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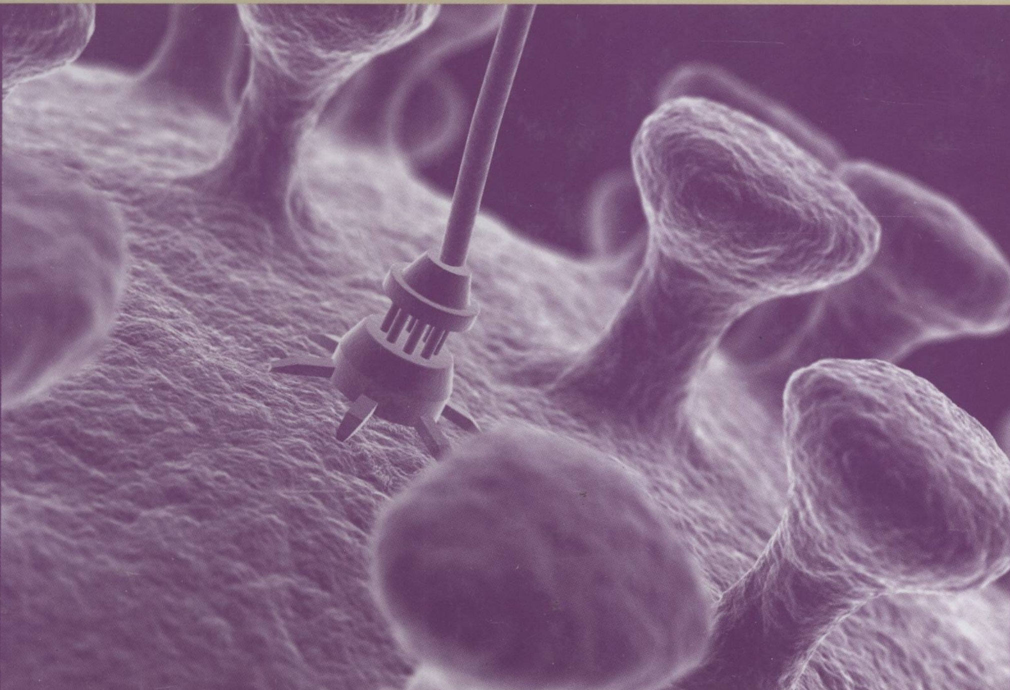

MICRO AND NANO MANIPULATIONS FOR BIOMEDICAL APPLICATIONS

Micro and Nano Manipulations for Biomedical Applications

Tachung C. Yih
Ilie Talpasanu

Editors

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Micro and Nano Manipulations for Biomedical Applications

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To our familes

To my wife Debbie and my daughter Jessica
—Tachung C. Yih

To my wife Lucretia-Dalia and my son Alexandru
—Ilie Talpasanu

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Preface

In the next decade, nanotechnology is expected to have a large impact on diseases such as cancer, neurodegeneration, and diabetes and those of the blood, lungs, cardiovascular system, and skeleton. The design of novel nanoparticles, capable of sensing and drug delivery, will increase. Chapter 2 presents an overview of technologies for cancer diagnosis and therapy. The fabrication and properties of metallic nanoparticles, as well as quantum dots, nanocrystals based on semiconductors, also are presented in this chapter.

Chapter 3 outlines the fundamentals of MEMS/NEMS actuator design and fabrication. A description of thermal, magnetic, electrostatic, piezoelectric microactuators is detailed in Chapter 4, which also focuses on the micromanipulators for minimally invasive procedures. Chapter 5 discusses end effector tools and electron microscopy for biomedical nanomanipulations.

Cell viability and behavior following nanoparticle injection are observed through imaging techniques. Chapter 6 presents current applications and trends in imaging manipulations such as 3-D imaging and optical dissection by nonlinear optical microscopy, laser-induced microdissection, nanosurgery characterization, optical trapping, and optical tweezers.

Chapter 7 discusses dielectrophoretic methods for cell and biomolecule manipulations. The design, modeling, and control of a piezo-actuated robotic system with microaccuracy and nanoaccuracy, as required in cell manipulations, are presented in Chapter 8. The main physical methods of gene manipulations and delivery such as electroporation, hydroporation, sonoporation, microneedle and microinjection, optoinjection and optoporation, magnetofection, and the gene gun method are described in Chapter 9. The performances and limitations of the gene delivery methods are also analyzed in this chapter.

The book covers basic principles and applications of micromanipulation and nanomanipulation for biomedicine and will provide the reader with the facts he or she needs to know about the manipulation, control, modeling, and simulation at the microscale and nanoscale levels. Microprecision and nanoprecision robotic systems are used by manufacturers or researchers involved in biorobotics projects, and by practitioners involved in applications from the emerging area of micro and nano bio devices. Presenting the most recent applications of biomanipulation of cells and genes, the book is suitable also for undergraduate and graduate students in biomedical applications.

We wish to thank Dr. Frank Caserta from the Wentworth Institute of Technology for his suggestions during the preparation of the manuscript. We would like to thank the reviewers, Dr. Jane Wang from the Northwestern University and Dr. Pak Kin Wong from the Systematic Bioengineering Lab at the University of Arizona, for their critical reviews. We also would like to thank Wayne Yuhasz, Barbara Lovenvirth, Judi Stone, and Rebecca Allendorf from Artech House for their efforts during the preparation of this book.

