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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

Springer

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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!

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Münster, February 2012 Mike Woerdemann

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