# PROCEEDINGS OF SPIE

# Optical Trapping and Optical Micromanipulation XIII

Kishan Dholakia Gabriel C. Spalding Editors

28 August–1 September 2016 San Diego, California, United States

Sponsored and Published by SPIE

Volume 9922

Proceedings of SPIE 0277-786X, V. 9922

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

Optical Trapping and Optical Micromanipulation XIII, edited by Kishan Dholakia, Gabriel C. Spalding, Proc. of SPIE Vol. 9922, 992201 · © 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2258066

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 *Optical Trapping and Optical Micromanipulation XIII*, edited by Kishan Dholakia, Gabriel C. Spalding, Proceedings of SPIE Vol. 9922 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510602359

ISBN: 9781510602366 (electronic)

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.ora

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. 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.



**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	Authors
ix	Conference Committee

# STATISTICAL MECHANICS OF SMALL SYSTEMS 9922 02 Optical Kapitza pendulum (Invited Paper) [9922-1] 9922 03 Using a Maxwell's demon to orient a microsphere in a laser trap and initiate thermodynamic assays of photonic nanofields [9922-2] TOWARD (OR IN) THE QUANTUM LIMIT OF OPTOMECHANICS / CAVITY OPTOMECHANICS I 9922 0A Optically driven self-oscillations of a silica nanospike at low gas pressures [9922-10] TOWARD (OR IN) THE QUANTUM LIMIT OF OPTOMECHANICS / CAVITY OPTOMECHANICS II 9922 OB Cooling the mechanical motion of a tapered optical fiber and a microsphere-cantilever using whispering gallery modes [9922-11] 9922 0C Cooling and manipulation of nanoparticles in high vacuum [9922-12] 9922 0D Nonlinear dynamics and cavity cooling of levitated nanoparticles [9922-13] 9922 OE Phase locking of the rotation of a graphene nanoplatelet to an RF electric field in a quadrupole ion trap [9922-14] 9922 0G Alq<sub>3</sub> coated silicon nanomembranes for cavity optomechanics [9922-16] OPTICAL MANIPULATION OF MATTER IN VACUUM OR THROUGH GASEOUS MEDIA 9922 01 Spectroscopy and optical imaging of coalescing droplets [9922-18] OPTICAL ANGULAR MOMENTUM AND FOUNDATIONS OF THE ELECTROMAGNETIC THEORY OF FORCE AND MOMENTUM 9922 OL Nanostructures creation by optical angular momentum transfer (Invited Paper) [9922-23] 9922 ON Generation of optimal annular vortex beams for orbital angular momentum transfer to microparticles [9922-25]

9922 OR	Polarization dependent particle dynamics in simple traps [9922-29]
9922 OT	Field and material stresses predict observable surface forces in optical and electrostatic manipulation [9922-31]
	OPTO-BIO AND OPTO-BIO TECHNIQUE I
9922 10	Temperature control and measurement with tunable femtosecond optical tweezers [9922-37]
9922 11	Controlled cellular fusion using optically trapped plasmonic nano-heaters [9922-39]
9922 12	Optical manipulation of a single human virus for study of viral-cell interactions (Invited Paper) [9922-40]
9922 13	Optical two-beam trap in a polymer microfluidic chip (Invited Paper) [9922-41]
	OPTO-BIO AND OPTO-BIO TECHNIQUE II
9922 16	High accuracy indirect optical manipulation of live cells with functionalized microtools
	ADVANCED IMAGING AND DETECTION
9922 1B	Real-time 3D video utilizing a compressed sensing time-of-flight single-pixel camera [9922-49]
	ENHANCED SENSITIVITY AND RESOLUTION OF OPTICAL FORCE ACTUATORS
9922 1D	Understanding local forces in electrophoretic ink systems: utilizing optical tweezers to explore electrophoretic display devices [9922-51]
	OPTICALLY ASSEMBLED MATTER
9922 1Q	Characterizing particle pairs optically bound in "tractor beam" [9922-64]
9922 1R	Light propagation in optical trapping assembling of colloidal particles at an interface [9922-65]
9922 1U	Optical binding between knotted and chiral nanoparticles [9922-68]

	PHOTONIC DEVICES FOR OPTICALLY INDUCED FORCES
9922 1X	Long-range optical binding in a hollow-core photonic crystal fiber using higher order modes [9922-71]
	TRAPPING AT EXTREMES ("GONZO" TRAPPING)
9922 22	A holographic optical tweezers module for the International Space Station [9922-76]
9922 23	Nanoparticle electrostriction acoustic resonance enhanced nonlinearity [9922-77]
	TRAPPING WITH RESONATORS: PLASMONICS, DIELECTRICS, AND NANO-SAMPLES
9922 27	Plasmonic trapping based on nanoring devices at low incident powers [9922-82]
9922 2A	All-optical manipulation of photonic membranes [9922-85]
	POSTER SESSION
9922 2D	Rotation rate measurement and calculation for calcite crystals in a C-point mode [9922-88]
9922 2E	Influence of optical angular momentum on filamentation of 800 nm femtosecond laser pulses in fused silica [9922-89]
9922 21	Interaction of aerosol particles with a standing wave optical field [9922-93]
9922 2J	Convection currents enhancement of the spring constant in optical tweezers [9922-94]
9922 2L	Experimental setup for the direct measurement of a light-induced attractive force between two metal bodies [9922-96]
9922 2M	Probing the interaction between two microspheres in a single Gaussian beam optical trap [9922-97]
9922 2N	Absolute calibration of optical tweezers: the MDSA+ theory [9922-98]
9922 2P	The effect of red light irradiation on spermatozoa DNA [9922-101]
9922 2R	Optical fiber loops and helices: tools for integrated photonic device characterization and microfluidic trapping [9922-103]
9922 2S	Fiber-based optical trapping for cell mechanics study and microrheology [9922-104]
9922 2T	Improved antireflection coated microspheres for biological applications of optical tweezers [9922-105]
9922 2V	Optical steering of thermally generated microbubbles in a liquid for targeted metallic nanoparticle delivery [9922-107]

