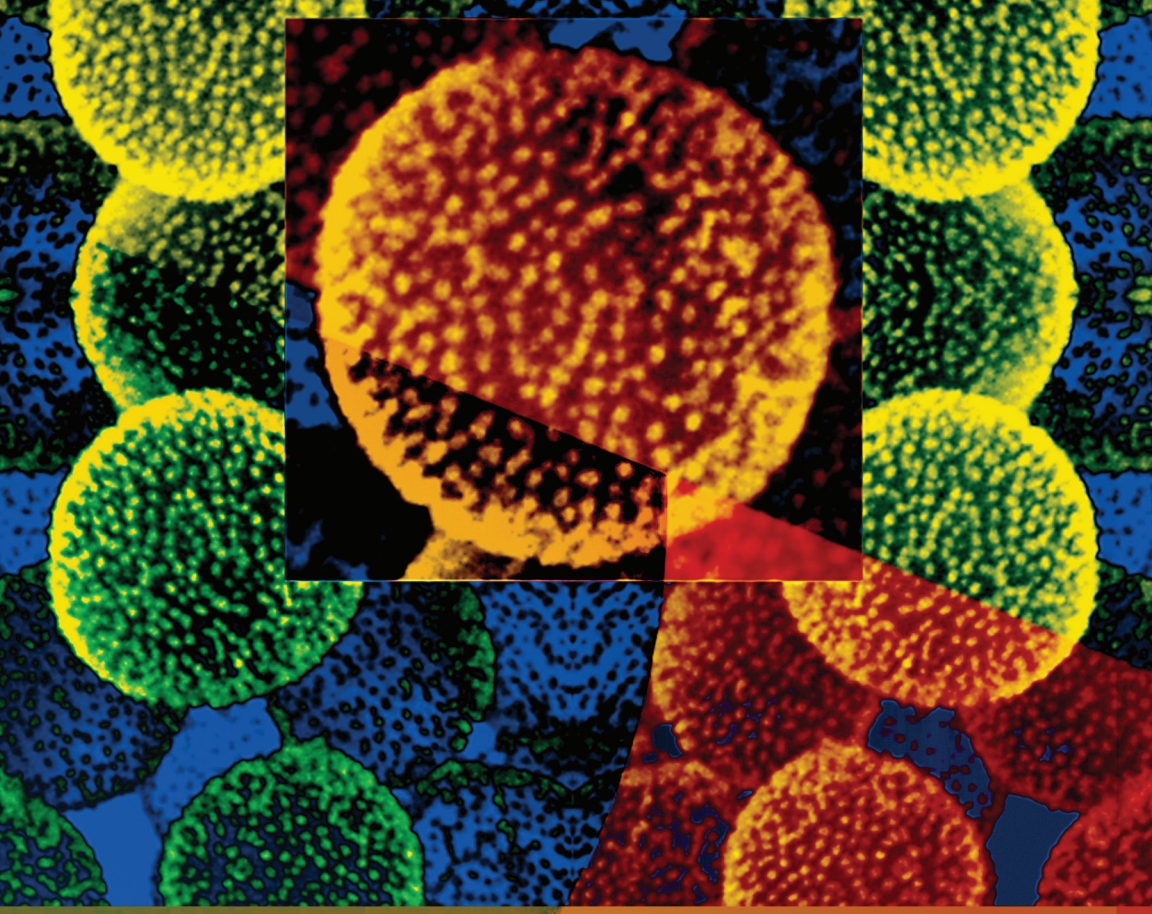
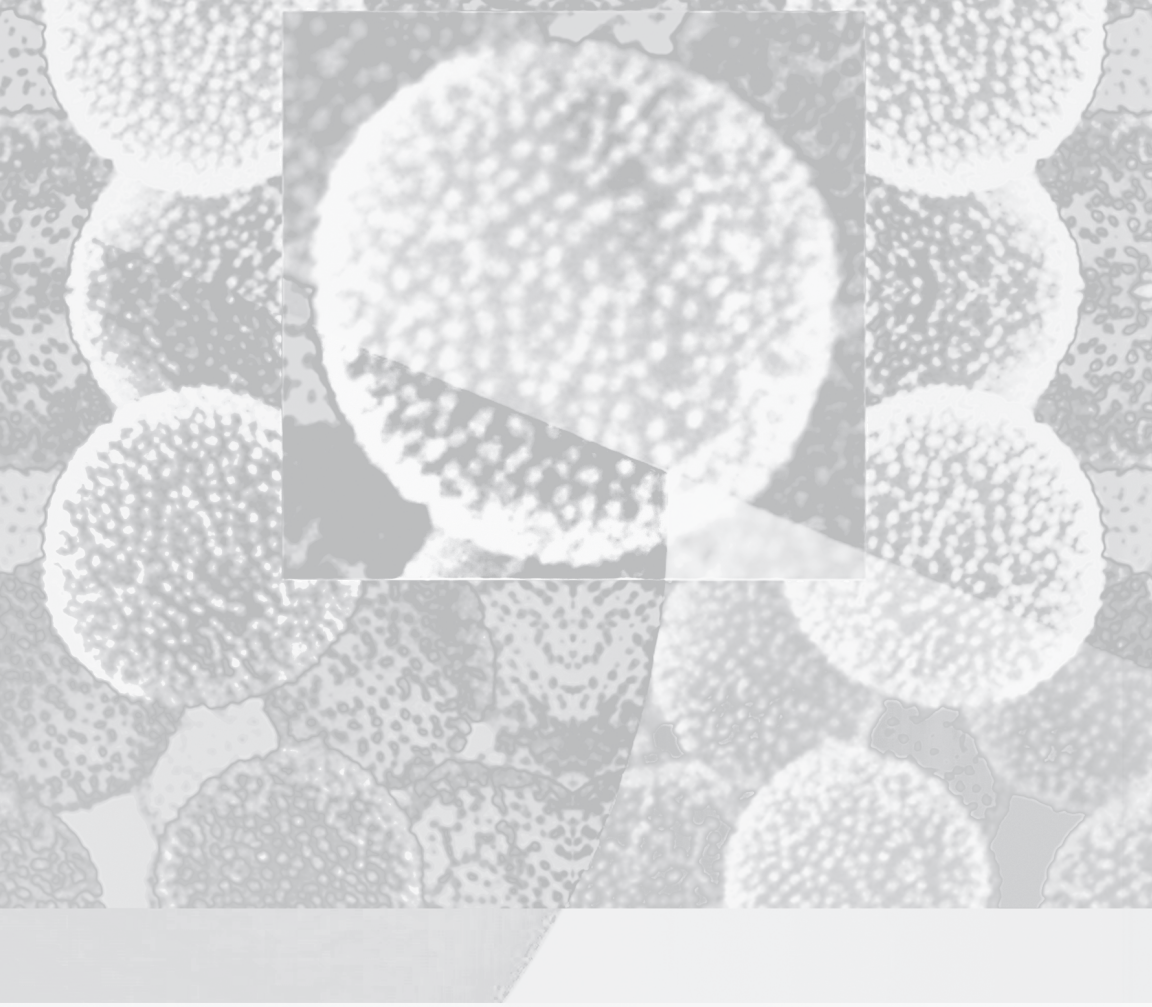


