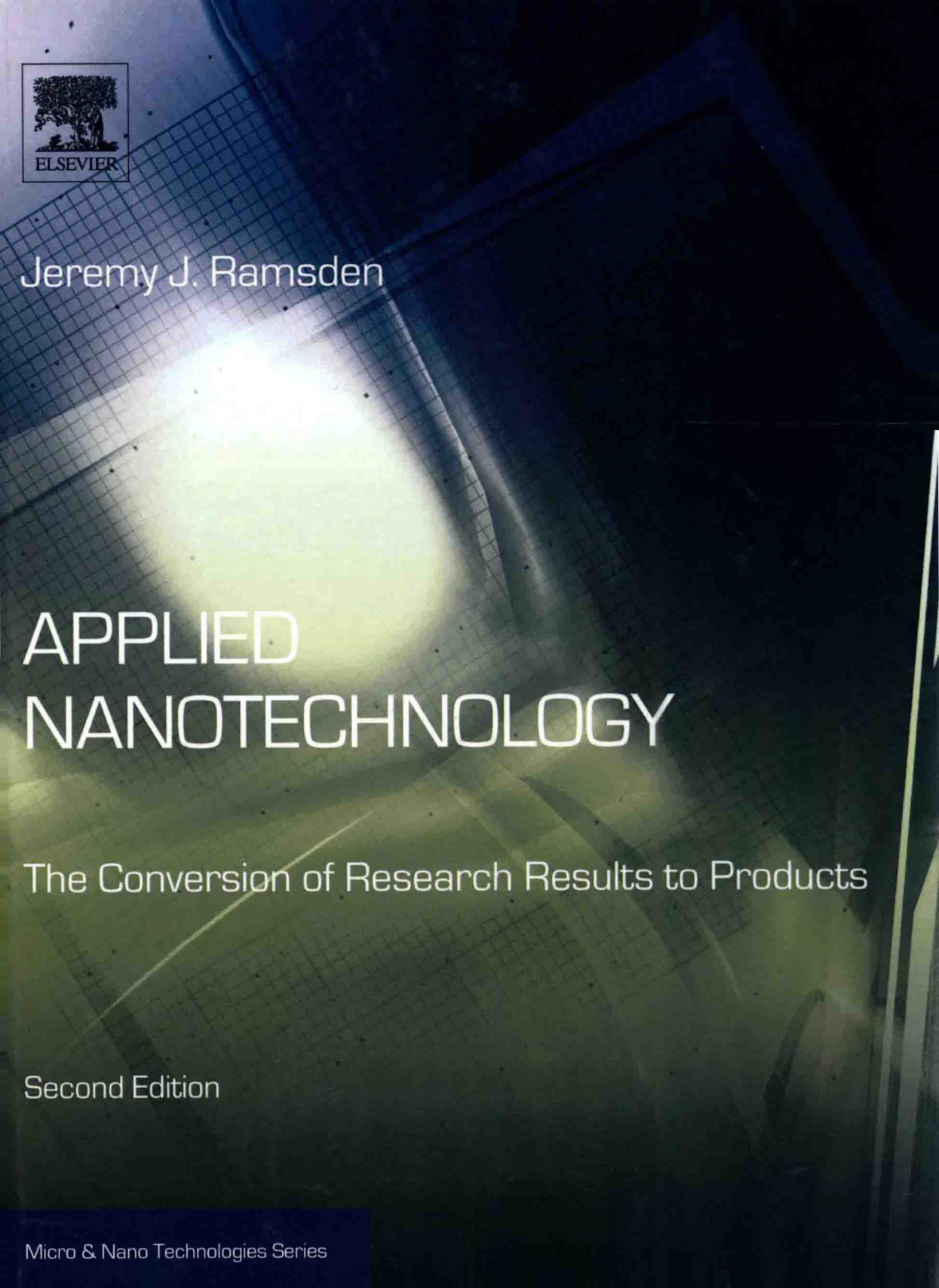
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Jeremy J. Ramsden
APPLIED NANOTECHNOLOGY
The Conversion of Research Results to Products
Second Edition
Micro & Nano Technologies Series

Applied Nanotechnology

The Conversion of Research Results to Products

Second Edition

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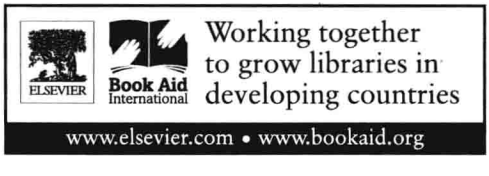

Applied Nanotechnology

The Conversion of Research Results to Products

Second Edition

No ládd, e nép, mely közt már senki nem hisz,
Ami csodás, hogyan kapkodja mégis.

