

METHODS IN MOLECULAR BIOLOGY

Series Editor
John M. Walker
School of Life and Medical Sciences
University of Hertfordshire
Hatfield, Hertfordshire, AL10 9AB, UK

For further volumes:
<http://www.springer.com/series/7651>


Optogenetics

Methods and Protocols

Edited by

Arash Kianianmomeni

*Department of Cellular and Developmental Biology of Plants,
University of Bielefeld, Bielefeld, Germany*

 Humana Press

Editor

Arash Kianianmomeni
Department of Cellular
and Developmental Biology of Plants
University of Bielefeld
Bielefeld, Germany

ISSN 1064-3745 ISSN 1940-6029 (electronic)
Methods in Molecular Biology
ISBN 978-1-4939-3510-9 ISBN 978-1-4939-3512-3 (eBook)
DOI 10.1007/978-1-4939-3512-3

Library of Congress Control Number: 2016931444

Springer New York Heidelberg Dordrecht London
© Springer Science+Business Media New York 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Humana Press is a brand of Springer
Springer Science+Business Media LLC New York is part of Springer Science+Business Media (www.springer.com)

Preface

During the past decade, specific light-sensitive modules have paved the way for the development of “Optogenetics,” a technology using light switches for precise and spatial control of signaling pathways in individual cells and even in complex biological systems. Although the idea behind controlling cellular, physiological, and behavioral processes using external light was an old scientific desire, crucial factor for rapid development of optogenetics was the discovery of a handful of algal sensory photoreceptors, i.e., light-gated ion channels (channel-rhodopsins), which can be easily used to control neural spiking with light. Concurrently, other light-sensitive modules were engineered to generate new photoswitches to control protein activity, protein localization, and gene expression. Fast progress in genome and transcriptome sequencing towards identification of new photoswitchable proteins as well as engineering of new variants with modified absorption and activity properties enriched the optogenetic toolkit and allowed fine-tuned regulation of multiple signaling pathways. In the light of current advances and growing diversity, future application of optogenetic tools for modulation of distinct cellular signaling pathways, even in complex biological systems, without need for chemical additives, seems to be more favorable in comparison to chemical systems.

In this book leading experts on optogenetics, synthetic biology, and neurobiology provide their state-of-the-art protocols and take a close look at current research and its promising applications. This volume provides a collection of the most recently developed technical protocols on optogenetic applications in neuroscience, brain mapping, treatment of neurological disorders, and restoration of visual function. Moreover, several introductory and discussion chapters give a deep, wide overview about sources and diversity of optogenetic tools, design strategies, and potential application in other fields like plant research. I assembled the volume to stimulate an interdisciplinary view of optogenetic applications and its great potential to develop as a fantastic molecular tool for basic research as well as biomedical and biotechnological applications.