- 9922 2X Nanoscale  $Si_3N_4$  tuning fork cavity optomechanical sensors with high  $f_mQ_m$  product [9922-109]
- 7922 2Y Toward automated formation of microsphere arrangements using multiplexed optical tweezers [9922-110]

## **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.

Abdosamadi, Mohammad K., 2T Abeywickrema, Ujitha, 2V Aekbote, Badri L., 16

Aksyuk, Vladimir, 2X Ananthamurthy, Sharath, 2M

Aranas, E. B., OD
Arimondo, E., OG
Arndt, M., OC
Arrizon, V., ON
Bahadori, Azra, 11
Banerjee, Ashis G., 2Y
Banerjee, Partha, 2V
Barker, P. F., OB, OD
Belai, O., 2L

Bendix, Poul M., 11 Beranek, Vaclav, 03 Berg-Sørensen, Kirstine, 13 Berns, Michael W., 2P

Bhattacharya, Sarbari, 2M Bilenberg, Brian, 13 Bollavaram, Manasa, 2Y Brzobohatý, Oto, 1Q Buetefisch, S., 2L

Buzás, András, 16 Bykov, Dmitry S., 1X Camposeo, A., 0G Catak, Darmin, 13

Chang, Kelken, Ol Cheng, Wei, 12 Chow, Kay W., 2P Chvátal, Lukáš, 1Q

Cirdiai, Lokas, 16 Ciampini, D., 0G Čižmár, Tomas, 2A Coppock, Joyce E., 0E Cubero, David, 02

Curry, John J., 2l Damková, Jana, 1Q Davanço, Marcelo, 2X DeSantis, Michael C., 12 Dickinson, Mark R., 1D

Di Falco, Andrea, 2A

Dutra, R. S., 2N Edgar, Matthew P., 1B Espina Palanco, Marta, 13

Espiria Palarico, Ma Euser, Tijmen G., 1X Evans, Evan A., 03 Ferro, Valentina, 2T Figliozzi, Patrick, 0R Fogliano, F., 0G Fonseca, P. Z. G., 0D

Fuso, F., 0G

Gibson, Graham M., 1B Gleeson, Helen F., 1D

Gomez-Godinez, Veronica, 2P

Gómez-Vieyra, A., 2J Gordon, Reuven, 23 Goswami, Debabrata, 10 Grexa, István, 16

Han, Xue, 27 Hanna, Simon, 1U Hanstorp, Dag, 01

Hejazi, Seyedeh Sahar Seyed, 27

Herne, Catherine M., 2D Hou, Ximiao, 12 Ivanov, Maksym, 0I

lyengar, Shruthi Subhash, 2M

Jones, Philip H., 02 Kane, Bruce E., 0E Kelemen, Lóránd, 16 Kemp, Brandon A., 0T Kirkpatrick, Blair C., 2A

Kosloff, A., 0C

Krishnappa, Arjun, 2V Kristensen, Anders, 13

Liu, Yuxiang, 2R, 2S, 2X

Kudo, T., 1R Kuhn, S., 0C

Kuznetsov, Igor R., 03 Lakkegowda, Yogesha, 2M

Li, Y. Lia, OB

Lund, Andreas R., 11 Maia Neto, P. A., 2N Marie, Rodolphe, 13 Masterson, H., 22 Masuhara, H., 1R Matteucci, Marco, 13 McDonald, Craig, 2T McGloin, David, 2T Mehlig, Bernhard, Ol Millen, J., OB, OC, OD Mondal, Dipankar, 10 Monteiro, T. S., 0D Murphy, Jacob P. J., 0E Nagornykh, Pavel, 0E Naparty, D., 2L Nesterov, V., 2L

Nic Chormaic, Síle, 27

Nies, D., 2L

Noskov, Roman E., 0A Nussenzveig, H. M., 2N O'Brien, Ann E., 2D Oddershede, Lene B., 11 Omatsu, Takashige, OL Ormos, Pál, 16 Ortu, A., 0G Padgett, Miles J., 1B Paez, R., 0N

Parthasarathi, Praveen, 2M Patolsky, F., 0C Pennetta, Riccardo, 0A Phillips, David B., 1B Pisignano, D., 0G Ploschner, Martin, 2A Preece, Daryl, 2P