IMRE MADÁCH

Preface to the Second Edition

During the four years that have elapsed since the first edition of this book was completed, many changes have taken place in the nano landscape. There have been no exceptionally outstanding scientific or technical developments during this interval—although that remarkable nanomaterial graphene was propelled into prominence by the 2010 Nobel Prize for physics—mostly it has been a time of continuous progress on a broad front. On the other hand there has been a dramatic change in the social and economic landscape. The financial crisis had just begun in September 2008 (if we take the collapse of Lehman Brothers in the USA as the marker) and the recession in the United Kingdom began in 2009. The new coalition government, which came to power in 2010, embarked on a rescue program of stringent austerity, which directly cut the availability of public funds for supporting emerging technologies and seems to have adversely affected the readiness of companies to invest in them.

A lackluster services sector, which until recently contributed about three quarters of Britain's gross domestic product, while manufacturing had shrunk to not much more than 10% (about the same as the contribution of the financial services sector, which has recently been rocked by a series of scandals), has led to a new appreciation of the value of having a solid manufacturing base, and it is now government policy to encourage it. In order to compete with the meteoric rise of China as a manufacturing country, it is recognized that to regenerate "old" economies,[1] manufacturing must, however, be placed on a new footing in order to be competitive with lower labor costs elsewhere. This view was shared by other countries. Nevertheless, they had their own crises. While some would assert that the eurozone crisis was inevitable from the start,[2] concrete evidence of grave instability emerged in Greece in late 2009 and during the course of 2010 spread to Ireland, Portugal, and Spain, with Cyprus becoming the latest eurozone country to sail precariously close to default in 2013.

In parallel with these economic crises, the global grand challenges (how to tackle climate change, pollution, energy and resource shortages, and demographic change) have remained in place. Most of them cry out for technology to come to the rescue, and nanotechnology appears to be the perfect answer: atomically precise manufacture should minimize energy and resource use and waste production and provide

[1]This is, of course, not a very accurate term if one looks back over the past few millennia. Until well into the Industrial Revolution the most important manufacturing countries in the world were India and China, a position that they had maintained for almost 2000 years. It was the policy of the British government to suppress indigenous Indian manufacturers in favor of British ones, a policy that was implemented very effectively: by the late 19th century Britain was the world's greatest manufacturing country. It was not long, though, before it was eclipsed by the United States of America, and for most of the 20th century (the exception being during the aftermath of World War II) the volume of German manufactures has exceeded that of Britain, but for the last 50 years Japan has held second place behind the USA (note that Japan entered a long deflationary period in the 1990s, from which it has yet to truly emerge).

[2]See B. Connolly, *The Rotten Heart of Europe*. London: Faber and Faber (1995).

new devices that can be directly used to collect energy from the sun. In essence, nanotechnology promises to do more with less. To give just one concrete example, the transparent conducting indium tin oxide windows presently used in a multitude of electronic devices and reliant on almost-exhausted supplies of indium (exacerbated by efforts to use less of the metal in each device, which has made its recycling more difficult) can be substituted by a percolating network of carbon nanotubes embedded in a polymer (in common with all carbon-based technologies, its deployment sequesters carbon from the atmosphere as a collateral benefit). Nanotechnology represents the cutting edge of the application of science, where Europe and its diaspora, along with Japan, still has a comparative advantage over the rest of the world. Yet, the nano enterprise is advancing falteringly. While some will simply point to the economic crisis rendering unaffordable the continuation of lavish government funding programs, this book will hopefully show that the opportunities have never been greater provided they are addressed in a sensible manner.

The basic structure of the first edition has been retained, but every chapter has been revised and a substantial amount of new material has been added, which has necessitated the appearance of some new chapters, resulting from the expansion of material that was previously fitted into sections within chapters. One of these new chapters deals with the regulation of nanotechnology, which is currently in a state of considerable flux and should be carefully monitored by all those with a stake in the business, coupled with a vigilant readiness to intervene in order to avoid unwanted and unworkable obligations slipping into the statute books.

Jeremy J. Ramsden
The University of Buckingham
April 2013

Preface to the First Edition

This is as much a book about ideas as about facts. It begins (Chapter 1) by explaining—yet again!—what nanotechnology is. For those who feel that this is needless repetition of a well-worn theme, may I at least enter a plea that as more and more people and organizations (latterly the International Standards Organization) engage themselves with the question, the definition is steadily becoming better refined and less ambiguous, and account needs to be taken of these developments.

The focus of this book is *nanotechnology in commerce*; hence, in the first part dealing with basics, Chapter 2 delves into the fascinating relationship between wealth, technology and science. Whereas for millennia we have been accustomed to technology emerging from wealth, and science emerging from technology, nanotechnology exemplifies a new paradigm in which science is in the van of wealth generation.

The emergence of nanotechnology products from underlying science and technology is an instantiation of the process called innovation. The process is important for any high technology; given that nanotechnology not only exemplifies but really epitomizes high technology, the relation between nanotechnology and innovation is of central importance. Its consideration (Chapter 3) fuses technology, economics and social aspects.

