PROGRESS IN OPTICS

VOLUME XXI

EDITED BY

E. WOLF

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VOLUME XXI

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E. WOLF

University of Rochester, N.Y., U.S.A.

Contributors

D. MAYSTRE, L. A. LUGIATO
H. H. BARRETT, N. M. CEGLIO, D. W. SWEENEY
J. C. ENGLUND, R. R. SNAPP, W. C. SCHIEVE

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PREFACE

Just as its twenty predecessors, this volume presents reviews of current developments in several areas of optics and related fields.

The first article gives an account of some of the theories that have been developed in recent years for the analysis of properties of diffraction gratings with very small groove spacing, of the order of the wavelength of light. Such gratings are now frequently encountered in the laboratory. Scalar diffraction theories are inadequate for the analysis of their performance, because polarization properties of light cannot be ignored under these circumstances. Vector theories of diffraction gratings, such as those described in this article, must then be used.

The second article is concerned with the theory of optically bistable systems, i.e., of systems whose transmittance has two stable states. This subject has attracted a good deal of attention in recent years, because bistable systems are likely to find useful applications, for example as optical transistors or as memory elements.

The third article deals with the basic theoretical aspects of a technique that has found important uses in connection with numerous inverse reconstruction schemes. The unifying mathematical concept that underlies these techniques is the so-called Radon transform. It is, for example, at the heart of computerized medical tomography, which makes it possible to determine the detailed distribution of the attenuation coefficient of selected portions of a patient's body from measurements of the intensity of transmitted X-ray beams.

The fourth article deals with the theory and application of a method of coded imaging. Coded imaging is a two-step process of image reconstruction. In the first stage information about a source is generated by geometrical shadowing through a coded aperture. In the second stage the image is reconstructed by means of numerical or optical techniques. This procedure is mainly used with sources that generate very short wavelength radiation (e.g., X-rays), because such radiation cannot easily be imaged or re-directed by reflection or refraction. In the last two decades such techniques have been frequently used in nuclear medicine, in nuclear engineering, in inertial confinement fusion research, and in X-ray astronomy. The article deals with one particular technique of this kind, which uses Fresnel zone plates as the aperture and in which the decoding is performed optically, with coherent light.

The concluding article deals with certain properties that in recent years have been found to occur in a variety of non-linear phenomena. They are discussed here with special reference to the laser-driven non-linear ring cavity. In particular, the onset of instability, deterministic switching in the bistable regime, fluctuation dynamics, and the generation of deterministic chaos from instabilities are discussed, and examples are given of the remarkable period-doubling sequences that accompany the transition to chaos.

Although the individual articles are self-contained, the reader will undoubtedly note that several of the topics covered in the different articles are interrelated.

EMIL WOLF

Department of Physics and Astronomy
University of Rochester
Rochester, NY 14627, USA

January 1984

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E. WOLF, PROGRESS IN OPTICS XXI

I

RIGOROUS VECTOR THEORIES OF DIFFRACTION GRATINGS

BY

D. MAYSTRE

Laboratoire d'Optique Electromagnétique, Equipe de Recherche Associée au C.N.R.S. n° 597,
Faculté des Sciences et Techniques,
Centre de Saint-Jérôme, 13397 MARSEILLE CEDEX 13, France.

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§ 1. Introduction

Diffraction grating was born almost two centuries ago. Its father, an American astronomer, saw a spectrum produced by hairs placed in the threads of two parallel screws (RITTENHOUSE [1786]). However, it was not until 1821 that the first metallic grating was ruled by FRAUNHOFER who found the famous grating formula giving the directions of diffraction (FRAUNHOFER [1821]). One century after the discovery of RITTENHOUSE, ROWLAND [1882] initiated the production of high quality ruled gratings. Recently there appeared a new type of diffraction grating, constructed by recording on a photoresist interference fringes produced by a laser source (RUDOLPH and SCHMAHL [1967], LABEYRIE and FLAMAND [1969]).

Indisputably, the diffraction grating is a valuable instrument for scientific research. Mainly, it is used for spectroscopy and filtering. Even though the holographic grating has not eliminated the classical, ruled grating which remains the most suitable for important applications, it has permitted a considerable extension of the use of gratings for industrial or scientific purposes: wavelength selectors for tunable lasers, selective surfaces for solar energy, masks for photolithography, beam sampling mirrors for high power lasers, spectrometers in extreme UV or X-ray regions for Space Optics (MAYSTRE, NEVIERE and PETIT [1980]).

Before the second world war, the pitch of the standard gratings was large with respect to the wavelengths of visible radiations, due to the difficulty of manufacturing high quality gratings having high space frequency. Under these circumstances, the properties of gratings do not depend, in practice, upon the polarization of the incident light. This explains why by far the major part of the theories dealing with these instruments are "scalar" and do not take the polarization into account (see for example BORN and WOLF [1965]). On the other hand, there exists experimental evidence that the distribution of energy among the various diffracted waves depends on polarization as soon as the wavelength to pitch ratio exceeds a number of the order of 0.2 (MADDEN and STRONG [1958]). Today, gratings having more than 1000 grooves per mm, i.e. with groove spacings lower than 1 μm, are commonplace. When these gratings are employed in the visible region, the wavelength of the light is of the order