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Chemical Techniques

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Preface

Nanotechnology has received tremendous interest over the last decade, not only from the scientific community but also from a business perspective and from the general public. Although nanotechnology is still at the largely unexplored frontier of science, it has the potential for extremely exciting technological innovations that will have an enormous impact on areas as diverse as information technology, medicine, energy supply and probably many others. The miniaturization of devices and structures will impact the speed of devices and information storage capacity. More importantly, though, nanotechnology should lead to completely new functional devices as nanostructures have fundamentally different physical properties that are governed by quantum effects. When nanometer sized features are fabricated in materials that are currently used in electronic, magnetic, and optical applications, quantum behavior will lead to a set of unprecedented properties. The interactions of nanostructures with biological materials are largely unexplored. Future work in this direction should yield enabling technologies that allows the study and direct manipulation of biological processes at the (sub) cellular level.

Nanotechnology has made considerable progress due to the development of new tools making the characterization and manipulation of nanostructures available to researchers around the world. Scanning probe technologies such as STM and AFM (and a range of modifications) allow the imaging and manipulation of individual nanoparticles or even individual molecules. At the same time, the development of extreme lithographic techniques such as e-beam, focused ion beam and extreme UV, now allow the fabrication of metal and polymer colloids with nanometer dimensions. Still, the fabrication of nanoscale building blocks is not a trivial task, especially when large numbers of identical nanostructures are required. For example, fascinating structures and devices can be made from nanosized GaAs islands grown on surfaces via nucleation and growth strategies. One of the inherent problems associated with such strategies is the variation of structures within the system. Even colloidal metals that are grown in solution like gold or CdSe quantum dots are not identical. There is reason to believe that entirely new manufacturing processes need to be invented to deliver these structures for economically viable processes. At the same time, new device layouts need to be developed that can tolerate a specific uncertainty in its building blocks.

Fabrication is difficult, but the large-scale assembly of nanoscale building blocks into either devices (e.g. molecular electronic, or optoelectronic devices), nanostructured materials, or biomedical structures (artificial tissue, nerve-connectors, or drug delivery devices) is an even more daunting and complex problem. There are currently no satisfactory strategies that allow the reproducible assembly of large numbers of nanostructures into large numbers of functional assemblies. It is unlikely that a robotic system could assemble nanoscale devices. A key issue will be the development of tools to integrate nanostructures into functional assemblies. Scanning probe lithographies such as AFM and STM that allow the manipulation of single molecules or nanoparticles could certainly provide a route towards functional structures and prototype devices. Recent examples such as the Millipede project of IBM have shown that 1000's of AFM tips that are individually addressable can be fabricated. However, such strategies require immense engineering efforts and are not generically applicable to a wide range of materials or structures. Furthermore, scanning probe techniques are essentially 2D and the fabrication of 3D nanostructures materials would present a significant hurdle. It is therefore very likely that any economically feasible assembly route will incorporate to a certain extent the principles of self-assembly and self-organization. After all, many inspirations for nanotechnology come from Nature where precisely these processes control the very fabric of life itself: The chemical recognition and self-assembly of complementary DNA strands into a double helix.

Chemists are beginning to master self-assembly as a tool to mimic biological processes using non-natural molecules or even nanoparticles. At the same time, our increased understanding of molecular biology should enable us to exploit biological "machinery" directly for the fabrication of synthetic nanostructures. Self-assembly is the spontaneous formation of ordered structures via non-covalent (or reversible) interaction between two objects (molecules, proteins, nanoparticles, or microstructures) can lead to a well-defined assembly. Directionality can be introduced through the type of interaction or via the shape of the object. Self-assembly is a spontaneous, energetically favorable process and leads, in principle, to perfect structures, if allowed to reach its lowest energy level. No nanoassemblers or nanorobots are required to physically manipulate objects. All information required for the assembly of a well-defined superstructure is present in the building blocks that are to be incorporated in the assembly. In practice, defect-free structures are difficult to obtain as it can take very long to reach equilibrium. Furthermore, all structures that are formed are dynamic, i.e. changing over time, as they are not covalently bound. It will hence be necessary to design device layouts with built-in defect tolerance.

In this book we will take a closer look at a great variety of different strategies that are pursued to assemble and organize nanostructures into larger assemblies and even into functional devices or materials.

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