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Stimulation and Recording Electrodes for Neural Prostheses

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Preface

Neural diseases have always been a challenge to the humankind. Paralysis, blindness, and Parkinson's disease (PD) are examples. A biological treatment to many of these neurological dysfunctions is either not available or does not yet provide satisfactory results. Biomedical engineering provides an alternative to the biological cure. Together with neuroscience, engineering builds up a new concept in the field of practice, called neuroprosthetics. Neuroprosthetics pertains to the creation of neural prosthetics in order to eliminate sensory, motor, or cognitive malfunctions.

Treating these kinds of dysfunctions requires interfacing with patient's neural system. Depending on the application, electrical neural signals must be read or injected by the implant. This is accomplished through electrodes which connect the internal circuits of the device to tissue. The direction of the electrical signal defines the type of the electrode, which is thus classified as recording or stimulating. The electrical characteristics and the lifetime limitation of this component are very important in designing a neural prosthesis.

In this book we will address this major cornerstone of neuroprosthetics. Being part of a leading research group in the field of subretinal neurostimulators in Europe, we have gathered lots of knowledge through research and experiment, from which we will try to share the most interesting and relevant parts here. The attempt in this book is also to provide a general perspective to the matter, and not specifically from the point of view of visual stimulators.

The physiological aspects of neural stimulation and recording such as the necessary characteristics of the signals for successful stimulation or the features of the neural signals to be read by the prosthetic system are not the main topic of this essay, although sometimes mentioned as support for the discussions, and should be studied elsewhere.

This book is intended to avoid complicated theoretical discussions in the field of chemistry as far as possible. The writers are all from the engineering field and therefore the focus is put here on the practical aspect. The electrochemistry behind the subject is covered briefly. The concept and necessity of charge balance

is investigated. The effect of electrode geometry on electrode lifetime is studied. Novel methods and hardware for electrode experimentation are developed and are introduced. Beside others, two kinds of electrode materials, titanium nitride and iridium, have been extensively investigated both qualitatively and quantitatively. The influence of the counter electrode on the safety margins and electrode lifetime in a two electrode system is explained. Electrode modeling is handled in the final chapter.

We would like to thank the people who helped us with the here accomplished research. We are thankful for the support provided by the following people: Steffen Kibbel, Mohammad Imam Hasan bin Asad, Anton Rommel, Jared Robertson, Sebastian Schleehauf, and Sandra Klinger. We are very thankful to Dr. Walter Wrobel for continuous interest and support.

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Contents

Acronyms

AIROF	Activated iridium oxide film
AWG	Arbitrary waveform generator
CPE	Constant phase element
CSC	Charge storage capacity
CV	Cyclic voltammetry
EIROF	Electrodeposited iridium oxide film
ESA	Electrochemical surface area
GSA	Geometric surface area
NHE	Normal hydrogen electrode
OCP	Open circuit potential
PBS	Phosphate buffered saline
PD	Parkinson's disease
SCE	Saturated calomel electrode
SHE	Standard hydrogen electrode
SIROF	Sputtered iridium oxide film
TiN	Titanium nitride
TIROF	Thermally prepared iridium oxide film

Authors

Naser Pour Aryan received his B.E. degree in electrical engineering from Ferdowsi University of Mashhad, Iran, in 2005 and M.Sc. degree in communication technology from the University of Ulm, Germany, in 2008. He received his Ph.D. degree from the University of Ulm in December 2013. He has been working as a researcher on the retinal prosthesis project at the University of Ulm since January 2008, studying and characterizing neural stimulation electrodes. He has had several publications on this topic.

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Albrecht Rothermel (M'90, SM'95) received his Dipl.-Ing. degree in electrical engineering from the University of Dortmund and Dr.-Ing. (Ph.D.) degree from the University of Duisburg, both Germany, in 1984 and 1989, respectively.

From 1985 to 1989, he was with the Fraunhofer Institute of Microelectronic Circuits and Systems, Duisburg, Germany, working on integrated digital CMOS and BiCMOS circuits for high-speed applications. From 1990 to 1993, he was with Thomson Consumer Electronics (Thomson multimedia), Corporate Research, Villingen-Schwenningen, Germany. He worked on digital signal processing concepts for present and future TV and HDTV sets. Then as Manager of the IC design laboratory, he was involved in analog and mixed circuit design for audio and video.

Since 1994, he has been with the Institute of Microelectronics, University of Ulm, Germany, as a Professor of Electrical Engineering. His research interests include analog and mixed signal circuits for various applications including implantable sensors and stimulators, and digital signal processing algorithms for video applications, mostly in automotive environments.

Dr. Rothermel was a guest scientist at Thomson Multimedia in Indianapolis, USA (1997), at the Edith-Cowan University in Perth, WA (2003), and at the Shandong University in Jinan, China (2006). He has published more than 130 papers, book chapters, and patents. He received the 1985 outstanding young scientist award of the German VDE, the 1991 outstanding publication award of the German GME, the 2003 award for remarkable cooperation between industry and university, and the 2006 best paper award of the IEEE ICCE. After acting as associate editor of the IEEE JSSC, TPC-Chair of the IEEE ICCE-B, and distinguished lecturer of the IEEE, he now is a member of the program committees of ESSCIRC and ICCE.

He is member of the German Society of Electrical Engineers (VDE), the German TV and Cinema Technology Society (FKTG), and senior member of the IEEE.