Bielefeld, Germany

Arash Kianianmomeni

Contents

<i>Preface</i>	<i>v</i>
<i>Contributors</i>	<i>ix</i>
1 Optogenetics: Basic Concepts and Their Development <i>Yong Ku Cho and Dan Li</i>	1
2 Natural Resources for Optogenetic Tools <i>Tilo Mathes</i>	19
3 Algal Photobiology: A Rich Source of Unusual Light Sensitive Proteins for Synthetic Biology and Optogenetics <i>Arash Kianianmomeni and Armin Hallmann</i>	37
4 Reversible Photoregulation of Gene Expression and Translation <i>Shinzi Ogasawara</i>	55
5 Controlling Protein Activity and Degradation Using Blue Light <i>Anne P. Lutz, Christian Renicke, and Christof Taxis</i>	67
6 Photo Control of Protein Function Using Photoactive Yellow Protein <i>Jakeb M. Reis and G. Andrew Woolley</i>	79
7 A Fluorometric Activity Assay for Light-Regulated Cyclic-Nucleotide- Monophosphate Actuators <i>Charlotte Helene Schumacher, Heinz G. Körschen, Christopher Nicol, Carlos Gasser, Reinhard Seifert, Martin Schwärzel, and Andreas Möglich</i>	93
8 Optogenetic Control of Pancreatic Islets <i>Thomas M. Reinbothe and Inês G. Mollet</i>	107
9 Optogenetics in Plants: Red/Far-Red Light Control of Gene Expression <i>Rocio Ochoa-Fernandez, Sophia L. Samodelov, Simon M. Brandl, Elke Wehinger, Konrad Müller, Wilfried Weber, and Matias D. Zurbriggen</i>	125
10 Enhancing Channelrhodopsins: An Overview <i>Jonas Wietek and Matthias Prigge</i>	141
11 Optogenetics in <i>Drosophila</i> Neuroscience <i>Thomas Riemensperger, Robert J. Kittel, and André Fiala</i>	167
12 Optogenetic Control of Mammalian Ion Channels with Chemical Photoswitches <i>Damien Lemoine, Romain Durand-de Cuttoli, and Alexandre Mourot</i>	177
13 Optogenetic Modulation of Locomotor Activity on Free-Behaving Rats <i>Kedi Xu, Jiacheng Zhang, Songchao Guo, and Xiaoxiang Zheng</i>	195
14 Combined Optogenetic and Chemogenetic Control of Neurons <i>Ken Berglund, Jack K. Tung, Bryan Higashikubo, Robert E. Gross, Christopher I. Moore, and Ute Hochgeschwender</i>	207
15 Intracranial Injection of an Optogenetics Viral Vector Followed by Optical Cannula Implantation for Neural Stimulation in Rat Brain Cortex <i>Christopher Pawela, Edgar DeYoe, and Ramin Pashaie</i>	227

16	An Optimized Calcium-Phosphate Transfection Method for Characterizing Genetically Encoded Tools in Primary Neurons	243
	<i>Shiyao Wang and Yong Ku Cho</i>	
17	Optogenetic Approaches for Mesoscopic Brain Mapping.	251
	<i>Michael Kyweriga and Majid H. Mohajerani</i>	
18	Optogenetic Tools for Confined Stimulation in Deep Brain Structures	267
	<i>Alexandre Castonguay, Sébastien Thomas, Frédéric Lesage, and Christian Casanova</i>	
19	Remote Patterning of Transgene Expression Using Near Infrared-Responsive Plasmonic Hydrogels	281
	<i>Francisco Martín-Saavedra and Nuria Vilaboa</i>	
20	Optogenetic Light Crafting Tools for the Control of Cardiac Arrhythmias	293
	<i>Claudia Richter, Jan Christoph, Stephan E. Lehnart, and Stefan Luther</i>	
21	Inscribing Optical Excitability to Non-Excitable Cardiac Cells: Viral Delivery of Optogenetic Tools in Primary Cardiac Fibroblasts.	303
	<i>Jinzhu Yu and Emilia Entcheva</i>	
22	Optogenetic Engineering of Atrial Cardiomyocytes.	319
	<i>Iolanda Feola, Alexander Teplenin, Antoine A.F. de Vries, and Daniël A. Pijnappels</i>	
23	A Multichannel Recording System with Optical Stimulation for Closed-Loop Optogenetic Experiments	333
	<i>Carmen Bartic, Francesco P. Battaglia, Ling Wang, Thoa T. Nguyen, Henrique Cabral, and Zaneta Navratilova</i>	
24	Optogenetic Control of Fibroblast Growth Factor Receptor Signaling	345
	<i>Nury Kim, Jin Man Kim, and Won Do Heo</i>	
25	Protein Inactivation by Optogenetic Trapping in Living Cells	363
	<i>Hyerim Park, Sangkyu Lee, and Won Do Heo</i>	
26	Optogenetic Manipulation of Selective Neural Activity in Free-Moving <i>Drosophila</i> Adults.	377
	<i>Po-Yen Hsiao, Ming-Chin Wu, Yen-Yin Lin, Chein-Chung Fu, and Ann-Shyn Chiang</i>	
27	Guidelines for Photoreceptor Engineering	389
	<i>Thea Ziegler, Charlotte Helene Schumacher, and Andreas Möglich</i>	
	<i>Erratum</i>	<i>E1</i>
	<i>Index</i>	<i>405</i>

