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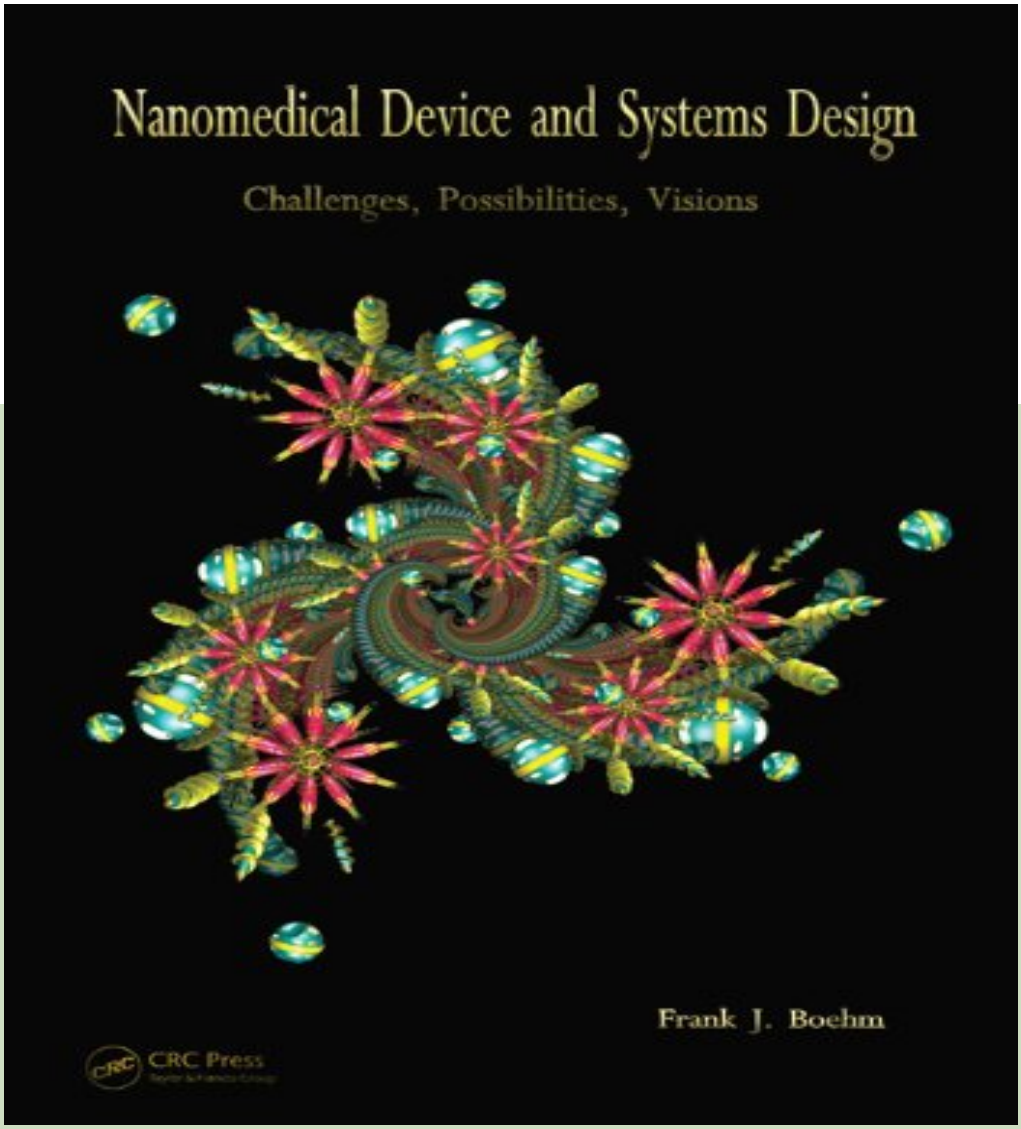

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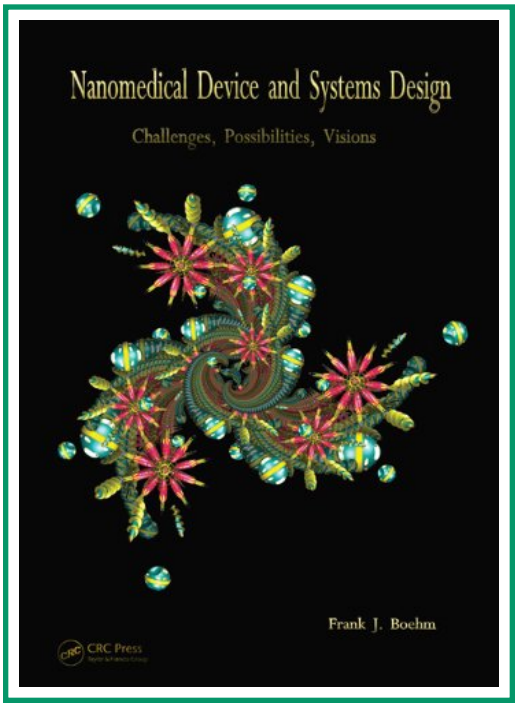

