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Mike Woerdemann

Structured Light Fields

Applications in Optical Trapping,
Manipulation, and Organisation

Doctoral Thesis accepted by
the University of Münster, Germany

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ISSN 2190-5053

ISBN 978-3-642-29322-1

DOI 10.1007/978-3-642-29323-8

Springer Heidelberg New York Dordrecht London

ISSN 2190-5061 (electronic)

ISBN 978-3-642-29323-8 (eBook)

Library of Congress Control Number: 2012937479

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Supervisor's Foreword

The manipulation of nano- and microparticles by trapping with light has developed in the last couple of years into a mature photonic technique with a number of impressive applications in biology and medicine. While the acceleration and trapping of particles by radiation pressure has been known for more than 40 years, classical optical tweezers first became a standard technique for measuring piconewton forces after their development by Arthur Ashkin 25 years ago. First applications were in the field of cold atoms, and other novel devices and applications have only developed quite recently. This is on the one hand due to the fact that by applying holography and—with the advent of off-the-shelf spatial light modulators—also dynamic holograms, novel configurations of almost arbitrary two- and three-dimensional multiple traps became feasible. On the other hand, singularities in the optical trapping beam can be used to transmit not only momentum, but also angular momentum to particles in a laser beam, allowing one to spin and rotate them.

In his thesis, Mike Woerdemann exploits this state of the art to make progress in a variety of cutting edge directions that will certainly have a major impact on the future development of optical trapping. First, he systematically studies the fundamental disadvantages of conventional holographic beam shaping and introduces an innovative method based on optical volume holography, and hence dramatically reduces the usually high computational effort. Complementing this, he applies optimised dynamic holographic optical tweezers to successfully achieve hierarchical supramolecular assembly, by organising nanocontainers in arbitrary artificial crystal structures. Moreover, he demonstrates how dynamic bacterial molecular motors can be arranged into two-dimensional structures. He also introduces novel, counterpropagating trapping configurations where the counterpropagating light field is generated in an ingenious way by optical phase-conjugation based on nonlinear optical two-beam coupling and four-wave mixing. Finally, and most importantly, the thesis opens up a completely new field using complex nondiffracting and self-similar beams in elliptical symmetries as optical potential landscapes, allowing entirely novel trapping configurations.

This remarkable number of highly interesting results has been honoured with several cover pages of journals, and some of his publications were selected among the best 30 research activities in optics by Optics and Photonics News in 2010 and 2011, respectively.

Alongside these highly original and novel results, the thesis also provides a concise but still easy-to-read description of the most important concepts of optical micromanipulation, beginning at an introductory level and extending up to current state-of-the-art research. Thus it will be informative and enjoyable reading even for the newcomer or non-specialist.

Acknowledgments

Physics in general and experimental physics in particular is a field of research where new findings are not discovered by isolated individuals but rather by teams. This work is no exception being the result of numberless discussions, cooperations, suggestions and technical assistances.

First and foremost I would like to thank Cornelia Denz, my boss and supervisor of this thesis, for establishing and maintaining an extraordinarily creative, scientifically fruitful and in all facets pleasant working atmosphere in her research group. Above all, however, I thank her for not seeing me as a student but rather as a scientist. She strongly supported me in presenting my results at various international conferences, making multiple external research visits, participating in numberless project meetings, contributing my ideas to different project proposals, and managing own projects self-dependently—from the initial idea to the final publications. Thank you very much!

I thank Berenike Maier for kindly serving as the second supervisor but mainly for her open-mindedness about new ideas and her critical and always very constructive opinion. Thank you very much for the absolutely uncomplicated collaboration and for several enlightening discussions.

I am deeply grateful to Christina Alpmann, Konrad Berghoff and Florian Hörner whom I had the pleasure to guide during their research activities for their theses and who constituted the most continuous and most essential participants of our optical tweezers team. Only by working as a team were we able to promote the field of optical micromanipulation so comprehensively in this short time. I thank you so much for your outstanding motivation, your pleasure to perform even most complex research tasks and to discuss even the most fantastic ideas and, most of all, for the very successful cooperation in our jointly accomplished projects.

Special thanks go to Michael Eßeling, Christina Heßeling, Frank Holtmann, Wolfgang Horn, Jörg Imbrock, Björn Kemper, Alvin Sashala Naik, Lena Dewenter, Álvaro Barroso Peña, André Devaux, Stefan Gläser, and Manoel Veiga Gutierrez with whom I had the pleasure to collaborate in smaller and bigger projects that did not directly find the way into this thesis but helped to open my mind and look at my research from different perspectives.

Many thanks go to Christian Mertens for the excellent and reliable aid with technical issues, Diana Nordhaus for her help with many administrative issues, and the employees of the electronics and mechanics workshops for the usually quick and always professional implementation of even unusual wishes.

Thank you very much, Peter Noçon, for proof-reading the original manuscript and for the very helpful hints concerning the English language.

Most of all, however, I wish to thank my wife Tanja, my son Justus as well as Justus' grandparents. Thank you so much for making the exciting but also risky experiment "doctorate, job and family" such a success!

Münster, February 2012

Mike Woerdemann

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