Contents

List of abbreviations — xi

List of notations — xiii

1 Introduction — 1

2 Fiber ring interferometry — 8

2.1 Sagnac effect. Correct and incorrect explanations — 8

2.1.1 Correct explanations of the Sagnac effect — 8

2.1.1.1 Sagnac effect in special relativity — 8

2.1.1.2 Sagnac effect in general relativity — 9

2.1.1.3 Methods for calculating the Sagnac phase shift in anisotropic media — 9

2.1.2 Conditionally correct explanations of the Sagnac effect — 10

2.1.2.1 Sagnac effect due to the difference between the non-relativistic gravitational scalar potentials of centrifugal forces in reference frames moving with counterpropagating waves — 10

2.1.2.2 Sagnac effect due to the sign difference between the non-relativistic gravitational scalar potentials of Coriolis forces in reference frames moving with counterpropagating waves — 10

2.1.2.3 Quantum mechanical Sagnac effect due to the influence of the Coriolis force vector potential on the wave function phases of counterpropagating waves in rotating reference frames — 11

2.1.3 Attempts to explain the Sagnac effect by analogy with other effects — 11

2.1.3.1 Analogy between the Sagnac and Aharonov–Bohm effects — 11

2.1.3.2 Sagnac effect as a manifestation of the Berry phase — 12

2.1.4 Incorrect explanations of the Sagnac effect — 12

2.1.4.1 Sagnac effect in the theory of a quiescent luminiferous ether — 12

2.1.4.2 Sagnac effect from the viewpoint of classical kinematics — 13

2.1.4.3 Sagnac effect as a manifestation of the classical Doppler effect from a moving splitter — 14

2.1.4.4 Sagnac effect as a manifestation of the Fresnel–Fizeau dragging effect — 15

2.1.4.5 Sagnac effect and Coriolis forces — 15

2.1.4.6 Sagnac effect as a consequence of the difference between the orbital angular momenta of photons in counterpropagating waves — 16

2.1.4.7 Sagnac effect as a manifestation of the inertial properties of an electromagnetic field — 16
2.1.4.8 Sagnac effect in incorrect theories of gravitation — 16
2.1.4.9 Other incorrect explanations of the Sagnac effect — 17
2.2 Physical problems of the fiber ring interferometry — 17
2.2.1 Milestones of the creation and development of optical ring interferometry and gyroscopy based on the Sagnac effect — 17
2.2.2 Sources for additional nonreciprocity of fiber ring interferometers — 20
2.2.2.1 General characterization of sources for additional nonreciprocity of fiber ring interferometers — 20
2.2.2.2 Nonreciprocity as a consequence of the light source coherence — 21
2.2.2.3 Polarization nonreciprocity: causes and solutions — 21
2.2.2.4 Nonreciprocity caused by local variations in the gyro fiber-loop parameters due to variable acoustic, mechanical, and temperature actions — 23
2.2.2.5 Nonreciprocity due to the Faraday effect in external magnetic field — 23
2.2.2.6 Nonreciprocal effects caused by nonlinear interaction between counterpropagating waves (optical Kerr effect) — 23
2.2.2.7 Nonreciprocity caused by relativistic effects in fiber ring interferometers — 24
2.2.3 Fluctuations and ultimate sensitivity of fiber ring interferometers — 24
2.2.4 Methods for achieving the maximum sensitivity to rotation and processing the output signal — 25
2.2.5 Applications of fiber optic gyroscopes and fiber ring interferometers — 26
2.3 Physical mechanisms of random coupling between polarization modes — 28
2.3.1 Milestones of the development of the theory of polarization mode linking in single-mode optical fibers — 28
2.3.2 Phenomenological models of polarization mode coupling — 30
2.3.3 Physical models of polarization mode coupling — 31
2.3.4 Inhomogeneities arising as a fiber is drawn — 32
2.3.4.1 Torsional vibration — 32
2.3.4.2 Longitudinal vibration — 33
2.3.4.3 Transverse vibration — 33
2.3.4.4 Transverse stresses — 34
2.3.5 Inhomogeneities arising in applying protective coatings — 34
2.3.6 Inhomogeneities arising in the course of winding — 34
2.3.7 Rayleigh scattering: the fundamental cause of polarization mode coupling — 35
2.4 Application of the Poincaré sphere method. . . — 35
2.5 Thomas precession. Interpretation and observation issues — 36
3 Development of the theory of interaction between polarization modes — 38
  3.1 Phenomenological estimates of the random coupling — 38
    3.1.1 Small perturbation method — 38
    3.1.2 Expanding the scope of the small perturbation method by partitioning
    the fiber into segments whose length is equal to the depolarization
    length — 40
  3.2 A physical model of the polarization mode coupling — 41
    3.2.1 A model of random inhomogeneities in SMFs with random twists of
    the anisotropy axes — 41
    3.2.2 Connection between the polarization holding parameter and statistics
    of random inhomogeneities — 42
    3.2.3 Polarization holding parameter in the case of random and regular
    twisting — 45
    3.2.4 Statistical properties of the polarization modes for fibers with random
    inhomogeneities — 47
  3.3 Evolution of the degree of polarization of nonmonochromatic
    light — 55
    3.3.1 Small perturbation method — 55
    3.3.2 A method for modeling random twists — 57
    3.3.3 A mathematical method for modeling random twists in the presence of
    a regular twist — 63
    3.3.4 Analytical calculation of the limiting degree of polarization of
    nonmonochromatic light — 68
    3.3.5 Increasing of the correlation length of nonmonochromatic light traveling
    through a single-mode fiber with random inhomogeneities — 69
  3.4 Anholonomy of the evolution of light polarization — 72

