

**BIOLOGICAL AND MEDICAL PHYSICS,  
BIOMEDICAL ENGINEERING**

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# BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING

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David D. Zhou  
Elias Greenbaum

Editors

# Implantable Neural Prostheses 1

Devices and Applications

 Springer

*Editors*

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# Preface

Significant progress has been made in the development of neural prostheses to restore human functions and improve the quality of human life. Biomedical engineers and neuroscientists around the world are working to improve design and performance of existing devices and to develop novel devices for artificial vision, artificial limbs, and brain–machine interfaces.

This book, *Implantable Neural Prostheses 1: Devices and Applications*, is part one of a two-book series and describes state-of-the-art advances in techniques associated with implantable neural prosthetic devices and their applications. Devices covered include sensory prosthetic devices, such as visual implants, cochlear implants, auditory midbrain implants, and spinal cord stimulators. Motor prosthetic devices, such as deep brain stimulators, Bion microstimulators, the brain control and sensing interface, and cardiac electro-stimulation devices are also included. Progress in magnetic stimulation that may offer a non-invasive approach to prosthetic devices is introduced. Regulatory approval of implantable medical devices in the United States and Europe is also discussed.

Advances in biomedical engineering, micro-fabrication technology, and neuroscience have led to many improved medical device designs and novel functions. However, many challenges remain. This book focuses on the device designs and technical challenges of medical implants from an engineering perspective. We are grateful to leading researchers from academic institutes as well as design engineers and professionals from the medical device industry who have contributed to the book. Part two of this series will cover techniques, engineering approaches, and R&D advances in developing implantable neural prosthetic devices. We hope a better understanding of design issues and challenges may encourage innovation and interdisciplinary efforts to push forward the frontiers of R&D of implantable neural prostheses.

Los Angeles, California  
Oak Ridge, Tennessee

David D. Zhou  
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# List of Acronyms

|       |   |
|-------|---|
| A1    | Primary auditory cortex                 |
| ABI   | Auditory brainstem implant              |
| ACI   | Auditory cortex implant                 |
| AF    | Activating function                     |
| AF    | Atrial fibrillation                     |
| AIROF | Activated iridium oxide film            |
| AMD   | Age-related macular degeneration        |
| AMI   | Auditory midbrain implant               |
| ANI   | Auditory nerve implant                  |
| ASIC  | Application specific integrated circuit |
| AV    | Atrioventricular                        |
| BBS   | Bicarbonate buffered saline             |
| BCI   | Brain-machine interface                 |
| BJT   | Bipolar junction transistor             |
| BON   | Bed of nails                            |
| CCD   | Charge coupled device                   |
| CFR   | Code of federal regulations             |
| CHF   | Congestive heart failure                |
| CI    | Cochlear implant                        |
| CIS   | Continuous-interleaved-sampling         |
| CL    | Current level                           |
| CMOS  | Complementary metal-oxide semiconductor |
| CRT   | Cardiac resynchronization therapy       |
| CS    | Coronary sinus                          |
| CSF   | Cerebrospinal fluid                     |
| CSP   | Chip-size packages                      |
| cTMS  | Controllable pulse-width TMS            |
| CV    | Cyclic voltammetry                      |
| DAC   | Digital analog converter                |
| DBS   | Deep brain stimulation                  |
| DRIE  | Deep reactive ion etching               |
| DRth  | Excitable dorsal root                   |
| DSP   | Digital signal processor                |