Contributors

- CARMEN BARTIC • *Department of Physics and Astronomy, KU Leuven, Heverlee, Belgium
Imec, Heverlee, Belgium*
- FRANCESCO P. BATTAGLIA • *Donders Centre for Neuroscience, Radboud Universiteit,
Nijmegen, The Netherlands*
- KEN BERGLUND • *Department of Neurosurgery, Emory University, Atlanta, GA, USA*
- SIMON M. BRANDL • *Faculty of Biology, University of Freiburg, Freiburg, Germany*
- HENRIQUE CABRAL • *Donders Centre for Neuroscience, Radboud Universiteit,
Nijmegen, The Netherlands*
- CHRISTIAN CASANOVA • *Laboratoire des Neurosciences de la Vision, École d'optométrie,
Université de Montréal, Montréal, QC, Canada*
- ALEXANDRE CASTONGUAY • *École Polytechnique de Montréal, Montréal, QC, Canada*
- ANN-SHYN CHIANG • *Institute of Biotechnology, National Tsing Hua University,
Hsinchu, Taiwan; Brain Research Center, National Tsing Hua University,
Hsinchu, Taiwan; Genomics Research Center, Academia Sinica, Taipei, Taiwan;
Kavli Institute for Brain and Mind, University of California, San Diego, La Jolla,
CA, USA*
- YONG KU CHO • *Department of Chemical and Biomolecular Engineering,
University of Connecticut, Storrs, CT, USA; Institute for Systems Genomics,
University of Connecticut, Storrs, CT, USA*
- JAN CHRISTOPH • *Research Group Biomedical Physics, Max Planck Institute
for Dynamics and Self-Organization, Göttingen, Germany; DZHK German Center
for Cardiovascular Research, Partnersite Göttingen, Göttingen, Germany*
- ROMAIN DURAND-DE CUTTOLI • *Sorbonne Universités, UPMC Univ Paris 06, Paris,
France; Neuroscience Paris Seine, CNRS, UMR 8246, Paris, France; Neuroscience
Paris Seine, INSERM, U1130, Paris, France*
- EDGAR DEYOE • *Radiology Department, Medical College of Wisconsin, Milwaukee, WI, USA*
- EMILIA ENTCHEVA • *Department of Biomedical Engineering, Institute for Molecular
Cardiology, Stony Brook University, Stony Brook, NY, USA*
- IOLANDA FEOLA • *Laboratory of Experimental Cardiology, Department of Cardiology,
Heart Lung Center Leiden, Leiden University Medical Center, Leiden, The
Netherlands*
- ANDRÉ FIALA • *Department of Molecular Neurobiology of Behavior, Johann-Friedrich-
Blumenbach-Institute for Zoology and Anthropology, Georg-August-Universität
Göttingen, Göttingen, Germany*
- CHEIN-CHUNG FU • *Institute of Photonics Technologies, National Tsing Hua
University, Hsinchu, Taiwan; Department of Power Mechanical Engineering,
National Tsing Hua University, Hsinchu, Taiwan; Institute of Nanotechnology and
Microsystems Engineering, National Tsing Hua University, Hsinchu, Taiwan*
- CARLOS GASSER • *Institut für Biologie, Biophysikalische Chemie, Humboldt-Universität
zu Berlin, Berlin, Germany*

