Institute for Advanced Studies
in Basic Sciences
Gava Zang, Zanjan, Iran

Diffractive Optics Applications in Optical Micromanipulation

PhD Thesis

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March 2009

Dedicated to

my family,

and to

the memory of the late Professor Galieno Denardo

Abstract

This thesis describes the optical trapping and manipulation of arbitrary arrays of microparticles in two and three dimensions as well as the arbitrarily shaped objects based on the use of Diffractive Optical Elements (DOEs). A new method to design the DOEs has been used in this work, which enables individual fine strength tuning in each of the trap sites. This has allowed the dielectric particle assembly of three dimensional structures and manipulation of red blood cells in desired and controlled configurations.

The thesis is divided into three chapters: Diffractive Optical Elements, Optical Manipulation, and Experimental Results.

Chapter 1 contains a review of the history and theory of diffraction and diffractive optics. Computer simulated examples are considered to illustrate the theory. The predated main DOE design methods including the global optimization, the ray tracing, and the iterative methods are described. A full description of the spherical wave propagation and superposition method on which most of the experimental work is based will be presented. This chapter ends with an overview of the DOE implementation techniques.

Chapter 2 introduces the technique of optical manipulation. A brief introduction to the basic theory, the history, the basic setup for this purpose and an overview of the applications are given. We explain the use of DOEs to generate multiple and multi force arrays of optical traps as well as novel laser beams. The potential of the technique will be argued for by introducing several examples pointing to special applications. Finally, we will show the ability of the technique to manipulate red blood cells in a spatially controlled environment.

Chapter 3 reports several experiments which demonstrate the capabilities of the DOEs designed by spherical wave approach and projected onto the Spatial Light

Modulator (SLM) for generating multiple and multi force dynamic arrays of intensity spots and then optical trapping in such arrays. Details of the setup which is developed to carry out these tasks and the steps to built the setup are explained in the beginning of the chapter. The experimental results for the examples we investigate in chapter 2 computationally, will be presented to confirm the idea. These results consist of beam shaping through experiments that use DOEs, multiple and multi force trapping of microparticles in volume, and optical manipulation of red blood cells. Finally, the results of real time manipulation of red blood cells will be described. A graphical user interface for this stage is considered and will be introduced. This interface helps the user to acquire the real time image of the trapping plane and design the DOE for the desired configuration of the trapping points. The results are achieved by inserting an extension to the first setup enabling simultaneous viewing of the sample in two orthogonal observation planes.

Appendix A provides technical details on the SLMs and the specifications of the available products on the market. Appendix B contains the trap stiffness measurement methods.

Acknowledgment

There are so many whose encouragement and support have made this work possible and to whom I owe gratitude. They are either in Iran or in Italy, the places I worked on my Ph.D. project.

First of all, I would like to thank my supervisors, Professor Dan Cojoc and Professor Mohammad Taghi Tavassoly, for their endless enthusiasm and ideas and for the opportunity they provided me to move forward in my research. I thank Professor Cojoc for introducing me to the fantastic fields of diffractive optics and optical manipulation. I have learnt a lot from him during my Ph.D. program. I have benefited endlessly from Professor Tavassoly's deep knowledge of optics, invaluable guidance and teaching experience that I was honored to be exposed to since the late 1990s, even before my Ph.D. research work.

My special thanks go to Professor Yousef Sobouti, the Founder and President of IASBS, whose intelligence, charisma, and vision helped many people at IASBS to study and work in an excellent environment and who taught me a great deal.

I partly dedicate this dissertation to the memory of the late Professor Galieno Denardo, the former leader of the optics and photonics program and the ICTP-IAEA STEP program at the Abdus Salam International Center for Theoretical Physics (ICTP). I have benefited immensely from his positive influence and helps during my Ph.D. I am very grateful to him for being an inspirational and very supportive coordinator from ICTP side of the STEP fellowship. I am also thankful to Professor Guiseppe Furlan, the head of the ICTP TRIL program for providing me an extra visit of the LILIT group to pursue further the project.

I am grateful to Dr Miltcho Danailov for motivating and encouraging me to study this project and for his very thorough support. I would like to thank Dr Enrico Ferrari for his endless friendship and assistance. I have enjoyed his company during my visits to Italy.

I am also grateful to the Head of the English Language Section at IASBS, Mr Bahman Farnudi, for helping me improve my English during my M.Sc. and Ph.D. years. He is one of the nicest and most perceptive people I know; many IASBS students have benefited from his excellent knowledge of the English language over the years.

I must also express my gratitude to many other people including LILIT and laser lab group members past and present in Elettra, and the Optics Group members at IASBS. Working in the friendly atmosphere of LILIT has been a great experience and I would like to thank every single member there. I thank all my friends at IASBS for making me feel very happy during my M.Sc. and Ph.D. years. I cannot name them because there are simply too many of them.

My thanks also go to the staff of IASBS, the staff of Elettra synchrotron and on the other side of Trieste town to the staff of ICTP, for helping me with all of my administrative needs in a cheerful and friendly manner. They were always there to help. In particular, I would like to thank Ms Dorettea Calligaro, the secretary of the STEP program for her impressive assistance.

I would also like to thank the other members of the examination committee for reading this thesis. They have been helpful with their comments and suggestions. I would also like to thank other faculty members at IASBS who taught courses that were relevant to my Ph.D. research.

More personally, my very special thanks go to my dear family, my parents, my brothers and my sisters for their love, endless patience, encouragement and support. This thesis is also dedicated to them.

Zanjan
Ali-Reza Moradi
March 2009

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