Contents

Foreword xi

Series Editors’ Preface xv

Preface xvii

1 Introduction. Briefly on the History and Essence of the Problem 1
   1.1 Functions and main kinds of optical resonators 1
      1.1.1 Plane resonators 2
      1.1.2 Stable resonators 4
      1.1.3 Unstable resonators 5
   1.2 Some other sides of the problem of angular divergence 8
      1.2.1 The optical homogeneity of a medium 8
      1.2.2 Wavefront correction 8
      1.2.3 Briefly on the history of the problem 8

2 The Laws of Light-beam Propagation 10
   2.1 Fundamentals of the theory of multielement optical systems 10
      2.1.1 Ray matrix 11
      2.1.2 The simplest optical systems in the diffraction approximation 18
      2.1.3 Complex optical systems with lenses and Gaussian diaphragms 23
      2.1.4 General case of circular symmetry or simple astigmatism (orthogonal system) 27
      2.1.5 Polarization characteristics of coherent light beams 31
## Contents

2.2 Laws of propagation for major types of light beams  
2.2.1 Plane and spherical waves. The concept of phase velocity  
2.2.2 Gaussian beams  
2.2.3 Hermite and Laguerre beams with real parameters  
2.2.4 Hermite and Laguerre beams with complex parameters. Off-axis beams  

2.3 Angular divergence of radiation  
2.3.1 General  
2.3.2 Ideal sources  
2.3.3 Non-ideal sources with plane and spherical equiphase surfaces  
2.3.4 Other types of sources. On coherent and incoherent addition  
2.3.5 The simplest methods to reduce the divergence and its measurement  

3 Ideal Resonators  
3.1 General information on open resonators  
3.1.1 Basics and a little history  
3.1.2 Integral equation and mode spectrum of an arbitrary empty resonator  
3.1.3 Resonators with semitransparent mirrors and a homogeneous active medium  

3.2 Classification, equations and conditions of equivalence for ideal resonators  
3.2.1 Matrices of linear resonators  
3.2.2 Classification of resonators according to their ray matrices  
3.2.3 Integral equations and conditions of equivalence for ideal resonators  

3.3 Stable resonators  
3.3.1 General solution for resonators having round-trip wave matrices  
3.3.2 Empty stable resonators with infinite mirrors  
3.3.3 Stable resonators with mirrors of finite size  

3.4 Plane resonators  
3.4.1 Auxiliary diffraction problem  
3.4.2 Reflection from the open waveguide end  
3.4.3 Modes of a plane strip mirror resonator  
3.4.4 Plane rectangular and circular mirror resonators  
3.4.5 Mode nomenclature and polarization
3.5 Unstable resonators 135
  3.5.1 A brief historical account 135
  3.5.2 Geometric approximation 137
  3.5.3 Unstable resonators with Gaussian mirrors 144
  3.5.4 Sharp-edge resonators in the diffraction approximation 147
  3.5.5 Unstable resonators with a partially ‘smoothed’ edge 154

4 Basic Concepts Concerning the Properties of Real Resonators and the Processes Occurring in Them 159
  4.1 Some experimental data and their discussion 159
    4.1.1 Early observations of lasing 159
    4.1.2 Beam divergence of plane-resonator solid state lasers 162
    4.1.3 On the theory of real resonators 164
  4.2 Principal kinds of perturbations and parasitic effects 167
    4.2.1 Conditions for the applicability of the perfect resonator model to the description of real lasers 167
    4.2.2 Interfaces 170
    4.2.3 Resonators with arbitrarily located diaphragms 173
    4.2.4 Self-supporting and induced parasitic oscillations 177
  4.3 Large-scale aberrations and light scattering 181
    4.3.1 Axis displacement resulting from resonator misalignment 181
    4.3.2 Stable resonators with arbitrary aberrations. Perturbation theory 184
    4.3.3 Plane resonators with large-scale aberrations 191
    4.3.4 Large-scale aberrations in unstable resonators 200
    4.3.5 Light scattering 205
  4.4 Mode competition in the onset of lasing and in steady-state operation 210
    4.4.1 Initial stage in the onset of lasing in low-diffraction-loss resonators. Iterative method 211
    4.4.2 Onset of oscillations in unstable resonators 216
    4.4.3 Multimode generation: basic concepts and its nature 220
    4.4.4 Spatial competition of modes with different axial indices 225
    4.4.5 Transverse mode competition 232
  4.5 Pump energy conversion efficiency in laser resonators 239
    4.5.1 ‘Local’ approach to the evaluation of efficiency 239
    4.5.2 Total energy balance of excitation and lasing 244
# Contents

4.5.3 Lasers with unstable resonators and local response media \(250\)
4.5.4 Lasers with a non-local response medium \(255\)

## 5 Resonator Applications and Special Configurations \(263\)

5.1 Basic resonator types \(264\)
5.1.1 Main factors determining the choice of resonator type \(264\)
5.1.2 Continuous-wave lasers \(266\)
5.1.3 Pulsed lasers. Principle of construction and parameter selection of unstable resonators \(271\)
5.1.4 Specific features of lasers with unstable resonators \(274\)

5.2 Methods of the angular selection of radiation \(281\)
5.2.1 Attempts at solving the divergence problem with low-diffraction-loss resonators \(282\)
5.2.2 Resonators with angular selectors \(285\)
5.2.3 Angular selection through reduction of the Fresnel number \(291\)

5.3 Resonators of lasers with controlled spectral and temporal characteristics \(297\)
5.3.1 General \(297\)
5.3.2 Oscillators with three-mirror unstable resonators \(300\)
5.3.3 Control with an external signal \(306\)

5.4 Specific resonator configurations \(310\)
5.4.1 Unidirectional oscillation and unstable ring resonators \(311\)
5.4.2 Resonators with corner reflectors \(314\)
5.4.3 Field rotation resonators \(321\)
5.4.4 Resonators of lasers with annular active medium cross section \(328\)

## 6 The Simplest Causes of Aberrations and Methods of Wavefront Correction \(337\)

6.1 Thermal deformations of resonators \(337\)
6.1.1 Thermal deformations of opaque mirrors \(339\)
6.1.2 Thermal deformations of semitransparent mirrors and output windows \(344\)
6.1.3 Thermal effects in circular active elements of solid state lasers \(349\)
6.1.4 Consequences of thermal aberrations in solid state lasers and attempts at their compensation \(354\)
6.1.5 Methods of reducing thermal resonator deformations \(358\)
## Contents

6.2 Optico-mechanical and holographic methods of wavefront correction. Stimulated scattering-based lasers  
6.2.1 Optico-mechanical correction systems 365  
6.2.2 Holographic methods of wavefront correction 370  
6.2.3 Amplifiers and oscillators based on stimulated scattering 377  
6.3 Wavefront conjugation 382  
6.3.1 Concept and possibilities of the method 382  
6.3.2 WFC by means of a Fourier filter 390  
6.3.3 Standard version of four-wave interaction 394  
6.3.4 Forward interaction 399  
6.3.5 Backward stimulated scattering and loop arrangements 404  

Appendix Paraxial Theory of Systems with Astigmatic Elements 415  

References 421  

Index 435