Chapter 4 addresses the question "Why might one wish to introduce nanotechnology?" Nanotechnology products may be discontinuous with respect to existing ones in the sense that they are really new, instantiating things that simply did not exist, or were only dreamt about, before the advent of nanotechnology. They may also be a result of *nanification*, decreasing the size of an existing device, or a component of the device, down to the nanoscale. Not every manufactured artifact can be advantageously nanified; this chapter tackles the crucial aspects of when it is technically, and when it is commercially advantageous.

These first four chapters cover Part I of this book. Part II looks at actual nanotechnology products—in effect, defining nanotechnology ostensively. It is divided into four chapters, the first one giving an overview of the entire market, followed by chapters dealing with, respectively, information technology and healthcare, which are the biggest sectors with strong nanotechnology associations; all other applications, including coatings of various kinds, composite materials, energy, agriculture, and so forth, are collected in another chapter.

Part III deals with more specifically commercial, especially financial aspects, and comprises three chapters. The first two are devoted to business models for nanotechnology enterprises. Particular emphasis is placed on the spin-off company, and the rôle of government in promoting nanotechnology is discussed in some detail. The third chapter deals with special problems of designing nano products.

The final part of the book takes a look toward the future, beginning with Productive Nanosystems; that is, what may happen when molecular manufacturing plays a significant rôle in industrial production. The implications of this future state

are so profoundly different from what we have been used to the past few centuries that it is worth discussing, even though its advent must be considered a possibility rather than a certainty. There is also a discussion about the likelihood of bottom–up nanofacture (self-assembly) becoming established as an industrial method. The penultimate chapter asks how nanotechnology can contribute to the grand challenges currently facing humanity. It is perhaps unfortunate that insofar as failure to solve these challenges looks as though it will jeopardize the very survival of humanity, they must be considered as threats rather than opportunities, with the corollary that if nanotechnology cannot contribute to solving these problems, then humanity cannot afford the luxury of diverting resources into it. The final chapter is devoted to ethical issues. Whether or not one accepts the existence of a special branch of ethics that may be called "nanoethics," undoubtedly nanotechnology raises a host of issues affecting the lives of every one of us, both individually and collectively, and which cannot be ignored by even the most dispassionate businessperson.

In summary, this book tries to take as complete an overview as possible, not only of the technology itself, but also of its commercial and social context. This view is commensurate with the all-pervasiveness of nanotechnology, and hopefully brings the reader some way toward answering the three questions: What can I know about nanotechnology? What should I do with nanotechnology (how should I deal with it)? What can I hope for from nanotechnology?

Nanotechnology has been and still is associated with a fair share of hyperbole, which sometimes attracts criticism, especially from sober open-minded scientists. But is this hyperbole any different from the exuberance with which Isambard Brunel presented his new Great Western Railway as the first link in a route from London to New York, or Sir Edward Watkin his new Great Central Railway as a route from Manchester to Paris? Moreover, apart from the technology, the nano viewpoint is also an advance in the way of looking at the world; it is a worthy successor to the previous advances of knowledge that have taken place over the past millennium. And especially now, when humanity is facing exceptional threats, an exceptional viewpoint coupled with an exceptional technology might offer the only practical hope for survival.

I should like to especially record my thanks to the members of my research group at Cranfield University, with whom our weekly discussions about these issues helped to hone my ideas, my colleagues at Cranfield for many stimulating exchanges about nanotechnology, and to Dr Graham Holt for his invaluable help in hunting out commercial data. It is also a pleasure to thank Enza Giaracuni for having prepared the drawings.

Jeremy J. Ramsden
Cranfield University
January 2009

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PART

Technology Basics

I

CHAPTER

What is Nanotechnology?

1

CHAPTER OUTLINE HEAD

In the heady days of any new, emerging technology, definitions tend to abound and are first documented in reports and journal publications, then slowly get into books and are finally taken up by dictionaries, which do not prescribe, however, but merely record usage. Ultimately the technology will attract the attention of the International Standards Organization (ISO), which may in due course issue a technical specification (TS) prescribing in an unambiguous manner the terminology of the field, which is clearly an essential prerequisite for the formulation of manufacturing standards, the next step in the process.

In this regard, nanotechnology is no different, except that nanotechnology seems to be arriving rather faster than the technologies with which we might be familiar from the past, such as steam engines, telephones, and digital computers. As a reflection of the rapidity of this arrival, the ISO has already (in 2005) set up a Technical Committee (TC 229) devoted to nanotechnologies. Thus, unprecedentedly in the history of the ISO, we shall have technical specifications in advance of the emergence of a significant industrial sector.

The work of TC 229 is not yet complete, however, hence we shall have to make our own attempt to find a consensus definition. As a start, let us look at the roots of the technology. They are widely attributed to Richard Feynman, who in a now famous lecture at Caltech in 1959 [1] advocated manufacturing things at the smallest possible scale, namely atom-by-atom—hence the prefix "nano," atoms typically being a few

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