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EMIL WOLF

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Preface

This volume presents five review articles of areas of current research interest in several branches of modern optics.

The first article, by U. Keller, discusses the progress which has been made in recent years in ultrafast pulse generation, using solid-state lasers. In the last decade, the performance of compact ultrafast solid-state lasers has been improved by several orders of magnitude in pulse duration, in average power, in pulse energies and in pulse repetition rates. In this article these and other breakthroughs are discussed. The article provides both the expert and the non-expert with an overview of this rapidly advancing field.

The second article, by A.V. Shchegrov, A.A. Maradudin and E.R. Méndez, reviews research on the scattering of electromagnetic waves from randomly rough surfaces. Unlike earlier investigations in this field, the article covers the more difficult subject of multiple scattering from such surfaces and discusses more recently discovered effects such as enhanced backscattering and enhanced transmission.

In the next article, by Y. Ishii, an interesting advance in interferometry is described, namely a phase-measuring technique which uses direct frequency modulation of a laser diode source by changing the current. This technique has been implemented in holographic interferometry and in phase conjugate interferometry, for example.

The fourth article, by J. Gea-Banacloche, reviews the theory of quantum teleportation and the ways in which this intriguing quantum phenomenon has been experimentally demonstrated in optical systems. Among the topics covered are the relationship between teleportation of discrete and continuous variables, entanglement and teleportation, the difficulty of Bell measurements, and schemes for near-deterministic teleportation with linear optics. The limitations of current experiments and some questions of interpretation are also discussed.

The concluding article, by H.J. Carmichael, G.T. Foster, L.A. Orozco, J.E. Reiner and P.R. Rice, uses intensity–field correlation functions of the electromagnetic field as a tool for studying quantum fluctuations of light. The relationship between the correlation functions and quadrature squeezing is noted and conditions are developed to distinguish between classical and non-classical field fluctuations. The theoretical analysis is illustrated by examples such as the optical parametric oscillator, a cavity QED system and the composite system of a single atom coupled to an optical parametric oscillator. The results of experimental measurements on a cavity QED system are also reviewed.

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Contents

E. Wolf, Progress in Optics 46

Chapter 1

Ultrafast solid-state lasers

by

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Contents

List of symbols

A	pulse envelope normalized such that $\|A(z,t)\|^2 = P(z,t)$ (eq. (6.2))
$\tilde{A}$	$\tilde{A}$ is the Fourier transformation of A, i.e. $\tilde{A} = \int A(t)e^{-i\Delta\omega t}\,dt$ (eqs. (6.8) and (6.9))
A_A	laser mode area on saturable absorber
A_L	laser mode area in laser gain media
A_p	pump mode area
b	depth of focus or confocal parameter of a Gaussian beam
D	dispersion parameter (eq. (6.18) and Table 7), i.e. half of the total group delay dispersion per cavity roundtrip
D_g	gain dispersion (eq. (6.10)) and Table 7)
D_p	width of the pump source (i.e. approximately the stripe width of a diode array or bar)
$DR(t)$	impulse response of a saturable absorber mirror measured with standard pump probe (fig. 4)
E	electric field of the electromagnetic wave
$\widetilde{E}$	$\widetilde{E}$ is the Fourier transformation of E, i.e. $\widetilde{E} = \int E(t)e^{-i\omega t}\,dt$ (eqs. (6.6) and (6.7))
E_p	intracavity pulse energy
$E_{p,\mathrm{out}}$	output pulse energy
$E_{\mathrm{sat},A}$	absorber saturation energy (Table 3)
$E_{\mathrm{sat},L}$	laser saturation energy $E_{\mathrm{sat},L} = F_{\mathrm{sat},L} \cdot A_L$
$f(t)$	$f(t) = \frac{P(t)}{E_p}$, with $\int f(t)\,dt = 1$ (eq. (4.7))
f_{rep}	pulse repetition frequency
F	fluence, $F = \int I(t)\,dt$, in units of $\frac{\mathrm{J}}{\mathrm{cm}^2}$
$F_{\mathrm{sat},A}$	absorber saturation fluence (Table 3)
$F_{\mathrm{sat},L}$	laser saturation fluence (eqs. (3.1) and (3.2))
$F_{p,A}$	incident pulse fluence on saturable absorber (Table 3)
g	saturated amplitude laser gain coefficient
g_0	small signal amplitude laser gain