- ROBERT E. GROSS • *Department of Neurosurgery, Emory University, Atlanta, GA, USA; Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA, USA*
- SONGCHAO GUO • *Qiushi Academy for Advanced Studies (QAAS), Zhejiang University, Hangzhou, China; Department of Biomedical Engineering, Key Laboratory of Biomedical Engineering of Education Ministry, Zhejiang University, Hangzhou, China; Zhejiang Provincial Key Laboratory of Cardio-Cerebral Vascular Detection Technology and Medicinal Effectiveness Appraisal, Hangzhou, China*
- ARMIN HALLMANN • *Department of Cellular and Developmental Biology of Plants, University of Bielefeld, Bielefeld, Germany*
- WON DO HEO • *Center for Cognition and Sociality, Institute for Basic Science, Seoul, Republic of Korea; Department of Biological Sciences, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea*
- BRYAN HIGASHIKUBO • *Department of Neuroscience, Brown University, Providence, RI, USA*
- UTE HOCHGESCHWENDER • *Neuroscience Program and College of Medicine, Central Michigan University, Mt. Pleasant, MI, USA*
- PO-YEN HSIAO • *Institute of Biotechnology, National Tsing Hua University, Hsinchu, Taiwan*
- ARASH KIANIANMOMENI • *Department of Cellular and Developmental Biology of Plants, University of Bielefeld, Bielefeld, Germany*
- JIN MAN KIM • *Graduate School of Medical Science and Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea*
- NURY KIM • *Center for Cognition and Sociality, Institute for Basic Science, Seoul, Republic of Korea*
- ROBERT J. KITTEL • *Department of Neurophysiology, Institute of Physiology, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
- HEINZ G. KÖRSCHEN • *Department of Molecular Sensory Systems, Research Center Caesar, Bonn, Germany*
- MICHAEL KYWERIGA • *Department of Neuroscience, Canadian Centre for Behavioural Neuroscience, University of Lethbridge at Lethbridge, Lethbridge, AB, Canada*
- SANGKYU LEE • *Center for Cognition and Sociality, Institute for Basic Science (IBS), Daejeon, Republic of Korea*
- STEPHAN E. LEHNART • *DZHK German Center for Cardiovascular Research, Partnersite Göttingen, Göttingen, Germany; Heart Research Center Göttingen, Clinic of Cardiology and Pulmonology, University Medical Center Göttingen, Göttingen, Germany*
- DAMIEN LEMOINE • *Sorbonne Universités, UPMC Univ Paris 06, Paris, France; Neuroscience Paris Seine, CNRS, UMR 8246, Paris, France; Neuroscience Paris Seine, INSERM, U1130, Paris, France*
- FRÉDÉRIC LESAGE • *École Polytechnique de Montréal, Montréal, QC, Canada; Research Center, Montreal Heart Institute, Montréal, QC, Canada*
- DAN LI • *Department of Chemical and Biomolecular Engineering, University of Connecticut, Storrs, CT, USA*
- YEN-YIN LIN • *Brain Research Center, National Tsing Hua University, Hsinchu, Taiwan; Institute of Photonics Technologies, National Tsing Hua University,*

Hsinchu, Taiwan; Department of Electrical Engineering, National Tsing Hua University, Hsinchu, Taiwan

STEFAN LUTHER • *Research Group Biomedical Physics, Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany; DZHK German Center for Cardiovascular Research, Partnersite Göttingen, Göttingen, Germany; Institute for Nonlinear Dynamics, Georg-August-Universität Göttingen, Göttingen, Germany*

ANNE P. LUTZ • *Department of Biology/Genetics, Philipps-University Marburg, Marburg, Germany*

FRANCISCO MARTÍN-SAAVEDRA • *CIBER de Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Madrid, Spain; Edificio de Investigación, Hospital Universitario La Paz-IdiPAZ, Madrid, Spain*

TILO MATHES • *Department of Exact Sciences/Biophysics, Vrije Universiteit, Amsterdam, The Netherlands*

