Current research into holography is concerned with applications in optically storing, retrieving, and processing information. Polarization holography has many unique properties compared with conventional holography, such as high efficiency, achromaticity, and special polarization properties. This book reviews the research carried out in this field over the last 15 years.

The authors provide basic concepts in polarization and the propagation of light through anisotropic materials, before presenting a sound theoretical basis for polarization holography. The fabrication and characterization of azobenzene-based materials, which remain the most efficient for the purpose, are described in detail. This is followed by a description of other materials that are used in polarization holography. An in-depth description of various applications, including display holography and optical storage, is given, and the book concludes with perspectives for the future. This book is an important reference for researchers.

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POLARIZATION HOLOGRAPHY

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Preface

In contrast to the conventional holographic process, in which intensity variations in an interference pattern between an object beam and a reference beam are recorded, polarization holography employs beams with two different polarizations for recording information. In this case, the polarization state of the resultant beam is recorded on a suitable medium. This process was discovered by Sh. D. Kakicheshvili, from Georgia (which was then part of the USSR). Currently there is only one monograph on polarization holography, namely that written in Russian by Kakicheshvili (Polyarizatsionnaya golografiya, Nauka, 1989). However, because of its complex presentation, this monograph is not easily amenable for application to practical work.

Polarization holographic storage has several unique properties: (1) it is possible to achieve theoretically 100% diffraction efficiency even in thin films; (2) the diffracted beams have unique polarization properties, depending on the polarization of the recording and read-out beams; (3) it is possible to fabricate polarization-sensitive optical elements; and (4) the optical elements fabricated with polarization holography are achromatic, allowing their use at all wavelengths.

Our book intends to fill a gap in the area of holography, and documents research done during the last two decades. High-capacity holographic storage remains a hot topic. This book is intended for scientists as well as students at graduate and postgraduate level. A basic undergraduate optics background is assumed, and a well-prepared undergraduate physics major will be able to appreciate the subtleties of polarization holography.

The chapters in the book are organized as follows.

In the first chapter, a description of the polarization of light is introduced. After discussing the different types of polarization, methods to describe light polarization such as the Jones matrix and Poincaré sphere are discussed, and a description of Stokes parameters is introduced.
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In the second chapter, we describe light propagation through polarizing systems. We utilize a matrix formalism to describe the propagation of light through anisotropic media in linear and circular coordinates. The coherency-matrix formalism as well as Mueller matrices are explained.

The third chapter provides the basic theory for polarization holography. Polarization modulation through an “interference” of two waves with orthogonal linear and circular polarizations is discussed. Experimental conditions under which these can be achieved are described. A coupled-mode theory for volume holography is also developed. A discussion of polarization holographic gratings with linear photoanisotropy follows. Properties of gratings recorded with orthogonal linear and circular polarized beams, gratings with both amplitude and phase modulation, reconstruction of the polarization of a light field with arbitrary polarization, and reflection polarization holograms are described. We also characterize the influence of a surface relief arising concomitantly with the anisotropic grating, providing a method of separating the contributions to the grating efficiency from the anisotropic and surface-relief gratings.

The fourth chapter is devoted to azobenzene and azobenzene-containing polymers, fabrication techniques and experimental results. There is a large amount of literature available on azobenzene systems. This chapter will discuss the different types and properties of the polymers, with particular reference to azobenzene polyesters. We discuss the cases of liquid-crystalline and amorphous polymers, measurement of thermal and light stability of the recorded information etc. We discuss polarization-holographic gratings in materials with linear and circular anisotropy. Again using the Jones-matrix formalism, we discuss the coexistence of both types of anisotropy and the dependence of the properties of the gratings on the ratio of the anisotropy to surface relief.

The fifth chapter discusses other non-azobenzene materials for recording photoinduced anisotropy. Silver halides, alkali halides, arsenic trisulfide, bacteriorhodopsin, organic dyes in polymer matrices and other non-azobenzene materials are discussed.

The sixth chapter describes applications of polarization holography: polarization-holographic elements for polarimetry, fabrication of polarization-sensitive optical elements, and display holography. The most important is, of course, storage of information. Systems to record bit-maps and multiplexing in polymer films are discussed.

The final chapter covers future prospects.

