Introduction to the Special Issue on Dynamic Gratings and Four-Wave Mixing

A grating is a material with spatially modulated optical properties. Mostly permanent periodic structures such as surface diffraction gratings, multilayer dielectric coatings, and volume holograms have been applied and investigated in classical optics [1]. An incident light wave is diffracted, scattered, or reflected at the grating elements resulting in secondary waves into certain directions due to constructive interference.

Various laser systems with sufficient power, developed since 1960, now can be used to modulate the optical poperties of matter in real time. Two intersecting light beams produce a dynamic grating in a material placed in the interference region. The grating spacing and amplitude are controlled by the intersection angle and beam power. Two excitation beams with different frequencies result in a propagating grating. Dynamic or transient gratings disappear after the inducing light source has been switched off.

The modulation of the optical properties in a dynamic grating can be described phenomenologically by an intensity-dependent absorption coefficient or refractive index. To obtain a better understanding, the change of the optical properties has to be related to some material excitation, e.g., temperature, carrier density in a semiconductor, or space charge in a photorefractive material. No special crystal symmetry as in frequency doubling is required to observe such intensity-dependent effects so that gratings can be induced in any material. However, the photosensitivities vary in a broad range.

Dynamic gratings have been induced in a large number of solids, liquids, and gases, and are detected by diffraction or "forced light" scattering of a third probing beam. Also, self diffraction of the light waves inducing the grating is possible. Waves diffracted into the directions of the incident waves give rise to amplitude and phase changes, in particular, beam amplification. Diffraction at propagating grating is accompanied by frequency shifts. In general, several diffracted waves are observed.

The Bragg condition implies that one diffracted beam is dominant using an optically thick grating. The combined interference and diffraction effect therefore corresponds to four-wave mixing (FWM) in the language of nonlinear optics [2], [3]. The process is called degenerate if the frequencies of the three incident waves and the generated wave are equal. Degenerate four-wave mixing (DFWM) is a simple method to achieve phase conjugation [4]–[6], i.e., to generate a wave with a phase which is the complex conjugate of one of the incident waves.

A phase-conjugated wave develops in a time-reversed way compared to the incident wave. Wavefront distortions can be healed thus by passing the phase-conjugated wave through the scatterer, restoring the incident beam quality. This healing process has been known in holography [7] for some time, but the use of instantaneous recording materials has made it possible to deal with rapidly time-dependent effects, e.g., atmospheric turbulence. Real-time phase conjugation has stimulated a great deal of interest in four-wave mixing materials recently.

The explicit consideration of the material response forming a dynamic grating allows a simple visualization of various nonlinear optical phenomena. Many physicists, chemists, and electrical engineers are not very familiar with nonlinear polarization and susceptibilities. They often have, however, some understanding of gratings and diffraction from work with grating spectrometers or electron and X-ray diffraction at crystalline solids. With such experience, four-wave mixing can be understood in terms of grating excitation and beam diffraction. Moreover, the relate results from acoustooptics [1], [5] and holography [7]–[9]. The abundant theoretical results in diffraction theory [1], [10] can be transferred to nonlinear optics.

Laser-induced dynamic gratings and four-wave mixing have been studied for the past 20 years and more than 500 papers have been published up to 1985. A summary and introduction into this rapidly expanding field is given in [11]. The present issue is intended to collect the most recent results and to indicate directions of further work.

Most papers deal with material investigations. Special materials can be found not only in papers under the corresponding index subheading, but are also discussed in other places. One aim is to find systems with high photosensitivity, i.e., large third-order nonlinear sucspetibilities. Also, forced light scattering is now an often-used technique to investigate other material properties and various physical and chemical processes, e.g., long-range electronic energy transport in inorganic dielectric crystals has been detected with this technique for the first time.

Technical applications in photonic devices seem possible using beam deflection, modulation, and amplification by wave mixing. The technological potential of dynamic gratings in real-time holography still has to be exploited. Phase conjugators based on Brillouin processes and distributed feedback dye lasers are already available as commercial systems.

Many people helped to prepare this issue. Special thanks are due to the authors of the papers and the referees. The editor of the JOURNAL, Dr. W. Streifer, provided invaluable organizational guidance, Prof. A. E. Siegman, Stanford University, suggested the title of the Special Issue, and Prof. H. Gerritsen, Brown University, gave a lot of scientific advice. I would like to also thank C. Thiel for secretarial assistance.

0018-9197/86/0800-1194$01.00 © 1986 IEEE

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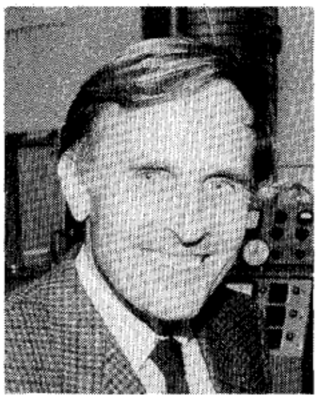

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