4 Experimental study of random coupling between polarization modes — 76
  4.1 A rapid method for measuring the output polarization state — 76
  4.2 Method for measuring the polarization beat length and
    ellipticity — 79
  4.3 Experimental comparison of the accuracy of different methods — 86
  4.4 Influence of winding of single-mode fibers on the amount of
    the polarization holding parameter — 89
  4.5 Experimental study of the polarization degree evolution of light — 92
  4.6 Method of fabricating ribbon single-mode fibers — 93
  4.7 Method for removing the effect of photodetector dichroism — 95

5 Fiber ring interferometers of minimum configuration — 98
  5.1 Polarization nonreciprocity of fiber ring interferometers — 98
  5.2 Fiber ring interferometers with a single-mode fiber circuit. . . — 107
5.3 Zero shift, deviation, and drift of fiber ring interferometers
5.3.1 Applicability conditions for the ergodic hypothesis
5.3.2 Influence of the amount of random twist of the fiber
5.3.3 Influence of the location of the random inhomogeneity
5.3.4 Influence of the mutual coherence of nonmonochromatic light in the main and orthogonal polarization modes at the point of inhomogeneity
5.3.5 Approximate calculation of the temperature zero drift
5.3.6 Calculation of the zero shift deviation of the FRI by the small perturbation method
5.3.7 Calculation of the zero shift deviation with the extended small perturbation method
5.3.8 Calculation of the zero shift deviation by the method of mathematical modeling of random inhomogeneities
5.3.8.1 Zero shift deviation of an FRI with a high-birefringence fiber
5.3.8.2 Zero shift deviation of an FRI with a low-birefringence fiber
5.3.9 Calculation of the zero shift deviation of FRIs
5.4 Domains of application of the different methods for calculating PN

6 Fiber ring interferometers of nonstandard configuration
6.1 New type of nonmonochromatic light depolarizer for FRIs
6.2 Zero drift and output signal fading in an FRI with a polarizer
6.2.1 Small perturbation method. The quasi-axis model
6.2.2 Extended small perturbation method
6.2.3 Method of mathematical modeling of random inhomogeneities in fibers
6.3 Fiber ring interferometers without a polarizer
6.3.1 FRIs with circularly polarized input light
6.3.2 Modulation method for removing the zero shift in a fiber ring interferometer without a polarizer
6.3.3 Fiber ring interferometer with a depolarizer of nonmonochromatic light
6.3.4 Fiber ring interferometer with a circuit made from a uniformly twisted fiber
6.3.5 Zero shift deviation in FRIs without a polarizer and with a circuit made from a high-birefringence fiber in a limited temperature range

