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Simulation of Optical Soliton Control in Micro- and Nanoring Resonator Systems

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Preface

Praise be to Allah s.w.t… Peace and Blessing be to Prophet Muhammad s.a.w…

In preparation of this research book, we were in contact with numerous researchers and academicians. They have contributed toward the understanding and thoughts of Physics and communication systems link. In particular, we wish to express our sincere appreciation and gratitude to Prof. Dr. Preecha P. Yupapin from KMITL, Thailand, Prof. Dr. Noriah Bidin from Laser Centre, Ibnu Sina ISIR, and Dr. Saktioto from the Physics Department, Universiti Teknologi Malaysia for their motivations and support. Also, we like to thank our family members for their patience. Without their continued support and interest, the completion of this book would definitely have been impossible.

This research book serves to design and analyze the optical soliton control in micro- and nanoring resonator systems. Optical soliton control in communication and sensors is performed with the ring resonator systems described in the book. The ring resonator systems are optimized as optical tweezers for photodetection. Numerous arrangements and configurations of micro- and nanoring resonator systems are explained. The analytical formulation and optical transfer function for each model and the interaction of the optical signals in the systems are discussed. The book shows that the models designed are able to control the dynamical behavior of generated signals.

This research book consists of six chapters, namely as Introduction, Literature Review, Theory, Research Methodology, Results and Discussion, and Conclusion. The background of study, problem statements, scope, and significance of research is discussed in Chap. 1. The objectives of the research are also explained in details. Literature reviews of the research are discussed in Chap. 2. The characteristics of bright and dark solitons, temporal solitons, optical trapping, and historical perspective of ring resonators are described in this chapter. Chapter 3 explains the theoretical part of the research. The fundamental principles of ring resonator are discussed in details. The nonlinearity of the optical solitons is discussed based on the Kerr effect of optical fibre waveguides. The resonance characteristics of the fibre is also presented. Besides, the basic principles of SPM, SFG, and Z-transform methods are also explained in this chapter. The mathematical formulation, modeling, and description of add-drop and PANDA ring resonator systems are explained in Chap. 4. The derivation of add-drop and PANDA ring resonator systems arrangements are discussed precisely. The transfer function of each model designed is derived based on the actual practical device values. The flowcharts that perform the simulation processes are described. Chapter 5 explains the results and discussions of the research findings. All parametric effects toward the system performance are discussed in details. The optimization process for both add-drop and PANDA ring resonator systems are explained accordingly. At the end, the conclusions of this research work are described in Chap. 6.

Contents

Abbreviations and Symbols

Abbreviations

FSR	Free spectral range
FWHM	Full width at half maximum
GVD	Group velocity dispersion
IDRI	Intensity dependent refractive index
MRR	Microring resonator
NLS	Nonlinear Schrödinger
NRR	Nanoring resonator
PMMA	Polymethyl methacrylate
SFG	Signal flow graph
SHG	Second harmonic generation
SOA	Semiconductor optical amplifier
SPM	Self-phase modulation
XPM	Cross-phase modulation

Symbols

A	Amplitude
A_{eff}	Effective mode core area
a	Acceleration
B	Build-up factor
c	Speed of light
D	Delay dispersion parameter
dB	Decibel
dBkm^{-1}	Decibel per kilometre
E	Electric field
E_{add}	Add port
E_d	Drop port

E_{in}	Input port
E_t	Throughput port
E_1	Circulating field 1
E_2	Circulating field 2
E_3	Circulating field 3
E_4	Circulating field 4
F	Finesse
F_g	Gradient force
F_{net}	Net force
F_s	Scattering force
f	Frequency
f_o	Center frequency
GHz	Giga Hertz
h	Plank's constant (6.63 x 10^{-34} m^2kg/s)
I	Intensity
I_o	Peak intensity
k	Wave number
k_n	Propagation constant
L	Propagation distance
L_D	Dispersion length
L_{eff}	Effective length
L_L	Circumference of left ring
L_{NL}	Nonlinear length
L_R	Circumference of right ring
L_u	Smallest path length or the unit delay length
m	Mass
mW	miliWatt
N	Number of photon
n	Refractive index
nm	nanometer
ns	nanosecond
nL	Optical path length
n_{eff}	Effective refractive index
n_g	Group refractive index
n_o	Linear refractive index
n_2	Nonlinear refractive index
P	Dielectric polarization
P_L	Linear polarization
P_{NL}	Nonlinear polarization
P_t	Transmission power
p	Momentum
pm	pikometre
Q	Quality factor
R	Ring radius
R_L	Radius of left nanoring

R_R	Radius of right nanoring
s	Electron travelling distance
T	Unit delay
T_o	Pulse propagating time at initial input
t	Time
t_{ij}	Transmittance
u_1	Inertial velocity
u_2	Final velocity
v	Velocity
W	Watt
τ	Pulse duration
ϕ	Instantaneous phase shift of the pulse
ϕ_L	Linear phase
ϕ_{NL}	Nonlinear phase
κ	Coupling coefficient
λ	Wavelength
λ_o	Center wavelength
θ	Angle
θ_1	Incident angle
θ_2	Refractive angle
ω	Optical frequency
ω_0	Reference frequency
ω'	Instantaneous frequency
β	Propagation constant
v_c	Center frequency
γ	Coupling loss
μm	micrometer
μm^2	micrometer square
ϕ	Phase shift
ϕ_o	Linear phase shift
ϕ_{NL}	Nonlinear phase shift
*	Conjugate
α	Loss coefficient
β	Propagation constant
$\|t\|$	Coupling losses
φ_t	Phase of coupler
ε_o	Vacuum permittivity
χ_{eff}	Effective susceptibility of the medium
$\chi^{(1)}$	Linear susceptibility
$\chi^{(2)}$	Second-order susceptibility
$\chi^{(3)}$	Third-order susceptibility
Δf	Frequency shift
Δn	Change in refractive index

$\Delta\lambda$	Wavelength shift
$\Delta\phi$	Phase change
γ	Coupling loss
Γ	Length scale
3-D	Three dimensional

Abstract

Over the past few years, the development of optical soliton technologies has progressed rapidly. This research book has been written to design and analyze the optical soliton control in micro- and nanoring resonator systems. The add-drop and PANDA ring resonator systems have been proposed for optical soliton control in communications, sensors, and biological applications. The operating system consists of a modified nonlinear add-drop configuration system based on InGaAsP/InP fibre materials integrated with a series of nonlinear nanoring resonators. Numerous arrangements and configurations of micro- and nanoring resonator systems were designed. The analytical formulation and optical transfer function for each model designed were developed based on these configurations and Z-transform method was used to derive and prove the interaction of the optical signals for the systems. Both the add-drop and PANDA ring resonator systems could be optimized as optical tweezers for photodetection by controlling the input power, ring radii, and coupling coefficients of the systems. The system was tuned to trap and accelerate the particles. The system named as optical multiplexer can be used to optimize the channel capacity and security of the signals. In conclusion, this research shows that the models designed are able to control the dynamical behavior of the generated signals.