$h\nu$ photon energy
I intensity
I_A incident intensity on saturable absorber
$I_{\text{sat},A}$ absorber saturation intensity (Table 3)
k vacuum wave number, i.e. $k = 2\pi/\lambda$
k_n wave number in a dispersive media, i.e. $k_n = nk$
l total saturated amplitude loss coefficient. l includes the output coupler, all the residual cavity losses and the unsaturated loss of the saturable absorber
l_{out} amplitude loss coefficient of output coupler
l_s amplitude loss coefficient of soliton due to gain filtering and absorber saturation (eq. (6.53))
L_a absorption length
L_g length of laser gain material
M modulation depth of loss modulator (eq. (6.11))
M_s curvature of loss modulation (eq. (6.11) and Table 7)
M^2 M^2 factor defining the laser beam quality (eq. (3.3))
M^2_{slow} M^2 factor in the "slow" axis, parallel to the pn junction of the diode laser
M^2_{fast} M^2 factor in the "fast" axis, perpendicular to the pn junction of the diode laser
n refractive index of a dispersive media
n_2 nonlinear refractive index (eq. (6.20))
P power
P_0 peak power of pulse
P_{abs} absorbed pump power
$P_{\text{av,out}}$ average output power
q saturable amplitude loss coefficient (i.e. nonsaturable losses not included) (eq. (4.2))
q_0 unsaturated amplitude loss coefficient or maximal saturable amplitude loss coefficient (eq. (4.1))
q_p total absorber loss coefficient which results from the fact that part of the excitation pulse needs to be absorbed to saturate the absorber
q_s residual saturable absorber amplitude loss coefficient for a fully saturated ideal fast absorber with soliton pulses (eq. (6.46))
R reflectivity for intensity
S saturation parameter $S = \frac{F_{p,A}}{F_{\text{sat},A}}$ (Section 4.2.1)
t time
t_D time shift (eq. (6.37))
T time that develops on a time scale of T_R (eq. (6.1))

T_{out}	intensity transmission of the laser output coupler
T_R	cavity roundtrip time
V_p	pump volume
$W_{0,G}$	beam waist of a Gaussian beam (eq. (3.3))
$W_{0,\text{opt}}$	optimized beam waist for efficient diode pumping (eq. (3.5))
x	chirp parameter (eqs. (6.30) and (6.31))
z	pulse propagation distance
z_0	Rayleigh range of a Gaussian beam, i.e. $z_0 = \frac{\pi W_0^2}{\lambda}$
ΔA	change in the pulse envelope
ΔR	modulation depth of a saturable absorber mirror (fig. 5)
ΔR_{ns}	nonsaturable reflection loss of saturable absorber mirror (fig. 5)
ΔT	modulation depth of saturable absorber in transmission
ΔT_{ns}	nonsaturable transmission loss of saturable absorber
$\Delta\lambda_g$	FWHM gain bandwidth
$\Delta\nu_g$	FWHM gain bandwidth, i.e. $\frac{\Delta\nu_g}{\nu_0} = \frac{\Delta\lambda_g}{\lambda_0}$
δ_L	SPM coefficient (eq. (6.22) and Table 7)
ϕ	phase shift, $\phi = k_n \cdot z$, z: propagation distance
ϕ_{nl}	nonlinear phase shift per cavity roundtrip (eq. (6.33))
$\phi_s(z)$	phase shift of the soliton during propagation along the z-axis (eq. (6.51))
ϕ_s	phase shift of the soliton per cavity round trip (eq. (6.54))
$\phi_{\text{nl}}(z)$	nonlinear phase shift of a pulse with peak intensity I_0 during propagation through a Kerr media along the z-axis, i.e. $\phi_{\text{nl}}(z) = kn_2 I_0 z$
ψ	phase shift (eq. (6.28))
γ_A	absorber coefficient (eq. (4.13) and Table 7)
λ	vacuum wavelength of light
λ_0	center vacuum wavelength
λ_n	wavelength in a dispersive media with refractive index n, i.e. $\lambda_n = \lambda/n$
λ_{eff}	effective wavelength (eq. (3.4))
ν	frequency
ν_{pump}	pump photon frequency
ω	radian frequency
ω_0	center radian frequency
ω_m	modulation frequency in radians/second
Ω_g	half-width-half-maximum (HWHM) gain bandwidth of laser in radians/seconds, i.e. $\Omega_g = \pi\Delta\nu_g$ (eq. (6.3))
θ	divergence angle of a pump source (i.e. the beam radius increases approximately linearly with propagation distance, defining a cone with half-angle θ)
θ_G	divergence angle of a Gaussian beam, i.e. $\theta_G = \frac{\lambda}{\pi W_{0,G}}$ (eq. (3.3))

σ_A	absorber cross section
σ_L	gain cross section
σ_L^{abs}	absorption cross section
τ_A	recovery time of saturable absorber
τ_{Au}	FWHM of intensity autocorrelation pulse
τ_c	photon cavity lifetime
τ_L	upper state lifetime of laser gain material
τ_p	FWHM intensity pulse duration
$\tau_{p,min}$	minimal τ_p