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R. Rigler
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Single Molecules and Nanotechnology

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Editors

Single Molecules and Nanotechnology

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Preface

The investigation of molecules as individuals has grown rapidly in recent years, and in the process has uncovered molecular properties not normally accessible by ensemble experiments. In particular, the direct characterization of biologically important molecules such as enzymes, molecular motors, or receptors and entire signaling complexes in action, for example in a live biological cell, yielded unexpected insights. Common approaches for studying single molecules include the electrical detection of ion channels in membranes, the measurement of the dynamics of (bio)chemical reactions between individual molecules, the imaging of individual molecules by scanning probe techniques or by fluorescence correlation spectroscopy, and the direct monitoring of single molecules by optical microscopies, to mention a few. The application of these techniques in physics, chemistry, and biology has opened new areas of nanotechnology. This book provides a representative selection of recent developments in the rapidly evolving field of single molecule techniques of importance in life sciences and will have future impact on the quantitative description of biological processes. The editors of this book hope that the chapters, written by leading scientists in the field, will attract students and scientists from different disciplines, provide them with an authentic insight into this young field of research, allow them to evaluate experimental methods and results, and thereby give them support for their own research.

Lausanne
September 2007

Rudolf Rigler
Horst Vogel

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Chapter 1

Nanophotonics and Single Molecules

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Abstract Single emitting molecules are currently providing a new window into nanoscale systems ranging from biology to materials science. The amount of information that can be extracted from each single molecule depends upon the specific photophysical properties of the fluorophore and how these properties are affected by the nearby environment. For this reason, it is necessary to develop single-molecule emitters with as many different reporter functions as possible. The first part of this chapter describes a relatively new class of single-molecule fluorophores which offer

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tunable photophysical properties and, in turn, improved local reporting functionality on the nanometer length scale. The second part of this chapter presents metallic nanostructures which can address a second issue: the mismatch between the typical size of a single fluorophore (~ 1 nm along a long dimension) and the wavelength of light (~ 500 nm). Such nanostructures could lead to more efficient excitation of single molecules, in particular, higher excitation probability as well as reduced backgrounds, and effectively higher spatial resolution. Metallic nanostructures based on two triangles formed into a bowtie shape feature large enhancements of the local electromagnetic field and give rise to strong surface-enhanced Raman scattering of molecules. In future work, enhanced electromagnetic structures can be combined with single-molecule reporters in a variety of applications.

1.1 Introduction

In recent decades, the ability to perform optical spectroscopy and microscopy of single molecules in condensed phase samples (Moerner and Orrit 1999) has fascinated scientists in fields ranging from biophysics (Zhuang and Rief 2000; Weiss 1999; Lu 2005; Rasnik et al. 2005), to cellular biology (Moerner 2003), to materials and polymer science (Cotlet et al. 2004; Barbara et al. 2005; Lee et al. 2005), and even to quantum-mechanical single-photon sources (Moerner 2004; Lounis and Orrit 2005). Using now-standard experimental methods (Ha et al. 1999; Ha 2001; Moerner and Fromm 2003), information on local interactions can be extracted, molecule by molecule, by the measurement of excited state lifetimes, spectra, orientations, brightness, degree of energy transfer, and photon correlations, thus removing ensemble averaging and allowing exploration of heterogeneity. Single-molecule studies often reveal complex statistical fluctuations, which allow useful comparison with theoretical models in a variety of cases (Barkai et al. 2004; Watkins and Yang 2004; Hummer and Szabo 2005).

A continuing need exists for the improvement and extension of these efforts in order to increase the variety and amount of information that may be obtained from single-molecule studies. For example, at room temperature, eventual photobleaching limits the knowledge that may be extracted from each individual molecule. To compensate for this, it is necessary to continually develop new reporter functions for robust fluorophores that provide sufficiently strong signals at the single-molecule level.

The first part of this chapter describes a relatively new class of single-molecule fluorophores which offer tunable photophysical properties and, in turn, improved local reporting functionality on the nanometer length scale. While a single molecule can report on its immediate nanoenvironment, in most experiments, there is a large mismatch between the size of a single fluorophore (~ 1 nm along a long dimension) and the wavelength of light (~ 500 nm). Developing ways to overcome this would lead to more efficient excitation of single molecules, in particular, higher excitation probability as well as reduced backgrounds, and effectively higher spatial resolution.