ANDREAS MÖGLICH • *Institut für Biologie, Biophysikalische Chemie, Humboldt-Universität zu Berlin, Berlin, Germany; Faculty of Biology, Chemistry and Earth Sciences, Lehrstuhl für Biochemie, Universität Bayreuth, Bayreuth, Germany*

MAJID H. MOHAJERANI • *Department of Neuroscience, Canadian Centre for Behavioural Neuroscience, University of Lethbridge at Lethbridge, Lethbridge, AB, Canada*

INÈS G. MOLLET • *Department of Clinical Sciences, Malmö, Lund University Diabetes Centre, Lund University, Malmö, Sweden*

CHRISTOPHER I. MOORE • *Department of Neuroscience, Brown University, Providence, RI, USA*

ALEXANDRE MOUROT • *Sorbonne Universités, UPMC Univ Paris 06, Paris, France; Neuroscience Paris Seine, CNRS, UMR 8246, Paris, France; Neuroscience Paris Seine, INSERM, U1130, Paris, France*

KONRAD MÜLLER • *Faculty of Biology, University of Freiburg, Freiburg, Germany; Novartis Pharma AG, Biologics Process R&D, Basel, Switzerland*

ZANETA NAVRATILOVA • *Donders Centre for Neuroscience, Radboud Universiteit, Nijmegen, The Netherlands*

THOA T. NGUYEN • *Department of Physics and Astronomy, KU Leuven, Heverlee, Belgium*

CHRISTOPHER NICOL • *Institut für Biologie, Neurobiologie, Freie Universität Berlin, Berlin, Germany*

ROCIO OCHOA-FERNANDEZ • *Institute of Synthetic Biology, University of Düsseldorf, Düsseldorf, Germany; iGRAD Plant International Graduate Program for Plant Science, University of Düsseldorf, Düsseldorf, Germany*

SHINZI OGASAWARA • *Creative Research Institution Sousei (CRIS), Hokkaido University, Sapporo, Hokkaido, Japan*

HYERIM PARK • *Department of Biological Sciences, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea*

RAMIN PASHAIE • *Electrical Engineering Department, University of Wisconsin-Milwaukee, Milwaukee, WI, USA*

CHRISTOPHER PAWELA • *Biophysics Department, Medical College of Wisconsin, Milwaukee, WI, USA*

- DANIËL A. PIJNAPPELS • *Laboratory of Experimental Cardiology, Department of Cardiology, Heart Lung Center Leiden, Leiden University Medical Center, Leiden, The Netherlands*
- MATTHIAS PRIGGE • *Department of Neurobiology, Weizmann Institute of Science, Rehovot, Israel*
- THOMAS M. REINBOTHE • *Department of Physiology, University of Gothenburg, Gothenburg, Sweden*
- JAKEB M. REIS • *Department of Chemistry, University of Toronto, Toronto, ON, Canada*
- CHRISTIAN RENICKE • *Department of Biology/Genetics, Philipps-University Marburg, Marburg, Germany*
- CLAUDIA RICHTER • *Research Group Biomedical Physics, Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany; DZHK German Center for Cardiovascular Research, Partnersite Göttingen, Göttingen, Germany*
- THOMAS RIEMENSBERGER • *Department of Molecular Neurobiology of Behavior, Johann-Friedrich-Blumenbach-Institute for Zoology and Anthropology, Georg-August-Universität Göttingen, Göttingen, Germany*
- SOPHIA L. SAMODELOV • *Faculty of Biology, University of Freiburg, Freiburg, Germany; Spemann Graduate School of Biology and Medicine (SGBM), University of Freiburg, Freiburg, Germany*
- CHARLOTTE HELENE SCHUMACHER • *Institut für Biologie, Biophysikalische Chemie, Humboldt-Universität zu Berlin, Berlin, Germany*
- MARTIN SCHWÄRZEL • *Institut für Biologie, Neurobiologie, Freie Universität Berlin, Berlin, Germany*
- REINHARD SEIFERT • *Department of Molecular Sensory Systems, Research Center Caesar, Bonn, Germany*
- CHRISTOF TAXIS • *Department of Biology/Genetics, Philipps-University Marburg, Marburg, Germany*
- ALEXANDER TEPLENIN • *Laboratory of Experimental Cardiology, Department of Cardiology, Heart Lung Center Leiden, Leiden University Medical Center, Leiden, The Netherlands*
- SÉBASTIEN THOMAS • *Laboratoire des Neurosciences de la Vision, École d'optométrie, Université de Montréal, Montréal, QC, Canada*
- JACK K. TUNG • *Department of Neurosurgery, Emory University, Atlanta, GA, USA; Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA, USA*
- NURIA VILABOA • *Edificio de Investigación, Hospital Universitario La Paz-IdiPAZ, Madrid, Spain; CIBER de Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Madrid, Spain*
- ANTOINE A.F. DE VRIES • *Laboratory of Experimental Cardiology, Department of Cardiology, Heart Lung Center Leiden, Leiden University Medical Center, Leiden, The Netherlands; ICIN-Netherlands Heart Institute, The Netherlands*
- LING WANG • *Department of Physics and Astronomy, KU Leuven, Heverlee, Belgium*
- SHIYAO WANG • *Department of Chemical and Biomolecular Engineering, University of Connecticut, Storrs, CT, USA*

