

PROCEEDINGS OF SPIE

# ***Complex Light and Optical Forces X***

**Jesper Glückstad  
David L. Andrews  
Enrique J. Galvez**  
*Editors*

**16–18 February 2016  
San Francisco, California, United States**

*Sponsored by*  
SPIE

*Cosponsored by*  
ICOAM (United States)

*Published by*  
SPIE

**Volume 9764**

Proceedings of SPIE 0277-786X, V. 9764

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Complex Light and Optical Forces X, edited by Jesper Glückstad, David L. Andrews,  
Enrique J. Galvez, Proc. of SPIE Vol. 9764, 976401 · © 2016 SPIE  
CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2239906

Proc. of SPIE Vol. 9764 976401-1

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Complex Light and Optical Forces X*, edited by Jesper Glückstad, David L. Andrews, Enrique J. Galvez, Proceedings of SPIE Vol. 9764 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781628419993

Published by

**SPIE**

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time) • Fax +1 360 647 1445

SPIE.org

Copyright © 2016, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at [copyright.com](http://copyright.com). Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/16/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL  
LIBRARY**  
SPIEDigitalLibrary.org

---

**Paper Numbering:** *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a six-digit CID article numbering system structured as follows:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

# Contents

vii	<i>Authors</i>
ix	<i>Conference Committee</i>
xi	<i>Introduction</i>

---

<b>SESSION 1</b>	<b>TOAST TO 10TH YEAR OF COMPLEX LIGHT AND OPTICAL FORCES</b>
------------------	---

---

9764 02	<b>Overview of selected seminal optical science and photonics processes in nature (Invited Paper) [9764-1]</b>
9764 03	<b>Transverse spin and momentum in structured light: quantum spin Hall effect and transverse optical force (Invited Paper) [9764-2]</b>

---

<b>SESSION 2</b>	<b>QUANTUM ASPECTS</b>
------------------	------------------------

---

9764 07	<b>Quantum issues with structured light [9764-7]</b>
9764 08	<b>Satisfying the Einstein-Podolsky-Rosen criterion with massive particles [9764-8]</b>

---

<b>SESSION 3</b>	<b>MICROFABRICATION FOR BEAM ENGINEERING</b>
------------------	--

---

9764 0A	<b>A platform for lab and industrial scale replication of phase optics and microfluidics (Invited Paper) [9764-10]</b>
9764 0B	<b>Structured amplitude and phase fields behind microstructures: the quest for high contrast modulation at proximity (Invited Paper) [9764-11]</b>
9764 0C	<b>Compact solutions for optical fiber tweezers using Fresnel zone and phase lenses fabricated using FIB milling (Best Student Paper Award) [9764-12]</b>

---

<b>SESSION 4</b>	<b>BEAM ENGINEERING AND APPLICATIONS</b>
------------------	--

---

9764 0F	<b>Cell sorting using efficient light shaping approaches [9764-15]</b>
9764 0H	<b>Dark GPC [9764-17]</b>
9764 0I	<b>Generation of complex light using uniaxial and biaxial crystals: an efficient and accurate vectorial simulation technique [9764-59]</b>

<b>SESSION 5</b>	<b>MEASUREMENTS AND CALIBRATION</b>
9764 0J	<b>Optical quantification of forces at play during stem cell differentiation (Invited Paper)</b> [9764-18]
9764 0L	<b>Measurement and accumulation of electric charge on a single dielectric particle trapped in air</b> [9764-20]
9764 0O	<b>Mapping the spectral twist of few-cycle vortex pulses</b> [9764-23]
<b>SESSION 6</b>	<b>SUPERPOSITION EFFECTS</b>
9764 0P	<b>Single-beam interference from plain Gaussian and OAM wavefronts (Invited Paper)</b> [9764-24]
9764 0Q	<b>Generation of Laguerre Gaussian beams using spiral phase diffractive elements fabricated on optical fiber tips using focused ion beam milling</b> [9764-58]
9764 0R	<b>High-order disclinations in the polarization of light</b> [9764-26]
9764 0S	<b>Soliton formation by interacting Airy beams</b> [9764-27]
<b>SESSION 7</b>	<b>CHIRALITY</b>
9764 0W	<b>Chiral separation and twin-beam photonics</b> [9764-30]
<b>SESSION 8</b>	<b>MODES, PROPAGATION, AND TRANSMISSION</b>
9764 0Y	<b>Untangled modes in multimode waveguides (Invited Paper)</b> [9764-32]
9764 10	<b>Optical vortex beam transmission with different OAM in scattering beads and brain tissue media (Travel Award)</b> [9764-34]
<b>SESSION 9</b>	<b>NANOSTRUCTURES AND NEAR-FIELD</b>
9764 14	<b>Optical binding between nanowires (Invited Paper)</b> [9764-37]
9764 16	<b>Novel non-imaging optic design for uniform illumination</b> [9764-55]
<b>SESSION 10</b>	<b>PARTICLE TRAPPING, MANIPULATION, AND TRACKING</b>
9764 1A	<b>Tractor beams for optical micromanipulation</b> [9764-44]

