Preface

Nanoscience and technology focuses on the synthesis and application of structures that have at least one dimension on the sub-100 nm length scale. It deals with investigating the fundamental properties of such structures, which usually differ significantly from that of the bulk material, and taking advantage of these qualities to construct novel materials and devices or develop unique applications that can address global challenges in health, energy, the environment, and beyond. Owing to widespread interest and investment, biomedical nanotechnology, geared toward the ultimate use of nanostructures in medicinal and clinical applications, is an area of intense research that is growing and progressing at an extraordinary pace. This rapid development is fueled by the fact that nanomaterials often offer superior capabilities when compared to materials that are conventionally used for the detection, diagnosis, and treatment of disease. Nanomaterials are enabling promising advances toward the attainment of long-standing goals within biomedicine, such as the ability to track and treat disease in real time and the capability to provide personalized or precision medicine approaches to each individual patient, among others.

The goal of this volume is to provide an overview of some of the types of nanostructures commonly utilized in nanobiomedicine; many of these nanostructures possess both inorganic and organic or biological components and are of a size that allows them to interface with biological systems. The majority of this volume consists of protocol chapters, which provide practical information on the synthesis and characterization of a variety of solution-phase and surface-bound nanomaterials and show how they can be used in sensing, imaging, therapeutics, or more than one of these capacities simultaneously. Most chapters provide step-by-step instructions and insight into overcoming possible pitfalls and challenges associated with the completion of the protocol. Most chapters also offer the reader insight into how the protocol can be changed with the reader's own research goals in mind (e.g., to target a different gene or to detect a different biomarker).

The ability to reliably and reproducibly synthesize highly uniform nanomaterials that can be fully characterized is important in many areas of nanoscience, including biomedicine. Chapters 1–6 discuss protocols for synthesizing and characterizing molecule and biomolecule-functionalized nanoconjugates with gold, iron oxide, or polymeric cores, which are often utilized in biomedical nanotechnology. Here, novel fluorescence (Chapter 1), ^{1}H nuclear magnetic resonance (NMR) (Chapter 2), nanoparticle tracking (Chapter 3), and superconducting quantum interference device (SQUID) magnetometer-based (Chapter 4) methodologies are discussed. Emphasis is placed on using such knowledge to uncover structure–function relationships that can be used to control how nanomaterials interact with biological systems. Chapter 5 describes the synthesis of dumbbell-like gold-iron oxide nanoparticles as well as other types of magnetic particles; many nanomaterials are designed with multiple components that lend them multifunctionality. Then, Chapter 6 shows the reader how to synthesize non-biodegradable polystyrene-based, polyethylene glycol functionalized nanoparticles useful for analyzing the brain microenvironment. Many researchers are currently interested in understanding and treating diseases of the brain; indeed, this topic represents a highly pertinent research area within biomedical nanotechnology.

A realm of biomedical nanotechnology that has experienced early success lies in the use of nanomaterials for biosensing and imaging applications. One example of a biosensing platform that utilizes well-characterized nanoparticles is presented in Chapter 7. The volumetric bar-chart chip, or V-chip, can be used for the instant visual quantitation of target proteins in a multiplexed manner. Flow cytometry-based methods have also emerged as powerful tools within biomedical nanotechnology. Researchers are devising ways to make this technique amenable to high-throughput, quantitative measurements (Chapter 8), and they are applying it to gain knowledge of how nanomaterials interact with and influence the behaviors of cells, especially immune cells, an important consideration for any nanomaterial that will be placed into a living system (Chapter 9). In fact, researchers in the field of biomedical nanotechnology are placing special attention on figuring out how to keep immune systems from negatively reacting to nanoparticles (eliciting toxicity), but also on understanding how nanoparticles can be used to upregulate or downregulate immune responses in the context of immunotherapy. Nanostructures that can be used to detect and track biomolecules intracellularly are also being developed. Chapter 10 presents a nanostructure that can track messenger RNA inside differentiating stem cells, using a method that does not result in cell death, and hence allows for downstream processing or long-term analysis. Nanoparticle tracking is also being used to understand the motion of membrane neurotransmitter transporters on the surface of cells (Chapter 11), and photoacoustic imaging is being used to map nanoparticle distribution in vivo (Chapter 12).

In addition to enabling applications in biosensing or imaging, there are various ways in which nanomaterials can function as therapeutic agents within the field of biomedical nanotechnology. A desirable feature of many nanomaterials is that their modular architectures allow them to perform multiple functions simultaneously. For example, in Chapter 13, conjugated gold nanorod structures that can utilize both drug delivery and photothermal therapy to treat disease are discussed. In Chapter 14, a nanostructure is presented that is designed to collapse upon irradiation into free oligonucleotides, drug molecules, and small molecule payloads (all with therapeutic potential), and Chapter 15 discusses structures composed of amphiphilic block copolymers containing the appropriate cargo (drug or diagnostic agent) and enzyme-responsive peptides that fall apart when they encounter specific enzymes. These chapters highlight an important push within the field of biomedical nanotechnology—to prepare dynamic, bioresponsive structures. Another thrust in the field is toward developing structures that mimic natural biological systems. The Nanoscript, which mimics the structure and function of transcription factors (TFs), is designed to interact directly with genes to provide a therapeutic benefit through the regulation of gene expression (Chapter 16). These chapters focus primarily on the synthesis of the nanoconjugates themselves, but allude to their downstream therapeutic applications.

Some types of nanostructures utilized in biomedical nanotechnology are effective when coupled to substrates comprised of nano- and microstructures, as demonstrated in Chaps. 17–19. In Chapter 17, nanovesicles are loaded into microneedle-array patches to aid in the delivery of insulin. Chapter 18 focuses on the synthesis of nanofiber configurations on surfaces that can be used as biological grafts and implants to engineer and regenerate soft tissues, and Chapter 19 shows how one can use nanopatterned surfaces to treat diseases of the eye. Nanoparticle toxicity is also discussed in this volume because it is particularly relevant when introducing nanomaterials to biological environments, especially the human body. Chapter 20 discusses how to assess toxicity related to graphene oxide nanomaterial exposure; importantly, this chapter highlights another important use of a flow cytometry-based method (imaging flow cytometry). Chapter 21 expounds on how to analyze the toxicity of nanoparticle aerosols using a special air-liquid exposure system; such studies are important to bolster the translation of nanoparticle treatments that employ this delivery method to the market. The final chapter in this volume provides a case study on patent landscapes within nanoscience and technology, following up on ideas presented in the first edition of this volume (Chapter 22).

The chapters are written by leading researchers from all over the world, several of whom also participated in the first edition of this volume, working within nanoscience and technology, biology, chemistry, physics, engineering, medicine, and the law. Together, these chapters demonstrate the potential of nanotechnology to revolutionize medical care. Moreover, they beautifully illustrate how the fundamental property differences associated with nanomaterials (relative to bulk materials) and their potential for use as multicomponent/multifunctional structures can be exploited to transform the study, detection, and treatment of disease. This volume is a useful reference for scientists and researchers at all levels who are interested in working in a new area of nanoscience and technology or in expanding their knowledge base in their current field. Chapter 22, in particular, will be of interest to the social scientist, lawyer, or businessperson, who wants to learn about how the patent process applies to the field of nanotechnology. We are optimistic that advances in nanotechnology, and related fields, will lead to solutions to key issues within biomedicine, as evidenced by the exciting work featured in the second edition of this volume.

Evanston, IL — ***Sarah Hurst Petrosko***
Newark, DE — ***Emily S. Day***

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