MOBILE MICROSPIES

Particles for Sensing and Communication

Michael Köhler



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PAN STANFORD PUBLISHING

Published by

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com
Web: www.panstanford.com

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Mobile Microspies: Particles for Sensing and Communication

ISBN 978-981-4800-14-3 (Hardcover)
ISBN 978-0-429-44856-0 (eBook)

Contents

Preface

Freedom in combinations of a few types of atoms in molecular architectures supplies an unlimited variability in the organic chemical microcosmos. It is also the fundament for forming biomolecules that are able to construct and manage biological cells. These and other atoms are able to form solids, microparticles, and nanoparticles, too, which possess the ability to generate a huge variability in structures and functions by structural combination at the mesoscale between the level of molecules and the macroscopic world. There is not only "plenty of room" at the molecular scale, but there also is an unimaginably huge space for constructing objects between the nanometer and the millimeter scale.

During the past two decades, it was recognized by many researchers that a treasure of possibilities is offered by the world of micro- and nanoparticles. One of the most fascinating aspects is that their properties can be influenced not only by their chemical composition but also by their size, shape, and environment. New synthesis strategies, new laboratory techniques (among them the microfluidic method), and new application requirements led to a large spectrum of new synthetic particle types. Many of them are of interest for new applications because they are usable for local conversion of chemical information into physically readable signals. These particles can be mobile and can be implemented in different liquid and technical systems, such as in cells, tissues, or the environment, too. In communication with suitable readout systems, they can report about local chemical conditions and processes. That's why they can be regarded as "mobile microspies" (in German "mobile mikro-Spione").