Raiasekaran, Keshav, 2Y Ramírez Contreras, Claudia, Ol Ramirez-San-Juan, J. C., 2J Ramos-García, R., 0N, 2J Ren, Yundong, 2R, 2X

Richards, Christopher J., 02

Ruiz, U., 0N

Russell, Philip St. J., OA, 1X Schäffer, Erik, 2T

Scherer, Norbert F., OR Semsey, Szabolcs, 11

Serati, R., 22 Serati, S., 22 Shane, J., 22 Shapiro, D., 2L

Sheppard, Cheyenne J., 0T

Shlenov, S. A., 2E Šiler, Martin, 1Q

Simpson, Stephen H., 1Q, 1U

Smart, Thomas J., 02

Smith, N., 1D

Sonnberger, Aaron, 2T Spalding, Gabriel C., 1B Srinivasan, Kartik, 2X Sule, Nishant, OR

Sun, Ming-Jie, 1B Svak, Vojtěch, 1Q

Tao, Mingjiang, 2S

Thomas, Gawain M., 2S

Ti, Chaoyang, 2R, 2S

Tian, Chunjuan, 12

Torres-Hurtado, S. A., 2J

Truong, Viet Giang, 27

Vasilyev, E. V., 2E

Viana, N. B., 2N

Viderström, Michel, 01

Vizsnyiczai, Gaszton, 16

Wang, S. F., 1R

Wei, David L., 1D

Wen, Qi, 2S

Wurm, M., 2L

Xiang, Dao, 23

Xie, Shangran, OA, 1X

Yifat, Yuval, OR

Yu, Xiaokong, 2S Yuyama, K., 1R Zeltner, Richard, 1X Zemánek, Pavel, 1Q Zenteno-Hernández, J. A., 2J Zhang, Rui, 2R, 2X

# **Conference Committee**

#### Symposium Chairs

 Harry A. Atwater, Jr., California Institute of Technology (United States)
 Nikolay I. Zheludev, Optoelectronics Research Centre (United Kingdom) and Nanyang Technological University (Singapore)

#### Symposium Co-chairs

**David L. Andrews**, University of East Anglia (United Kingdom) **James G. Grote**, Air Force Research Laboratory (United States)

#### Conference Chairs

**Kishan Dholakia**, University of St. Andrews (United Kingdom) **Gabriel C. Spalding**, Illinois Wesleyan University (United States)

#### Conference Program Committee

**Roberto Di Leonardo**, Università degli Studi di Roma La Sapienza (Italy)

Jesper Glückstad, Technical University of Denmark (Denmark)

**Reuven Gordon**, University of Victoria (Canada)

**Simon Hanna**, University of Bristol (United Kingdom)

**Masud Mansuripur**, College of Optical Sciences, The University of Arizona (United States)

Daniel H. Ou-Yang, Lehigh University (United States)

**Thomas T. Perkins**, JILA (United States)

**David B. Phillips**, University of Glasgow (United Kingdom)

**Ruben Ramos-Garcia**, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

**Halina Rubinsztein-Dunlop**, The University of Queensland (Australia) **Nick Vamivakas**, University of Rochester (United States)

#### Session Chairs

- Statistical Mechanics of Small Systems
  Yuxiang Shawn Liu, Worcester Polytechnic Institute (United States)
- 2 Toward (or in) the Quantum Limit of Optomechanics / Cavity Optomechanics I

Nick Vamivakas, University of Rochester (United States)

- Toward (or in) the Quantum Limit of Optomechanics / Cavity Optomechanics II
  - **Nick Vamivakas**, University of Rochester (United States)
- 4 Optical Manipulation of Matter in Vacuum or Through Gaseous Media
  - **Masud Mansuripur**, College of Optical Sciences, The University of Arizona (United States)
- Optical Angular Momentum and Foundations of the Electromagnetic Theory of Force and Momentum
  - Halina Rubinsztein-Dunlop, The University of Queensland (Australia)
- Opto-Bio and Opto-Bio Technique I
   Daryl Preece, University of California, San Diego (United States)
- Opto-Bio and Opto-Bio Technique II
   Michael W. Berns, University of California, San Diego (United States)
- 8 Advanced Imaging and Detection
  Rubén Ramos-Garcia, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)
- 9 Enhanced Sensitivity and Resolution of Optical Force Actuators **Reuven Gordon**, University of Victoria (Canada)
- Novel Drives, Active Matter, and Hydrodynamics
   David B. Phillips, University of Glasgow (United Kingdom)
   Simon Hanna, University of Bristol (United Kingdom)
- Optically Assembled Matter **Kishan Dholakia**, University of St. Andrews (United Kingdom)
- Photonic Devices for Optically Induced Forces Kishan Dholakia, University of St. Andrews (United Kingdom)
- 13 Trapping at Extremes ("Gonzo" Trapping) **Kishan Dholakia**, University of St. Andrews (United Kingdom)
- 14 Trapping with Resonators: Plasmonics, Dielectrics, and Nano-samples **Simon Hanna**, University of Bristol (United Kingdom)