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Nanoparticle Technologies: From Lab to Market

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Nanoparticle Technologies

From Lab to Market

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Dedication

To my Mother, to my Queen and Princesses, and to my late Father

Preface

My interest in nanoparticle science and technology started when I was investigating self-assembled monolayers of ultrasmall silver alkanethiolate particles in the mid-1990s [1,2]. In my efforts to understand and control the synthetic process, I was carried so far away that I found myself reading the controversial book of Eric Drexler, *Engines of Creation*. I was reading so much about nanotechnology that I quickly realized that the line between nanotechnology and nanomaterials is quite blurred. These days, these two words become somehow synonymous particularly to the general public, decision makers, and even to some scientists.

This book is neither about nanotechnology nor about nanomaterials, although it may cover some aspects in both fields. Nanotechnology, originally coined in 1974 by Norio Tanugushi, has been receiving a lot of interest from both academia and industry. Hundreds of reports and books have described the potential of this new field. However, as it often happens with new technologies, the line between hype and reality is sometimes fuzzy. Furthermore, an unattended consequence of this hype is the raise of voices opposing or at least trying to slow down nanotechnology development. Public fears are often based on perception and misunderstanding, which could be addressed through open discussion on the advantages and risks of wider use of nanomaterials.

Another source of confusion in this field is related to the difference between nanomaterials and nanoparticles. Nanomaterials are materials that have at least one physical dimension less than 100 nm. This may include carbon nanotubes, nanofibers, nanoclays, nanocomposites, nanoporous materials, nanowires, and nanoparticles. The definition of a nanoparticle is more restrictive. Nanoparticles are spherical (or quasispherical) particles having a diameter of less than 100 nm. Thus, the size in all three geometrical dimensions should be less than 100 nm without any significant aspect ratio. This restriction is fundamental and practical. With the intent of using nanoparticles as building blocks, nanoparticles are considered as artificial atoms, referring to their small size and spherical shape. Furthermore, limiting this book to nanoparticles will allow us to focus on a relatively smaller field. Otherwise, other nanomaterials with a wider scope such as carbon nanotubes will obscure some specific characteristics of nanoparticles. In some cases nanomaterials do not add any value when compared to conventional materials.

Nanoparticle science and technology is a wide and far-reaching field. It encompasses all the conventional scientific disciplines. Their applications include most industrial sectors. Around 40 words have been found in the

literature referring to spherical or quasispherical materials and with submicron size features: aerogel, aerosol, cluster, colloid, crystallite, giant crystal, nanoaggregate, nanobead, nanocapsule, nanocolloid, nanocomposite, nanocluster, nanocompound, nanocrystal, nanodisperse, nanodot, nanogel, nanograin, nanogranule, nanomaterial, nano-object, nanoparticle, nanoparticulate, nanophase, nanophosphor, nanopowder, nanoscale particle, nanosized particle, nanospecies, nanosphere, nanostructured, nanosuspension, quantum dot, submicron, super-cluster, ultrafine, ultrasmall, zero-dimensional. This could be quite confusing even for an expert in this field.

Nanoparticle science and technology predated the age of nanotechnology. Practical utilization of nanoparticles could be traced back to the Roman Empire days. Nanoparticle-based catalysts are also used since 1940s in petrochemical industry and later as catalytic converters in cars. Numerous nanoparticle technologies are under development. Today nanoparticles are faced with similar challenges that any new technology needs to address. Most current nanoparticle applications are based on technology push. Curiosity-driven research in academia dominates this field. New discoveries provide opportunities for new products or improvements of existing products. As the field matured, different nanoparticle value chains are developed. In general, a value chain includes production, formulation, component fabrication, and system integration. Integration of nanoparticles into products and systems brings new and unforeseen scientific and engineering challenges. These challenges appear when using conventional processes in nanoparticle fabrication and integration. These challenges often lead to delays and frustrations of the proponents and/or skepticism from consumers and investors.

When I started working on practical applications of nanoparticles, I realized that integration is the most critical challenge. Only recently this challenge and potential solutions are recognized and described. Indeed, there is no overview of the different assembling techniques to form cost-effective functional film and device. In a few publications, this field was mentioned and/or presented often in a narrow view. A new reader in the field will have difficulty in grasping the actual state of the art and finding the most appropriate solution to current challenges. Integration technology should be adapted to the nanoparticle characteristics and/or applications. This book intends to fill the gap. We have dedicated one chapter to integration of nanoparticles into 1D, 2D and 3D structures. Three application sectors are described in some detail in three different chapters: (i) energy, (ii) optoelectronics, and (iii) biomedical. The last chapter of this book is dedicated to health, safety, and environmental effects of nanoparticles. A general overview of scalable nanoparticle production techniques is also provided.

This book could be used as a general introduction to nanoparticle technology. It also provides brief description of recipes on how to produce and integrate nanoparticles. The reader is implicitly invited to consult the reference for more details. Throughout this book, we will limit ourselves to illustrative

examples instead of aiming at a broad coverage of all publications. Although I have not spared any effort in acknowledging every relevant work, one has to recognize the limitations particularly with the modern age of multiple sources of information, with some significant amount of background noise. Besides higher cost and reliability, nanoparticle-based productions and applications are also facing numerous health and safety issues. Indeed, the lack of data and understanding of nanoparticle properties has raised legitimate concerns from the general public. This challenge stems from the particularity of nanoparticles. Their small size makes them difficult to fully characterize. For example, toxicity of nanoparticles is found to depend on the size and surface chemistry. Unfortunately, measuring the size and chemical composition of these nanoparticles is challenging, given the limitation of the current instrumentation.

Simplicity is another striking difference between nanoparticle technology and other emerging technologies. Indeed, numerous methods used at the different stages of nanoparticle value chain do not require high capital equipment and installations. Furthermore, these methods are not technology intensive. Thus, adoption of these technologies is within reach of small and underfunded startups around the world, researchers in nondeveloped countries, and small-budget research institutions in developed countries. However, this does not mean success will be very easy. Defining clear objectives that could address local issues and understanding current nanoparticle technologies are very important for a successful endeavor in this field.

This book took over 6 years to complete. This does not mean that I have been working all this period on this book. Numerous times I have been carried away by social and professional obligations. Revisiting numerous times the content of this book has helped me improve the overall scope, organization, and presentation of the different chapters. We hope this final version will be helpful for newcomers as an introductory text, and to established researchers and managers as a more complete overview, of this challenging and fast moving field. We certainly welcome any feedback and suggestions by sending your inquiries to: nanoparticletechnologies@gmail.com.

Farid Bensebaa
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