---

**SESSION 11      LASER MICROFABRICATION AND MICROASSEMBLY**

---

- 9764 1C      **Holographic vector-wave femtosecond laser processing (Invited Paper)** [9764-46]
- 9764 1D      **Complex light in 3D printing (Invited Paper)** [9764-47]
- 9764 1E      **Optical screw-wrench for interlocking 2PP-microstructures** [9764-48]

---

**SESSION 12      OPTICAL FORCES: ENHANCEMENT AND OTHER EFFECTS**

---

- 9764 1F      **Photothermal heating in metal-embedded microtools for material transport (Invited Paper)**  
[9764-49]

---

**POSTER SESSION**

---

- 9764 1J      **Photo-induced force for spectroscopic imaging at the nanoscale** [9764-53]



# Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Alfano, Robert R., 02, 10	Morales Delgado, Edgar, 1D
Andrews, David L., 07, 0W	Moser, Christophe, 1D
Arlt, J., 08	Oddershede, Lene B., 0J
Babadi, S., 16	Ostendorf, A., 1E
Bañas, Andrew Rafael, 0F, 0H, 1F	Palima, Darwin, 0F, 0H, 1F
Bernasconi, Johana, 0B	Park, Haesung, 0L
Bliokh, Konstantin Y., 03	Peise, J., 08
Bock, M., 0O	Pezzè, L., 08
Boutaleb, T., 16	Plöschner, Martin, 0Y
Bradshaw, David S., 07, 0W	Popov, S., 0P
Brickman, Joshua M., 0J	Potma, Eric Olaf, 1J
Čižmár, Tomáš, 0Y	Psaltis, Demetri, 1D
Dahal, P., 0C, 0Q	Puthankovilakam, Krishnaparvathy, 0B
Delrot, Paul, 1D	Ramirez-Iniguez, R., 16
Denz, C., 0S	Ritter, Christine M., 0J
Diebel, F., 0S	Rodrigues Ribeiro, R. S., 0C, 0Q
Ertmer, W., 08	Santos, L., 08
Esen, C., 1E	Scharf, Toralf, 0B
Favier, M., 0P	Shi, Lingyan, 10
Galvez, Enrique J., 0R	Simpson, Stephen H., 14
Glückstad, Jesper, 0F, 0H, 1F	Smerzi, A., 08
Grier, David G., 1A	Stensborg, Jan F., 0A
Grunwald, R., 0O	Timotijević, D. V., 0S
Guerreiro, Ariel, 0C, 0Q	Tork Ladani, Faezeh, 1J
Hammerer, K., 08	Tyc, Tomáš, 0Y
Hanna, Simon, 14	Viegas, J., 0C, 0Q
Hasegawa, Satoshi, 1C	Villangca, Mark Jayson, 0F, 0H, 1F
Hayasaki, Yoshio, 1C	Voelkel, Reinhard, 0B
Herzig, Hans-Peter, 0B	Vogler, Uwe, 0B
Jahng, Junghoon, 1J	Wang, W. B., 10
Jorge, P. A. S., 0C, 0Q	Wang, Zongzhao, 0I
Jović Savić, D. M., 0S	Williams, Mathew D., 07
Khajavi, Behzad, 0R	Wyrowski, Frank, 0I
Khan, Ryan Muhammad, 1J	Yde, Leif, 0A
Kim, Myun-Sik, 0B	Yevick, Aaron, 1A
Klempt, C., 08	Zhang, Site, 0I
Köhler, J., 1E	Zyla, G., 1E
Kruse, I., 08	
Ksouri, S. I., 1E	
Lange, K., 08	
Lavery, M. P. J., 10	
LeBrun, Thomas W., 0L	
Lindvold, Lars R., 0A	
Lindwasser, Lukas, 10	
Loterie, Damien, 1D	
Lücke, B., 08	
Mallick, T., 16	
Marque, Paulo, 10	
Modestino, Miguel, 1D	





# Conference Committee

## *Symposium Chairs*

**Jean-Emmanuel Broquin**, IMEP-LAHC (France)  
**Shibin Jiang**, AdValue Photonics, Inc. (United States)

## *Symposium Co-chairs*

**David L. Andrews**, University of East Anglia (United Kingdom)  
**Alexei L. Glebov**, OptiGrate Corporation (United States)

## *Conference Chairs*

**Jesper Glückstad**, Technical University of Denmark (Denmark)  
**David L. Andrews**, University of East Anglia (United Kingdom)  
**Enrique J. Galvez**, Colgate University (United States)

