Cationic and anionic clay–polymer nanocomposite materials attract great attention as they offer enhanced mechanical, thermal, and catalytic properties as compared to conventional materials. They are also studied as possible solid electrolytes for batteries and fuel cells. Simulations of structure and dynamics of clay–polymer nanocomposites are presented, including Li-ion conduction and catalytic properties.

The last three chapters present specific structural spectroscopies, which were extensively applied to the domain of nanocomposites and have brought significant advances in the understanding of these systems. In all these chapters, the specific techniques are first introduced briefly; the advantages of the technique, the information available and significant examples are then presented again with particular emphasis on ionic conducting systems.

X-ray absorption spectroscopy studies of nanocomposites can provide information on the local environment and oxidation state of an atom, the technique being element specific, usable at low concentrations of target atom, and not restricted to crystalline systems. The case of nanoparticles dispersed in an inorganic matrix or a polymer matrix and nanoparticle/nanoparticle composites are examined.

Nuclear magnetic resonance (NMR) is a valuable tool for studying ionic diffusion in materials and dynamical aspects of nanocrystalline ceramics and composites. This technique is particularly useful to differentiate alternative transport mechanisms, like fast interfacial vs. slower bulk diffusion, via the NMR relaxation rates. In this chapter, F- and Li-ion conducting nanostructured materials are particularly discussed.

Mössbauer spectroscopy is another nonconventional technique, which has proven to be of great relevance for the investigation of electrode materials for Li-ion batteries. The mechanism of lithium insertion/deinsertion during cycling of the battery can be followed in situ during the cycles. The local structure and oxidation state of ions can also be deduced from Mössbauer spectra.

The sum of these eight contributions should give a broad range of readers from solid state chemistry, solid state physics, and materials science an outlook on the status of research and development in the domain of nanostructured composites. The emphasis on ionic conducting materials makes this book particularly attractive for the solid state ionics and electrochemistry community. Given the particular impact of these materials for environmental and energy applications, readers interested in these topics should also profit from this book.

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