

# FOREWORD

This book is the outcome of years of collaboration among the three coauthors. The collaboration resulted in a number of papers, whose most significant results compose the major portion of this book. The principal coauthor is Dr. Yiqi Zhang. He joined the postdoctoral research station of Electronic Science and Technology at Xi'an Jiaotong University in 2012, under the supervision of Prof. Yanpeng Zhang, who is in charge of the “Quantum Control of Multi-Wave Mixing-Key Scientific and Technological Innovation Team” of the Shaanxi Province. In the past few decades, Prof. Y.P. Zhang and his research team generated a lot of notable scientific results, owing to a solid foundation and inspiring academic atmosphere, which provided abundant nourishment for quick development of younger researchers. Prof. Milivoj Belić is team’s international collaborator, who started collaborating with Dr. Y.Q. Zhang during his stay in Germany. Prof. Belić is professor in physics at the Texas A&M University at Qatar and the team leader of the Qatar Nonlinear Science Initiative. Thanks to the strong support for research by the Qatar National Research Fund, Dr. Y.Q. Zhang was able to visit Doha for extended periods in the past few years.

The book is a summary of coauthors research during the past five years, and the results are obtained and published jointly. The results involve not only analytical analysis but also extensive numerical simulations. The book covers a series of research topics in photonics of high current interest, including photonic topological insulators, optical rogue waves, Airy beams, Talbot effect, optical vortices, and other. The contents of the book are as follows.

In Chapter 1, the theory of physical models that will be expounded in this book is briefly introduced, which includes the derivation of the paraxial wave equation and the development of susceptibilities in atomic vapors.

In Chapter 2, the spatial periodic modulation of light is considered. By using the three-beam interference method and nonlinear phase shift modulation, we first investigate the photonic topological insulators in atomic vapors. Secondly, we investigate the Talbot effect resulting from periodically modulated multi-wave mixing. Thirdly, we discuss the nonlinear Talbot effect of rogue waves, which is a real nonlinear optical effect. The effects mentioned are generated in atomic or bulk dielectric media. In the last section of the Chapter, we discuss spatial light modulation in

discrete systems, resulting in the proposal of a beam combiner and splitter.

In Chapter 3, the role of nonlinearities in light modulation is discussed. We first demonstrate that optical vortices (as well as vortex pairs) appear in atomic vapors during propagation, when the third- and fifth-order nonlinearities (the so-called cubic-quintic competing nonlinearities) are considered. Secondly, the interaction of incoherent solitons in a photorefractive medium is investigated, in which the nonlinearity is saturable. The last topic discussed in this Chapter is that of azimuthons, which connect necklace solitons and optical vortices. In this part, we consider a weak Kerr nonlinearity, but with deep potentials of different symmetries.

In Chapter 4, the propagation dynamics of some novel optical beams is investigated, including Airy, Bessel-Gauss, and Laguerre-Gauss beams, as well as Fresnel diffraction patterns. In addition, Mathieu and Weber beams are discussed from the same point of view. The media in which these beams propagate include linear media, Kerr and saturable nonlinear media, and media with harmonic potential. We find that spatial solitons can be formed during interaction of Airy beams in nonlinear media, but the solitons do not exhibit the self-accelerating property. We also show how Airy wave functions, Airy breathers and (dual) Airy-Talbot effect can be considered from a unified viewpoint. Based on the harmonic potential model, we discover a new class of self-Fourier beams – the beams whose Fourier transform are the beams themselves. In addition, if the harmonic potential is inserted into the fractional Schrödinger equation, we show that a Gaussian beam propagates along a zigzag and a funnel-like path in one and two dimensions.

In Chapter 5, a summary of the book is presented, with an outlook on future investigations.

Such an arrangement of the book not only provides for a relative independence of topics discussed in different chapters, but also allows for immanent connections among the topics. We believe this book may become a useful reference for researchers in photonics. Despite our careful exposition, mistakes cannot be avoided in a book addressing very recent research advances. Therefore, comments and criticisms are welcome.

In addition to the support from the China Postdoctoral Science Foundation (Nos. 2014T70923 and 2012M521773), the project was also supported by the National Basic Research Program of China (No. 2012CB921804), the National Natural Science Foundation (Nos. 61308015 and 11474228), the Key Scientific and Technological Innovation Team of Shaanxi Province (No. 2014KCT-10), the Natural Science Foundation of Shaanxi province (No. 2014JQ8341), the Fundamental Research Funds for the Central Universities (No. xjj2013089), and the National Priorities Research Pro-

gram (projects No. 6-021-1-005 and 09-462-1-074) from the Qatar National Research Fund (a member of the Qatar Foundation).

Last but not least, the coauthors would like to express sincere appreciation to Prof. Song Jianping, Dr. Li Changbiao, Dr. Zheng Huaibin, Dr. Chen Haixia, Dr. Wang Zhiguo, Dr. Wang Ruimin, Dr. Wu Zhenkun, Dr. Milan S. Petrović, Dr. Wen Feng, Dr. Zhang Zhaoyang, Mr. Liu Xing, Miss Zhong Hua, Prof. Lu Keqing, Prof. Li Yuanyuan, and other scientists who generously helped us in obtaining research results exposed in this book. We also express our gratitude to Prof. Xiao Min from Arkansas University, Prof. Huang Tingwen from Texas A&M University at Qatar, and Prof. Zhong Weiping from Shunde Polytechnic. Finally, special thanks go to the Postdoctoral Office at Xi'an Jiaotong University, the China Postdoctoral Science Foundation, and the Science Press.