- WILFRIED WEBER • *Spemann Graduate School of Biology and Medicine (SGBM), University of Freiburg, Freiburg, Germany; Faculty of Biology, University of Freiburg, Freiburg, Germany; BIOS-Centre for Biological Signalling Studies, University of Freiburg, Freiburg, Germany*
- ELKE WEHINGER • *Faculty of Biology, University of Freiburg, Freiburg, Germany*
- JONAS WIETEK • *Experimental Biophysics, Humboldt University Berlin, Berlin, Germany*
- G. ANDREW WOOLLEY • *Department of Chemistry, University of Toronto, Toronto, ON, Canada*
- MING-CHIN WU • *Brain Research Center, National Tsing Hua University, Hsinchu, Taiwan*
- KEDI XU • *Qiushi Academy for Advanced Studies (QAAS), Zhejiang University, Hangzhou, China; Department of Biomedical Engineering, Key Laboratory of Biomedical Engineering of Education Ministry, Zhejiang University, Hangzhou, China; Zhejiang Provincial Key Laboratory of Cardio-Cerebral Vascular Detection Technology and Medicinal Effectiveness Appraisal, Hangzhou, China*
- JINZHU YU • *Department of Biomedical Engineering, Stony Brook University, Stony Brook, NY, USA*
- JIACHENG ZHANG • *Qiushi Academy for Advanced Studies (QAAS), Zhejiang University, Hangzhou, China; Department of Biomedical Engineering, Key Laboratory of Biomedical Engineering of Education Ministry, Zhejiang University, Hangzhou, China; Zhejiang Provincial Key Laboratory of Cardio-Cerebral Vascular Detection Technology and Medicinal Effectiveness Appraisal, Hangzhou, China*
- XIAOXIANG ZHENG • *Qiushi Academy for Advanced Studies (QAAS), Zhejiang University, Hangzhou, China; Department of Biomedical Engineering, Key Laboratory of Biomedical Engineering of Education Ministry, Zhejiang University, Hangzhou, China; Zhejiang Provincial Key Laboratory of Cardio-Cerebral Vascular Detection Technology and Medicinal Effectiveness Appraisal, Hangzhou, China*
- THEA ZIEGLER • *Institut für Biologie, Biophysikalische Chemie, Humboldt-Universität zu Berlin, Berlin, Germany; Lehrstuhl für Biochemie, Universität Bayreuth, Bayreuth, Germany*
- MATIAS D. ZURBRIGGEN • *Institute of Synthetic Biology, University of Düsseldorf, Düsseldorf, Germany; Faculty of Biology, University of Freiburg, Freiburg, Germany*