

APPLICATIONS

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# COMPUTATIONAL LIQUID CRYSTAL PHOTONICS

## FUNDAMENTALS, MODELLING AND APPLICATIONS

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# COMPUTATIONAL LIQUID CRYSTAL PHOTONICS

All Praise is due to Allah, and peace and blessings be upon. Prophet Muhammad and upon his family and his Companions.

The authors would like to dedicate this book to Prof. Ahmed Zewail for his continuous encouragement, support, and the opportunity to contribute to the Egypt National project of renaissance: Zewail City of Science and Technology.

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## **Preface**

The turn toward optical computers and photonic integrated circuits in high-capacity optical networks has attracted the interest of expert researchers. This is because all optical packet switching and routing technologies can provide more efficient power and footprint scaling with increased router capacity. Therefore, it is aimed to integrate more optical processing elements into the same chip and, hence, on-chip processing capability and system intelligence can be increased. The merging of components and functionalities decreases packaging cost and can bring photonic devices one step (or more) closer to deployment in routing systems.

Photonic crystal devices can be used functionally as part of a comprehensive all-photonic crystal-based system where, on the same photonic crystal platform, many functionalities can be realized. Therefore, photonic crystals have recently received much attention due to their unique properties in controlling the propagation of light. Many potential applications of photonic crystals require some capability for tuning through external stimuli. It is anticipated that photonic crystals infiltrated with liquid crystals (LCs) will have high tunability with an external electric field and temperature. For the vast majority of LCs, the application of an electric field results in an orientation of the nematic director either parallel or perpendicular to the field, depending on the sign of the dielectric anisotropy of the nematic medium. The scope of this book is to propose, optimize, and simulate new designs for tunable broadband photonic devices with enhanced high levels of flexible integration and enhanced power processing, using a combination of photonic crystal and nematic LC (NLC) layers. The suggested NLC photonic devices include a coupler, a polarization splitter, a polarization rotator, and a multiplexer-demultiplexer for telecommunication applications. In addition, LC photonic crystal-based encryption and decryption devices will be introduced and LC-based routers and sensors will be presented. In almost all cases, an accurate quantitative theoretical modeling of these devices has to be based on advanced computational techniques that solve the corresponding, numerically very large linear, nonlinear, or coupled partial differential equations. In this regard, the book will also offer an easy-to-understand, and yet comprehensive, state-of-the-art of computational modeling techniques for the analysis of lightwave propagation in a wide range of LC-based modern photonic devices.

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There are many excellent books on LCs; however, several of these concentrate on the physics and chemistry of the LCs especially for LC display (LCD) applications. In addition, many books on photonic devices have been published in the recent years. However, it is still difficult to find one book in which highly tunable photonic crystal devices based on LC materials are discussed with a good balance of breadth and depth of coverage. Therefore, the book will represent a unique source for the reader to learn in depth about the modeling techniques and simulation of the processing light through many tunable LC devices.

The primary audience for this book are undergraduate students; the student will be taken from scratch until he can develop the subject himself. The secondary audience are the business and industry experts working in the fields of information and communications technology, security, and sensors because the book intends to open up new possibilities for marketing new commercial products. The audience of this book will also include the researchers at the early and intermediate stages working in the general areas of LC photonics. The book consists of three parts: LC basic principles, numerical modeling techniques, and LC-based applications. The first part includes three chapters where the basic principles of waveguides and modes, photonic crystals, and liquid crystals are given. From Chapters 4 to 6, the numerical techniques operating in the frequency domain are presented. Among them, Chapter 4 presents the governing equations for the full-vectorial finite-difference method (FVFDM) and perfectly matched layer (PML) scheme for the treatment of boundary conditions. The FVFDM is then assessed in Chapter 5 where the modal analysis of LC-based photonic crystal fiber (PCF) is given. The FV beam propagation method (FVBPM) is presented in Chapter 6 to study the propagation along the LC-PCF-based applications. After deriving the governing equations, the FVBPM is numerically assessed through several optical waveguide examples. The conventional finitedifference time domain (FDTD) method in 2D and 3D, as an example of the numerical techniques operating in the time domain is presented in Chapter 7.

The third part consists of six chapters to cover the applications of the LC-based photonic crystal devices. From Chapters 8 to 10, the applications of the LC-PCF for telecommunication devices, such as couplers, polarization rotators, polarization splitters, and multiplexer–demultiplexers, are introduced. In addition, the LC-PCF sensors, such as biomedical and temperature sensors, are explained in Chapter 11. Photonic crystal-based encryption systems for security applications are covered in Chapter 12. Optical computing devices, such as optical routers, optical memory, and reconfigurable logic gates, are introduced in Chapter 13.

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