把Milan S.放到后面

Zhang Yiqi  
Xi'an Jiaotong University  
Xi'an 710049, China  
Email: zhangyiqi@mail.xjtu.edu.cn  
Homepage: <http://zhangyiqi.gr.xjtu.edu.cn>

Belić Milivoj  
Texas A&M University at Qatar  
23874 Doha, Qatar  
Email: milivoj.belic@qatar.tamu.edu  
Homepage: <http://science.qatar.tamu.edu/FacultyandStaff/Pages/default.aspx>

Zhang Yanpeng  
Xi'an Jiaotong University  
Xi'an 710049, China  
Email: ypzhang@mail.xjtu.edu.cn  
Homepage: <http://ypzhang.gr.xjtu.edu.cn>



# CONTENTS

《博士后文库》序言

FOREWORD

<b>Chapter 1 BASIC THEORY</b> .....	1
1.1 The paraxial wave equation .....	1
1.2 Susceptibilities in atomic vapors .....	3
REFERENCES .....	8
<b>Chapter 2 SPATIAL LIGHT CONTROL</b> .....	10
2.1 Photonic topological insulators in atomic ensembles .....	10
2.1.1 Theoretical model .....	11
2.1.2 Refractive index change .....	13
2.1.3 Topology of the photonic band gap structure .....	14
2.1.4 Photonic Floquet topological insulator .....	17
2.1.5 Discussion .....	20
2.1.6 Summary .....	23
Appendix I: Band structure of a honeycomb lattice – the tight-binding method .....	24
AI.1 Full band structure .....	24
AI.2 Strained band structure .....	27
Appendix II: Band structure of a honeycomb lattice – the plane-wave expansion method .....	29
2.2 Talbot effect of multi-wave mixings .....	31
2.2.1 Theoretical model and analysis .....	33
2.2.2 Suppression and enhancement conditions .....	35
2.2.3 Talbot effect of multi-wave mixing signals .....	37
2.2.4 Summary .....	42
2.3 Nonlinear Talbot effect from rogue waves .....	42
2.3.1 Basic rogue wave solutions .....	43
2.3.2 One-dimensional case .....	45
2.3.3 Two-dimensional case – linear Talbot effect .....	47
2.3.4 Two-dimensional case – nonlinear Talbot effect .....	51
2.3.5 Summary .....	57
2.4 Beam splitter and combiner based on Bloch oscillations .....	57
2.4.1 Waveguide array with $m \leq 0$ members modulated .....	59

2.4.2	Beam splitter based on the V-type modulated waveguide array	61
2.4.3	Beam combiner based on the $\Lambda$ -type modulated waveguide array	62
2.4.4	Summary	64
	REFERENCES	65
<b>Chapter 3</b>	<b>NONLINEARITY-INDUCED SPATIAL MODULATION</b>	<b>75</b>
3.1	Introduction	75
3.2	Optical vortices induced in atomic vapors	76
3.2.1	Theoretical model	77
3.2.2	Simple vortex and necklace incidence	79
3.2.3	Azimuthon incidence	81
3.2.4	The enhancement region	85
3.2.5	The liquid-like behavior of light and potential experiment	87
3.2.6	Summary	87
3.3	Interactions between incoherent solitons	88
3.3.1	Theoretical model	88
3.3.2	Numerical simulations and discussions	90
3.3.3	Summary	95
3.4	Azimuthons in weakly nonlinear waveguides	95
3.4.1	Theoretical model	95
3.4.2	Rotating localized dipoles	97
3.4.3	Rotating higher order localized modes	105
3.4.4	Summary	106
	REFERENCES	107
<b>Chapter 4</b>	<b>SPATIAL CONTROL OF NOVEL LIGHT BEAMS</b>	<b>114</b>
4.1	Introduction	114
4.2	Interactions between Airy beams	114
4.2.1	Theoretical model	115
4.2.2	Interactions of Airy beams	118
4.2.3	Interactions of nonlinear accelerating beams	121
4.2.4	Interactions of different accelerating beams	123
4.2.5	Summary	125
4.3	Airy beams with initial velocity	126
4.3.1	One-dimensional case	126
4.3.2	Two-dimensional case	130
4.3.3	A little discussion	132
4.3.4	Summary	132
4.4	Dual accelerating Airy-Talbot recurrence effect	133

4.4.1	Theoretical model	133
4.4.2	Numerical simulations	134
4.4.3	Superposition of finite-energy Airy beams	137
4.4.4	Summary	138
4.5	Nonparaxial self-accelerating beams	139
4.5.1	Theoretical model	140
4.5.2	Mathieu beams	141
4.5.3	Weber beams	143
4.5.4	Fresnel integrals	145
4.5.5	Summary	146
4.6	Fresnel diffraction patterns as self-accelerating beams	147
4.6.1	One-dimensional case	147
4.6.2	Two-dimensional case	152
4.6.3	Summary	153
4.7	Spatial control of light due to harmonic potential	154
4.7.1	Theoretical model	155
4.7.2	Solutions and numerical simulations	156
4.7.3	Chirped finite energy Airy beams	162
4.7.4	Two-dimensional Airy beams	166
4.7.5	Two-dimensional case—the rotating light	168
4.7.6	Summary	174
4.8	Self-Fourier beams	174
4.8.1	Theoretical model	175
4.8.2	Discussion	177
4.8.3	Analytical solutions	179
4.8.4	Self-Fourier beams	181
4.8.5	Summary	184
4.9	Spatial control in a fractional Schrödinger equation	185
4.9.1	Theoretical model	186
4.9.2	One-dimensional case	188
4.9.3	Two-dimensional case	191
4.9.4	Summary	192
	REFERENCES	193
<b>Chapter 5</b>	<b>CONCLUSION AND OUTLOOK</b>	202
5.1	Summary	202
5.2	Outlook	203
	REFERENCES	204
编后记		206