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CHAPTER 1

Introduction

Tachung C. Yih and Ilie Talpasanu

1.1 The Third Industrial Revolution?

In 2000, then-President William J. Clinton launched the National Nanotechnology Initiative (NNI) as a top science and technology priority [1]. The President's Council of Advisors on Science and Technology (PCAST) described NNI as an excellent multiagency framework to ensure U.S. leadership in this emerging field that will be essential for economic and national security leadership in the first half of the next century [2]. The speech by President Clinton given at the California Institute of Technology on January 21, 2000, was titled "National Nanotechnology Initiative: Leading to the Next Industrial Revolution." Is nanotechnology leading us into our third Industrial Revolution? To answer this question, we must understand what happened in previous industrial revolutions [3–12].

Humans walked through the Stone Age, Bronze Age, and Iron Age, periods covering thousands of years, with a dawdling speed of technology advancement. The common cause of the Industrial Revolution is the advancement of new technology, triggered by scientific innovations. The Industrial Revolution transformed countries from agricultural to industrial, communities from rural to urban, and people from farmers to factory workers. The significant impacts resulting from the Industrial Revolution cover a broad range such as productivity growth, culture, and the daily lives of the populace. The long-term effects brought about by the industrial revolutions remain debatable. However, many believe that, on the whole, the benefits that came with the Industrial Revolution outweigh the problems.

1.1.1 The First Industrial Revolution—Manufacturing and Transportation

The first Industrial Revolution occurred in Great Britain between 1750 and 1850, followed by those of the United States and other countries in Europe during the nineteenth century as well as those of Russia and Japan in the first half of the twentieth century.

The earliest factories appeared in 1740, producing textile merchandise. Eli Whitney, an American, changed the textile industry from using wool to using cotton as its raw material with his invention of the cotton gin (1792). Other important English inventions included the flying shuttle (John Kay, 1733), the hand-powered cotton-spinning jenny (James Hargreaves, 1765) [13], the water frame spinning device (Richard Arkwright, 1766), and the improvements in weaving powered by a steam engine (Samuel Crompton, 1790). Samuel Slater, known as the father of the American Industrial Revolution, emigrated from England to America in 1789 and built the first successful water-powered textile mill in Pawtucket, Rhode Island, in 1793 [14, 15]. The first sewing machine was designed by Elias Howe in 1843. Sewing machines were the first major consumer appliance. In 1851, Isaac Singer invented the first practical, domestic sewing machine and widely marketed his machines.

The early steam engines were developed in England by Thomas Savery (1698) and Thomas Newcomen (1705) to pump water out of coal mines, but they could not generate power. Henry Cort (1780) developed the steam-powered rolling mills that revitalized the iron industry. James Watt (1782) developed power-generating steam engines to drive rotary shafts in other machinery. Watt's engines were widely used during the period of the Industrial Revolution. Richard Trevithick (1805) built several full-size, high-pressure steam carriages, known as locomotives, which were used to haul coal and ore out of the mines. George Stephenson opened the first public railway in the world in 1825, which was worked by a Stephenson *Rocket* locomotive. During the nineteenth century, steam locomotives were exported from England to many other countries. The steam-powered locomotive and iron railway system revolutionized the means of transportation in human history; people and goods could be transported in mass quantities at lower cost, which enabled the market economy.

In the United States [16, 17], Oliver Evans pioneered and invented the high-pressure steam engine. He built the first automatic mill in Delaware in 1782, and in 1789, the first U.S. patent for a steam-powered land vehicle was granted to him. John Fitch designed and tested a steam-powered boat on the Delaware River in 1786. The first practical steamboat was built by William Symington in Scotland in 1801. Robert Fulton constructed the *Clermont* to carry fare-paying passengers on the Hudson River in 1807.

To construct the steam engines and machines, the growing need for machine tools was inevitable. The oldest known machine tool was the wood-working lathe. Jasse Ramsden, an English instrument maker, developed the first screw-cutting lathes in 1770. Henry Maudslay, in 1800, produced the first large, high-accuracy (1/10,000 of an inch) screw-cutting lathe. Maudslay's assistants introduced the first gear-cutting machine (Richard Roberts, 1818), a punching machine for making rivet holes (Richard Roberts, 1847), a measuring machine with an accuracy of one-millionth of an inch (Joseph Whitworth, 1856; he also standardized the screw threads in English), and the milling machine and shaper (James Nasmyth, 1854). One of the most important inventions, which made Watt's steam engine a practical power source, was John Wilkinson's cylinder boring machine (1775).

The post–Industrial Revolution (1850–1950) mainly carried on in the United States. One of the most important landmarks in the history of engine design was the invention of the internal combustion engine (Nikolaus A. Otto, 1876) [18]. He constructed the first practical gas-motor, four-stroke piston cycle internal combustion engine, named the Otto Cycle Engine. Otto's invention was the first practical alternative to the steam engine and the foundation of the modern engine. By applying Otto's engine, Gottlieb Daimler built a motorcycle (1885) and the first four-wheeled automobile (1886) in the world. Karl Benz also constructed his first three-wheel