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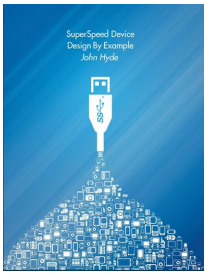

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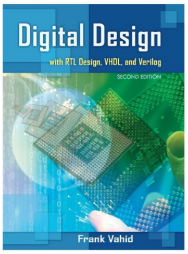

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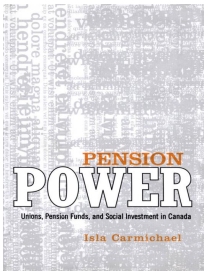

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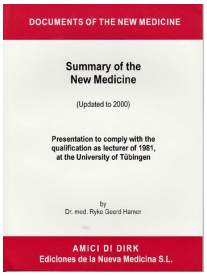

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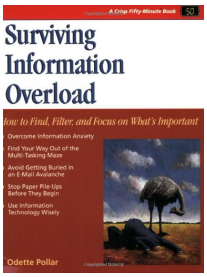

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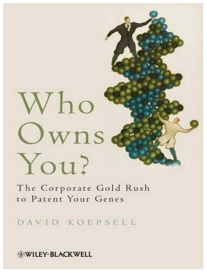

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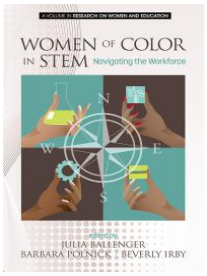

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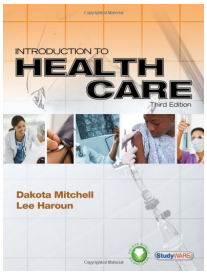

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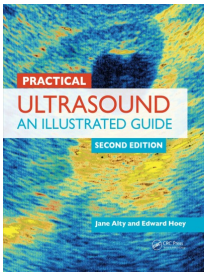

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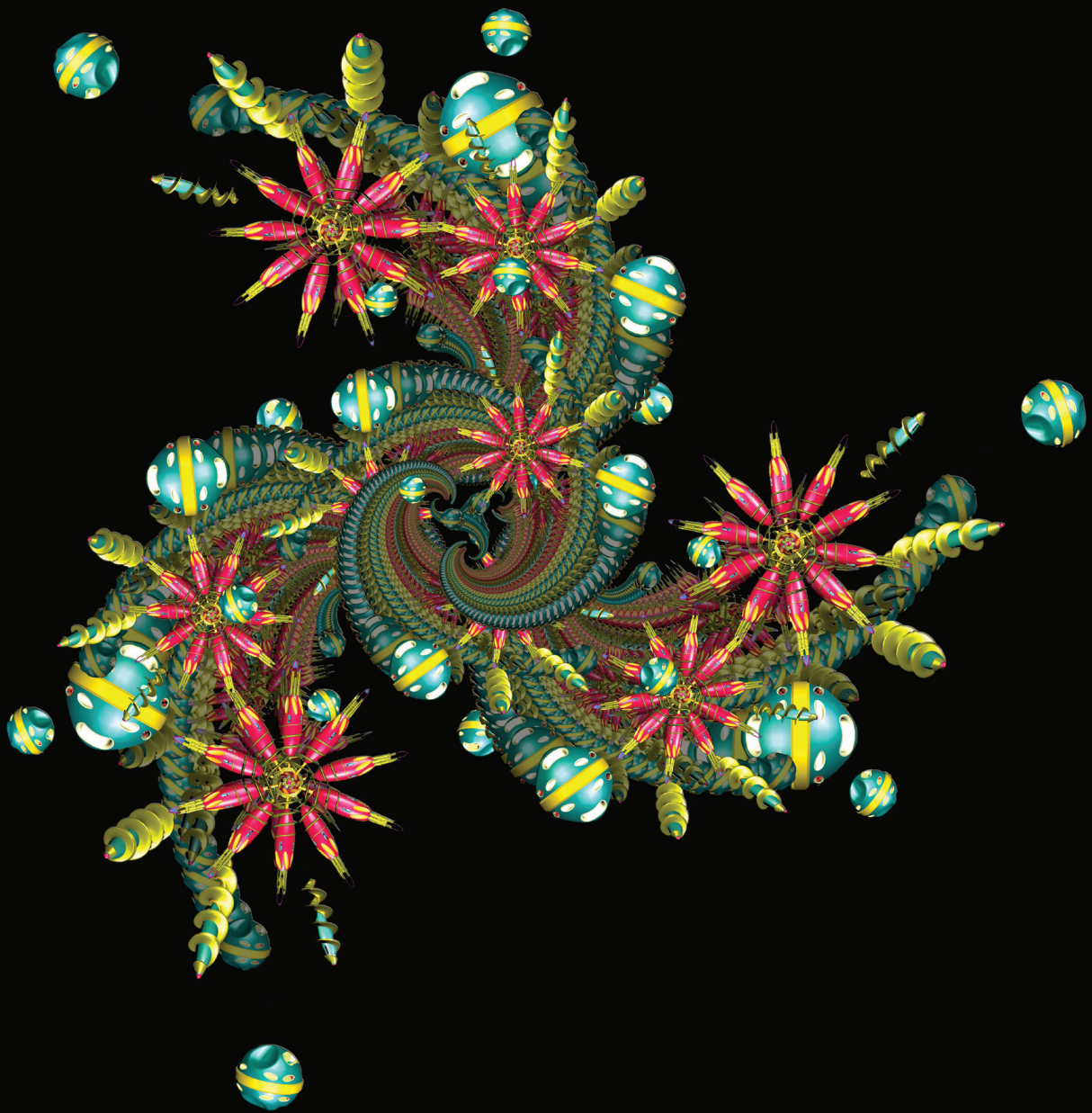
Nanomedical Device and Systems Design