|         |   |
|---------|---|
| EEP     | Electrically evoked potential                                   |
| EIROF   | Electroplated iridium oxide film                                |
| EIS     | Electrochemical impedance spectroscopy                          |
| EMI     | Electromagnetic interference                                    |
| ERG     | Electroretinograms  |
| ESC     | Environmental stress cracking                                   |
| EtO     | Ethylene oxide  |
| FBC     | Field balancing and cycling                                     |
| FDA     | Food and Drug Administration                                    |
| FEM     | Finite element method   |
| FES     | Functional electrical stimulation                               |
| FMEA    | Failure modes & effects analysis                                |
| FMS     | Functional magnetic stimulation                                 |
| FOA     | Focus of attention  |
| FRCB    | Frequency-related conduction block                              |
| FS      | Field steering  |
| GABA    | Gamma-aminobutyric acid   |
| GCL     | Ganglion cell layer   |
| GERD    | Gastroesophageal reflux disease                                 |
| Gpi     | Globus pallidus internus  |
| HDE     | Humanitarian device exemption                                   |
| HMD     | Head-mounted display  |
| HUD     | Humanitarian use device   |
| IC      | Inferior colliculus   |
| ICC     | Its central nucleus   |
| ICD     | Implantable cardioverter defibrillators                         |
| ICP     | Inductively-coupled plasma                                      |
| IDE     | Investigational device exemption                                |
| IGBT    | Insulated gate bipolar transistor                               |
| ILM     | Internal limiting membrane                                      |
| INL     | Inner nuclear layer   |
| IPG     | Implantable pulse generator                                     |
| IPL     | Inner plexiform layer   |
| IR      | Infrared  |
| IRB     | Institutional review board                                      |
| IR drop | Voltage drop across a resistance - current (I) x resistance (R) |
| IrOx    | Iridium oxide   |
| LCR     | Inductance capacitance resistance                               |
| LES     | Lower esophageal sphincter                                      |
| LGN     | Lateral geniculate nucleus                                      |
| LiI     | Lithium iodide  |
| LPCVD   | Low-pressure chemical vapor deposition                          |
| MEA     | Microelectrode arrays   |
| MEMS    | Micro-electro-mechanical system                                 |

|                                |   |
|--------------------------------|---|
| MIDAS                          | Migraine disability assessment                  |
| MIO                            | Metal ion oxidation                             |
| MPTP                           | 1-methyl-4-phenyl-1, 2, 3, 6-tetrahydropyridine |
| NF2                            | Neurofibromatosis type 2                        |
| NFL                            | Nerve fiber layer                               |
| NRT                            | Neural response telemetry                       |
| OCT                            | Optical coherence tomography                    |
| OLM                            | Outer limiting membrane                         |
| ONL                            | Outer nuclear layer                             |
| OPL                            | Outer plexiform layer                           |
| PCU                            | Prosthetic control unit                         |
| PBS                            | Phosphate-buffered saline                       |
| PD                             | Parkinson's disease                             |
| PDCA                           | Plan-do-check-act                               |
| PDMS                           | Polydimethylsiloxane                            |
| PECVD                          | Plasma-enhanced chemical vapor deposition       |
| PGC                            | Programmable gain control                       |
| PMA                            | Premarket approval                              |
| PSA                            | Pacing system analyzer                          |
| PSD                            | Power spectral density                          |
| PU                             | Pressure ulcer                                  |
| PW                             | Pulse width                                     |
| RF                             | Radio frequency                                 |
| RMS                            | Root mean square                                |
| RP                             | Retinitis pigmentosa                            |
| RPE                            | Retinal pigment epithelium                      |
| rTMS                           | Repetitive TMS                                  |
| SBON                           | Slanted bed of nails electrode                  |
| SC                             | Superior colliculus                             |
| SCR                            | Silicon controller rectifier                    |
| SCS                            | Spinal cord stimulation                         |
| SD                             | Standard deviation                              |
| SDRAM                          | Synchronous dynamic random access memory        |
| Si <sub>3</sub> N <sub>4</sub> | Silicon nitride                                 |
| SiC                            | Silicon carbide                                 |
| SiO <sub>2</sub>               | Silicon dioxide                                 |
| SNR                            | Signal-to-noise ratio                           |
| SIROF                          | Sputtered iridium oxide film                    |
| SOI                            | Silicon-on-insulator                            |
| STN                            | Subthalamic nucleus                             |
| SVO                            | Silver vanadium oxide                           |
| Ta <sub>2</sub> O <sub>5</sub> | Tantalum pentoxide                              |
| T cell                         | Transmission cell                               |
| TDMA                           | Time domain multiplexed access                  |

|      |                                     |
|------|-------------------------------------|
| TiN  | Titanium nitride                    |
| TMS  | Transcranial magnetic stimulation   |
| TTS  | Transverse tripolar system          |
| V1   | Visual cortex                       |
| VEP  | Visual evoked potentials            |
| UF   | Urgency frequency syndrome          |
| UNCD | Ultrananocrystalline diamond        |
| UUI  | Urinary urge incontinence           |
| VF   | Ventricular fibrillation            |
| VLSI | Very large-scale integrated circuit |