## *Program Track Chair*

**Zameer U. Hasan**, Temple University (United States)

## *Conference Program Committee*

**Robert R. Alfano**, The City College of New York (United States)  
**Cornelia Denz**, Westfälische Wilhelms-Universität Münster (Germany)  
**Kishan Dholakia**, University of St. Andrews (United Kingdom)  
**Wolfgang A. Ertmer**, Leibniz University Hannover (Germany)  
**Andrew Forbes**, University of the Witwatersrand (South Africa) and  
CSIR National Laser Center (South Africa)  
**Jörg B. Götte**, Max-Planck-Institut für Physik komplexer Systeme  
(Germany)  
**David G. Grier**, New York University (United States)  
**Rüdiger Grunwald**, Max-Born-Institut für Nichtlineare Optik und  
Kurzeitspektroskopie (Germany)  
**Jandir M. Hickmann**, Universidade Federal do Rio Grande  
do Sul (Brazil)  
**Thomas R. Huser**, Universität Bielefeld (Germany)  
**Lorenzo Marrucci**, Università degli Studi di Napoli Federico II (Italy)  
**Miles J. Padgett**, University of Glasgow (United Kingdom)  
**Darwin Palima**, Technical University of Denmark (Denmark)  
**Monika Ritsch-Marte**, Medizinische Universität Innsbruck (Austria)  
**Halina H. Rubinsztein-Dunlop**, The University of Queensland (Australia)

**Marat S. Soskin**, Institute of Physics (Ukraine)  
**Grover A. Swartzlander Jr.**, Rochester Institute of Technology  
(United States)  
**Nirmal K. Viswanathan**, University of Hyderabad (India)

*Session Chairs*

- 1 Toast to 10th Year of Complex Light and Optical Forces  
**David L. Andrews**, University of East Anglia (United Kingdom)
- 2 Quantum Aspects  
**Enrique J. Galvez**, Colgate University (United States)
- 3 Microfabrication for Beam Engineering  
**Mark Jayson Villangca**, DTU Fotonik (Denmark)
- 4 Beam Engineering and Applications  
**Lars R. Lindvold**, DTU Risø Campus (Denmark)
- 5 Measurements and Calibration  
**Tomáš Čižmár**, University of Dundee (United Kingdom)
- 6 Superposition Effects  
**Rüdiger Grunwald**, Max-Born-Institut für Nichtlineare Optik und  
Kurzeitspektroskopie (Germany)
- 7 Chirality  
**Lene B. Oddershede**, University of Copenhagen (Denmark)
- 8 Modes, Propagation, and Transmission  
**Sergei Popov**, KTH Royal Institute of Technology (Sweden)
- 9 Nanostructures and Near-field  
**Craig B. Arnold**, Princeton University (United States)
- 10 Particle Trapping, Manipulation, and Tracking  
**Simon Hanna**, University of Bristol (United Kingdom)
- 11 Laser Microfabrication and Microassembly  
**Kishan Dholakia**, University of St. Andrews (United Kingdom)
- 12 Optical Forces: Enhancement and Other Effects  
**David L. Andrews**, University of East Anglia (United Kingdom)

## Introduction

This year marked the 10th Anniversary Edition of the conference on Complex Light and Optical Forces that is part of Photonics West. We again had a record number of submissions, indicative of the rising visibility and stature of this conference. Indeed, Complex Light and Optical Forces is still the only yearly venue worldwide for presenting research on complex light. This year we did not find a need to organize joint sessions with other conferences at Photonics West.

The 10th anniversary of our conference had three full days of sessions with the following 12 sessions: Toast to 10th Year of Complex Light and Optical Forces; Quantum Aspects; Microfabrication for Beam Engineering; Beam Engineering and Applications; Measurements and Calibration; Superposition Effects; Chirality; Modes, Propagation and Transmission; Nanostructures and Near-field; Particle Trapping, Manipulation, and Tracking; Laser Microfabrication and Microassembly; Optical Forces, Enhancement and Other Effects. The conference featured more than 60 presentations, with numerous invited, contributed, and poster presentations.

Bringing most of these papers to the SPIE proceedings provides a welcome opportunity to thank all the contributors. In particular, we gladly acknowledge the support of the members of our highly active and supportive Program Committee, whose sterling work underpins the success of this conference each year. We remain indebted to the SPIE staff at every level, for reliable management and production processes, achieved with customary hallmark professionalism.

In summary, the present volume is representative of a strongly growing field of photonics that has contributed much to our understanding of light and its applications in manipulation, and which remains leaving much promise of more to come.

**Jesper Glückstad**  
**David L. Andrews**  
**Enrique J. Galvez**