Challenges, Possibilities, Visions



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I lovingly dedicate this book to the memory of my recently passed father, Josef Boehm, who ignited in me the flame of imagination by example of his unquenchable curiosity, quest for knowledge, and fascination with life and the universe; to my mother, Charlotte Boehm, whose amazing fortitude, generosity, and contagious enthusiasm for life continues to inspire all around her to never give up on their dreams and to always look up; and to my sweeties, Liz Balfour and Jazmyn Balfour-Boehm, whose unconditional love and support has allowed me to realize one of my dreams.

Contents

Preface

It would seem that the unfathomable wellsprings of cumulative human imagination, ingenuity, passion, and effort are not subject to any tether or constraint that cannot, over time, be unbound or circumvented. This tenet may certainly be applied to the continuously evolving field of medicine generally and particularly to the rapidly emerging discipline of nanomedicine. The incessant drive for more compact, robust, powerful, sophisticated, and effective diagnostic and therapeutic strategies within the purview of medicine has been and increasingly continues to be a critical and potent motivator for radical innovation. There is an underlying and omnipresent sense of urgency toward the investigation and development of tangible and efficacious solutions for the most vexing of humankind's medical challenges. These include heart disease, cancer, HIV/AIDS, diabetes, Alzheimer's, and a host of other serious maladies and pathogenic afflictions that relentlessly threaten to undermine the innate integrity and optimal functionality of the human body.

The rapidly emerging discipline of nanomedicine has unprecedented potential to dramatically transmute current medical paradigms, spanning diagnostics, therapeutics, and surgical procedures. Since nanomedical devices and systems will be designed and engineered to operate and impart beneficial influence at cellular, organellar, molecular, and (hypothetically) atomic domains, the realms within which diseases originate, it may be envisaged that sophisticated autonomous nanodevices and systems can be imbued with capacities for the accurate diagnoses and meticulous and thorough eradication of virtually any disease state and pathogenic or toxic threat. Further, due to facilitative nanotechnological self-assembly processes, and in light of the inevitable future advent of advanced molecular manufacturing, elegant and cost-effective nanomedical technologies might be readily accessible to those in the developing as well as developed worlds.

Concomitantly, the requirement for invasive surgeries might be relegated to obsolescence, as all corrective activities would be conducted in vivo by interactive multitudes of nanomedical cell repair devices. Myriad options for human cognitive and physiological augmentation, and the potential slowing, prevention, or possible (to a degree) reversal of the *disease* of aging may become reality. In conjunction with the option for radically increased life spans, those who are driven to venture out to the stars may undergo additional specialized nanomedical enhancements to enable efficient protective countermeasures against the degradative effects of microgravity and deep space radiation and to facilitate (barring the discovery of highly advanced spacecraft propulsion systems that approach the speed of light), if required, prolonged suspended animation.