We are grateful to many of our colleagues, with whom we had collaborated for many years. In particular, we acknowledge our collaboration with S. Hvilsted, R.H. Berg, A.S. Matharu, T. Todorov, and Ts. Petrova and our
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colleagues at the Technical University of Budapest. We thank L. Lindvold for many useful discussions. The properties of the combined anisotropic and surface-relief gratings presented in this book are from the Ph.D. thesis of N. C. R. Holme, which we gratefully acknowledge. We also thank Michael Diegelmann for giving permission to use his program, in depicting the polarization states in chapter 1 (http://www2.fh-rosenheim.de/~diegelmann/index_English.htm#Polarisation). Special thanks are due to the technical staff who helped us over the years. Finally we thank Dr. Laszlo Gazdag for donating the Gabor medal whose holographic reconstruction is displayed on the cover.

We dedicate this book to Sh. D. Kakichashvili, who had the insight to envision vectorial holography.

L. Nikolova

P. S. Ramanujam
List of symbols and abbreviations

\( a \) azimuth of linear polarization
\( \beta \) latitude on the Poincaré sphere
\( \gamma \) longitude on the Poincaré sphere
\( \delta \) phase difference between interfering beams
\( \varepsilon \) ellipticity angle
\( \theta \) angle of incidence
\( \lambda \) wavelength of light
\( \phi \) phase of the electromagnetic wave
\( \psi \) rotation angle
\( \omega \) angular frequency of the electromagnetic wave
\( a_1, a_2 \) extinction coefficients for the light component polarized and perpendicular to the transmittance axis of the polarizer
\( \Lambda \) grating period
\( \Delta \Phi \) anisotropy in radians
\( \Delta n \) birefringence
\( \Delta n_{\text{lin}} \) linear birefringence
\( \Delta n_{\text{cir}} \) circular birefringence
\( \Delta h \) height of surface relief
\( \Delta \psi \) extra phase acquired in passing through \( \Delta h \)
\( \lambda_0 \) wavelength of light in vacuum
\( J_{xx}, J_{yy}, J_{yy}, J_{yz} \) elements of the coherency matrix
\( n_\parallel \) refractive index for light polarization parallel to the induced optical axis
\( n_\perp \) refractive index for light polarization perpendicular to the induced optical axis
\( n_0 \) isotropic refractive index
\( k_1, k_2 \) absorption coefficients for light polarized parallel and perpendicular to the transmission axis of the polarizer
Symbols and abbreviations

$S$  coefficient of scalar response (refractive index)
$L$  coefficient of linear anisotropy (refractive index)
$S_e$ coefficient of scalar response (absorption)
$L_e$ coefficient of linear anisotropy (absorption)
$s$  polarization of a light beam perpendicular to the plane of incidence
$p$  polarization of a light beam parallel to the plane of incidence
$D_\parallel$ optical density for light polarized parallel to the induced optical axis
$D_\perp$ optical density for light polarized perpendicular to the induced optical axis
$\Delta D$  difference in optical density
$a$  major axis of the polarization ellipse
AFM atomic-force microscope
Ag silver
AgBr silver bromide
AgCl silver chloride
AgHal silver halide
AgI silver iodide
Ar argon
$b$  minor axis of the polarization ellipse
bR, BR bacteriorhodopsin
BS beamsplitter
CCD charge-coupled device
d thickness of film
DCG dichromated gelatin
DG diffraction grating
DNO diamino acid – N°-substituted oligopeptide
DR1 disperse red
E ethanediol
HeNe helium–neon
HWP half-wave plate
$i$  imaginary number
JTC joint transform correlator
LC liquid crystal
LCD liquid-crystal display
LCP left-circularly polarized
LCSLM liquid-crystal spatial light modulator
Symbols and abbreviations

mW milliwatt
MG malachite green
P propanediol
PAP photoaddressable polymers
PBS polarization beamsplitter
PDG polarization diffraction grating
PEO polyethylene oxide
PMMA polymethyl methacrylate
PVA polyvinyl alcohol
QWP quarter-wave plate
RCP right-circularly polarized
$S_0, S_1, S_2, S_3$ Stokes parameters
SLM spatial light modulator
SRG surface-relief grating
$T_g$ glass-transition temperature
THF tetrahydrofuran
TN twisted nematic
TPMD triphenylmethane dye
UV ultraviolet
W watt
YAG yttrium–aluminum garnet
Xe xenon
$z$ direction of propagation