7 Geometric phases in optics. The Poincaré sphere method
7.1 Application of the Poincaré sphere method
7.1.1 Analysis of the properties of the Pancharatnam phases. The Poincaré sphere
7.1.1.1 Type I Pancharatnam phase — 172
7.1.1.2 Type II Pancharatnam phase — 173
7.1.2 Birefringence in SMFs due to mechanical deformations — 175
7.1.2.1 Kinematic phase in SMFs — 175
7.1.2.2 Bending induced linear birefringence of SMFs — 176
7.1.2.3 Twisting-induced circular birefringence of SMFs. The spiral polarization modes — 176
7.1.3 Rytov effect and the Rytov–Vladimirskii phase in SMFs and FRIs in the case of noncoplanar winding — 177
7.1.3.1 Rytov effect in the FRI circuit fiber — 177
7.1.3.2 Rytov–Vladimirskii phase and PP2 in SMFs with noncoplanar winding — 179
7.1.3.3 Rytov phase detection in FRIs — 180
7.2 Polarization nonreciprocity in FRIs. Nonreciprocal geometric phase — 182
7.3 Determination of a polarization state ensuring the absence of NPDCM — 189
7.4 Criticism of unsubstantiated hypotheses relating to geometric phases — 191
7.5 Opto-mechanical analogies relating to light propagation in SMFs — 195
7.5.1 The analogy between the Rytov effect polarization optics and Ishlinskii effect in classical mechanics — 195
7.5.2 An opto-mechanical analogy of an SMF with twisting of the linear birefringence axes — 198

8 Time-dependent, nonlinear, and magnetic effects — 201
8.1 Influence of the second harmonic of the phase modulation frequency — 201
8.1.1 In-phase and quadrature components of the parasitic phase modulation — 201
8.1.2 Numerical estimates of the incidental phase modulation — 203
8.1.3 Optimal harmonic of the phase modulation frequency — 206
8.2 Experimental investigation of the piezo transducer’s nonlinearity — 207
8.3 Methods for removing the influence of the nonlinear Kerr effect — 209
8.4 Influence of random inhomogeneities on the Faraday zero shift deviation — 215

9 Relativistic effects in optical and non-optical ring interferometers — 220
9.1 Sagnac effect for waves of any nature in special relativity — 220
9.1.1 Sagnac effect in the laboratory frame of reference — 220
9.1.2 Sagnac effect in a rotating frame of reference. Zeno’s relativistic paradox — 223
9.2 Non-optical Sagnac sensors of angular velocity — 226
9.2.1 A ring interferometer based on slow acoustic or magnetic waves — 226
9.2.1.1 Advantages of using slow waves in ring interferometers — 226
9.2.1.2 Choosing an optimal frequency of the slow waves in ring interferometers — 227
9.2.1.3 A method for detecting the phase difference between counterpropagating waves in slow-wave ring interferometers — 229
9.2.2 A ring interferometer based on de Broglie waves of pions — 232
9.3 Influence of Thomas precession on the zero shift — 236
9.3.1 Thomas precession as a corollary of Ishlinskii’s solid angle theorem applied to the angle of relativistic aberration — 236
9.3.1.1 Thomas precession — 236
9.3.1.2 Ishlinskii’s theorem as a classical analogue of Thomas precession — 237
9.3.1.3 Observed rotation of an object rapidly moving in a circular path and Thomas precession — 238
9.3.1.4 Physical meanings of the Thomas precession and Ishlinskii angle — 241
9.3.2 Influence of Thomas precession on the zero shift of ring interferometers based on de Broglie waves of matter particles with spin — 241
9.4 Potential usage of FRIs for detecting fundamental effects — 243
9.4.1 Verification of the basic postulates of special and general relativity using FRIs — 243
9.4.2 Analysis of the possibility of detecting nonreciprocal effects with FRIs — 246

10 Conclusion — 250

Index — 299