This book is divided into three sections. Section I utilizes a conceptual exemplar nanodevice and system (Vascular Cartographic Scanning Nanodevice VCSN), which I have envisaged, to explore various prospective design considerations that might enable selected functionalities of advanced autonomous nanomedical devices. Section II is comprised of seven chapters, which have been submitted by a diverse group of expert contributing authors, describing actual laboratory-based research toward the advancement of nanomedical capabilities. Section III delves into more highly conceptual nanomedical

possibilities and visions relating to the implementation of nanomedical technologies in remote regions and the developing world, as well as nanomedicine in space applications, human augmentation, and longevity.

It is hoped that this book might assist in some small measure to serve as a preliminary guide to possibly inspire specific investigative pathways that may lead to meaningful discourse and significant advances in this nascent but potentially very powerful discipline.

Acknowledgments

I am indeed deeply appreciative to all the individuals and organizations who assisted in the evolution of this book. Initially, I would like to express my gratitude to K. Eric Drexler for forging the original vision of the boundless possibilities of nanotechnology, molecular manufacturing, and nanomedicine as laid out in his highly inspirational book *Engines of Creation*. Eric subsequently translated these possibilities into technical/practical terms with his book *Nanosystems: Molecular Machinery, Manufacturing, and Computation*. Second, I would like to extend my true appreciation to Robert A. Freitas Jr. for further enlightening me as to the virtually limitless potential of nanomedicine with his excellent and groundbreaking Nanomedicine book series. Robert has been very generous and patient in responding to my many queries over the years. Both of these visionaries have contributed greatly to the illumination of my mind toward the formulation of the nanomedical concepts that inhabit these pages. It is hoped that these prospective concepts may further inspire others to one day make such nanomedical diagnostic and therapeutic devices and systems a reality for the benefit of humankind.

I would like to express my deep appreciation to the following individuals for providing information, insights, and other forms of support and assistance in facilitating the realization of this project: Kellar Autumn, Elizabeth Balfour, Jazmyn Balfour-Boehm, Scott Cheadle, Aicheng Chen, Gautam Das, Angelika Domschke, Eric Drexler, Ted Duke, Barb Eccles, Robert Freitas Jr., Billy Garrioch, Aubrey de Grey, Rose Hayeshi, Bruce Johnson, Challa Kumar, Sylvain Martel, Gina Miller (nanogirl), Bruce Philips, Chris Phoenix, Judy Sander, Ottilia Saxl, Mark Schultz, Ned Seeman, Mohsen Shahinpoor, Vesselin Shanov, Hayat Sindi, Michael Slaughter, Zach Suntres, Yuriy Svidinenko, Hulda Swai, Jessica Vakili, Dennis Wood, and Kai Yan. I apologize to any individuals whom I may have unintentionally overlooked.

My sincere thanks and gratitude go out to my publisher, Taylor & Francis Group/CRC Press, for taking a chance, having the confidence and trust in me to see this project through, and allowing me the complete freedom to explore some of the exciting possibilities of the nascent discipline of nanomedicine. In particular, I wish to convey my appreciation to Michael Slaughter and Jessica Vakili for their incredible patience and support throughout the writing process. In addition, I very much appreciate the efforts of the staff at Taylor & Francis Group/CRC Press in the production of this book.

I would also like to express my heartfelt gratitude to my dear friend Angelika Domschke, an accomplished scientist and visionary artist, for her continual encouragement, understanding, and smiles that helped to keep me going to the completion of the project. I sincerely thank Angelika for both her excellent chapter and her amazing cover art, *Angstroms in Space*.

Last, I am forever grateful to my truly inspiring and wise father, Josef Boehm; my ever sweet and generous mother, Charlotte Boehm; my loving sister, Renata Swanson, and brother, John Boehm; Jackie Balfour, Elizabeth Balfour, and our incredible daughter Jazmyn Balfour-Boehm for their unconditional love, encouragement, and unwavering support without which this book could not have been written.

Editor

Frank J. Boehm has been involved with nanotechnology and especially nanomedicine since 1996, which has inspired the development of numerous concepts and designs for advanced nanomedical diagnostic and therapeutic components, devices and systems to potentially address myriad disease states. His aim is to develop and transform these concepts into real-world applications for global benefit.

Frank serendipitously encountered the concept of nanotechnology on the Internet and immediately become fascinated with its virtually limitless potential, particularly as relates to the field of medicine. He passionately proceeded to evolve and textually articulate various advanced near-term and longer-term nanomedical concepts and designs. Concomitantly, he initiated correspondence with numerous nanotechnology and nanomedicine research scientists and thought leaders from across the globe.