After giving a talk at a meeting in San Diego in December 2016, the publisher asked me to write a book about *mobile sensor particles*. The topic is fascinating to me for about 25 years. In this time, some colleagues and I had worked mainly on using micro- and millifluidics for improving lab methods for the synthesis and development of new types of micro- and nanoparticles. For a fruitful collaboration on

microfluidic synthesis and application of nanoparticles, in particular, I would like to thank Christophe Serra, Chenqi Chang, Wolfgang Fritzsche, Andrea Csaki, Jörg Reichert, Jörg Wagner, Andrea Knauer, Shuning Li, Steffen Schneider, Aniket Thete, Nikunjkumar Visaveliya, Stefan Nagl, Anette Funfak, Jialan Cao, Lars Hafermann, and Xiang Li. I also have to thank them for their cooperation, interesting and stimulating discussions, and essential support. The common work mainly motivated me to deal with the large world of small particles.

Michael Köhler

2018

Introduction

Particle-based sensing techniques have attracted quickly increasing interest during the past two decades. This development is driven by a broad spectrum of new technologies for the preparation and measurement of micro- and nanoparticles and by fascination of the possibilities for designing and functionalization of all specificities in the structure shapes and behavior of these tiny objects, on the one hand. On the other hand, there evolves a fast-growing need of new sensing and communication paths for medicine, biotechnology, and analytical science, as well as for new and efficient information transfer and storage systems, in general. No longer are particles regarded only as special types of materials, but it is better understood that they are bridging the gap between material and system, between structure and function. Thus, micro- and nanoparticles can act as transducers and can used for local signal conversion and for readout of information from any environment in which they are embedded.

The book introduces the concepts of bead-based sensing and "mobile spies" at the micro- and nanoscale. It gives an overview of the role of particles in contact signal conversion and noncontact signal transfer and of the interaction of these two processes. Therefore, a large spectrum of methods for coupling molecular recognition with primary signal transduction and optical signal transfer is presented. Besides, fluorescence and fluorescence resonance energy transfer (FRET) beads, microparticles using phosphorescence or chemoluminescence, photoacoustic transduction, pohotochemical switching, and bead-based plasmonic and Raman sensing, are discussed. But it becomes clear that optical signal transduction with visible light is not the only way for realizing microsensor particles. Ultraviolet (UV) and infrared (IR) waves, electrochemical functions, and magnetic functions can also be involved in realizing miniaturized and mobile transducers.

Synthesis and surface functionalization are key issues in the entire sensor particle development. The methods and procedures are dependent on particle materials; their functions, transport,

and storage requirements; and the required particle sizes and homogeneity requirements. It is shown that techniques for the production of composite particles, hierarchically composed particles, and particles from microfluidic syntheses are of particular interest from the point of view of the need of high-quality sensing micro-objects.

The following chapter is devoted to the application of microscopic "spy"-like particles for information read out from different systems. These applications reach from technical microenvironments, biotechnology, and lab applications in biomedicine to environmental tasks. Meanwhile, an impressive part of investigations shows the applicability of a particle-based readout of different local concentrations of chemical species and biomolecules from organs, tissues, and single cells, too.

The use of particle-like objects for spreading information and communication is a not completely new invention in recent technology. The principle had already been developed by living nature many million years ago. Therefore, the analogies between particle-based information transfer in organisms and natural environments, on the one hand, and particle-based sensing and communication by technical systems, on the other hand, are discussed. It has to be recognized that a certain convergence of these technical developments in the direction of the natural principle is evident. This convergence is due to the efficiency of particle-based transduction, transport, and information storage principles. And it is also required for reaching an eco-compatible and sustainable application of these materials and technologies. Environmental requirements and the question of how we can interconnect better natural and technical information systems' demand for a new concept of particle-based technologies drive the search for new particle designs and particle-related technologies. The state of the art in the development of particles as "mobile spies," for communication and information management, allows us to speculate about future particle-based components and systems in a completely sustainable world economy.

In the last chapter of this book, some aspects of possible future developments are discussed.