In recognizing the immense potential of nanomedicine to impart positive paradigm shifts across the medical domain (e.g., precisely targeted drug delivery, vascular/neurological/cellular plaque removal, totally non-invasive surgical procedures, enhancement of physiological systems, and extended longevity), Frank was deeply motivated to write more extensively on the topic. The result has culminated in the generation of this text. In parallel, he managed to engage the interest of several researchers in the United States and Canada in his nanomedical concepts, and in 2009 he formed the startup company NanoApps Medical, Inc. The aim of this company is to investigate and develop advanced, innovative, and cost-effective nanomedical diagnostic and therapeutic devices and systems for the benefit of individuals in both the developing and developed worlds.

Contributors

Asieh Ahmadalinezhad
Department of Chemistry
Lakehead University
Thunder Bay, Ontario, Canada

Misagh Alipour
Medical Sciences Division
Northern Ontario School of Medicine
Lakehead University
Thunder Bay, Ontario, Canada

and

Programme of Biomolecular Sciences
Laurentian University
Sudbury, Ontario, Canada

Frank J. Boehm
NanoApps Medical Inc.
and
NanoApps Consulting
and
Lakehead University
Thunder Bay, Ontario, Canada

Aicheng Chen
Department of Chemistry
Lakehead University
Thunder Bay, Ontario, Canada

Wondong Cho
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Gautam Das
Photonics Research Group
Department of Physics
Lakehead University
Thunder Bay, Ontario, Canada

Angelika Domschke
Angelika Domschke Consulting, LLC
Duluth, Georgia

Zhongyun Dong
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Rose Hayeshi
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Jianjun Hu
Department of Chemical and Materials Engineering
University of Dayton
and
Air Force Research Laboratory
Wright-Patterson Air Force Base
Dayton, Ohio

Lonji Kalombo
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Lebogang Katata
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Yolandy Lemmer
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Weifeng Li
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Sylvain Martel
NanoRobotics Laboratory
Department of Computer and Software Engineering
Institute of Biomedical Engineering
Polytechnic School of Montreal
University of Montréal
Montréal, Québec, Canada

David Mast
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Chris Muratore
Department of Chemical and Materials Engineering
University of Dayton
and
Air Force Research Laboratory
Wright-Patterson Air Force Base
Dayton, Ohio

Abdelwahab Omri
Programme of Biomolecular Sciences
Laurentian University
Sudbury, Ontario, Canada

Sarah Pixley
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Brad Ruff
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Pravahan Salunke
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Mark J. Schulz
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Boitumelo Semete
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Vesselin Shanov
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Hayat Sindi
Founder and CEO of i2 Institute of Imagination and Ingenuity

and

UNESCO Goodwill Ambassador for Sciences

and

Member of Shura Council of Saudi Arabia

and

Visiting Scholar
Department of Chemistry and Chemical Biology
Harvard University
Cambridge, Massachusetts

Yi Song
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Anshuman Sowani
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Bolaji Suberu
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Zacharias E. Suntres
Medical Sciences Division
Northern Ontario School of Medicine
Lakehead University
Thunder Bay, Ontario, Canada

and

Programme of Biomolecular Sciences
Laurentian University
Sudbury, Ontario, Canada

Hulda Swai
Polymers and Composites
Council for Scientific and Industrial Research
Pretoria, South Africa

Rajiv Venkatasubramanian
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

John Yin
Nanoworld Smart Materials and Devices Laboratory
University of Cincinnati
Cincinnati, Ohio

Section I

Envisaged Nanomedical Device and System Design Strategies

1

Exemplar Nanomedical Vascular Cartographic Scanning Nanodevice

Frank J. Boehm

CONTENTS

1.1 Introduction

Envisioners and designers of nanomedical devices may draw their inspiration from a number of sources. These might include the myriad mechanisms and processes that operate both at macroscale and nanoscale domains in the natural world, which may be interpreted and transformed into functional synthetic analogs via biomimetics. Other inspirational sparks may emanate from purely anthropogenic dreamscapes, which reside within the realms of fantasy and science fiction. There is always the chance that completely unexpected serendipitous discovery might arrive from "nowhere" to the utter joy of long toiling recipients who might have been looking for answers for many years in one area, only to have a pivotal insight surprisingly light up, when triggered by a completely unrelated event, as if a gift from some parallel universe that has "crossed over." Incremental inspirational glimmers, and much more rarely, dramatic brilliant bursts thereof may indeed be gleaned through voluminous thoughtful, disciplined, and deliberate experimentation. From whatever quarter such inspiration may appear, it may be suggested that a certain "cognitive stance" might serve as a useful prerequisite to facilitate and breed the flames of inspiration, creativity, and innovation, which may likely percolate into reality. This attitude might encompass in varying degrees, a blend of excitement and prospective adventure,

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