

Contents

Title Page	I
Abstract	VI
List of publications	VIII
Abbreviations	X
List of Tables	XI
List of Figures	XII
1. Introduction	1
1.1 History of quantum optics.....	2
1.2 Objectives.....	4
1.3 Outline of the work.....	5
1.4 Quantization.....	7
1.4.1 Quantization of electromagnetic field.....	7
1.5 Quantum state.....	9
1.5.1 Number or Fock state.....	10
1.5.2 Coherent state.....	10
1.6 Dynamics of a system.....	12
1.6.1 Heisenberg-Langevin equation.....	12
1.6.2 Master equation.....	13
2. Review of optical, optomechanical systems and nonclassical effects	14
2.1 Introduction.....	15

2.2 Optical and optomechanical systems.....	16
2.3 Optical and mechanical resonators.....	17
2.3.1 Optical resonator.....	17
2.3.2 Mechanical resonator.....	18
2.4 Basic cavity optomechanics.....	20
2.4.1 Radiation pressure and optomechanical coupling.....	20
2.4.2 Cavity cooling.....	22
2.5 Quasi probability distribution.....	25
2.6 Nonclassical effects.....	26
2.6.1 Squeezing.....	26
2.6.1.1 Types of squeezing.....	27
2.6.1.2 Inequalities of squeezing.....	27
2.6.2 Antibunching.....	30
2.6.2.1 Inequalities of antibunching.....	31
2.6.3 Entanglement, EPR steering and Bell states.....	32
2.6.3.1 The inequalities of two mode quantum entanglement.....	33
2.6.3.2 The inequalities of three and four mode entanglement.....	36
2.6.3.3 Inequalities of quantum steering and Bell states.....	37
3. Nonclassical effects in quadratically coupled OMS	38
3.1 Introduction.....	39
3.2 The Model Hamiltonian and its solution.....	40
3.3 Quadrature Squeezing.....	43
3.3.1 Single mode squeezing.....	43
3.3.2 Compound mode squeezing.....	46

3.3.3	Spin squeezing.....	48
3.3.4	Sum and Difference squeezing.....	49
3.4	Quantum Statistics.....	50
3.4.1	Single mode statistics.....	50
3.4.2	Intermodal statistics.....	51
3.5	Entanglement.....	52
3.5.1	Lower order entanglement.....	52
3.5.2	Higher order entanglement.....	54
3.6	Numerical solutions.....	55
3.7	Summary.....	57
4.	Nonclassical properties of coupled cavity OMS	60
4.1	Introduction.....	61
4.2	System description.....	62
4.3	Quantum dynamics.....	63
4.4	Quantum squeezing.....	65
4.4.1	Lower order single mode squeezing.....	65
4.4.2	Higher order single mode squeezing.....	67
4.4.3	Intermodal squeezing.....	68
4.5	Particle statistics.....	71
4.5.1	Lower order antibunching.....	71
4.5.2	Higher order antibunching.....	73
4.6	Intermodal entanglement.....	75
4.6.1	Lower order two mode entanglement.....	76
4.6.2	Higher order two mode entanglement.....	79

4.6.3 Three mode entanglement.....	81
4.6.4 Four mode entanglement.....	86
4.6.5 Numerical solutions.....	88
4.7 Summary.....	92
5. Nonclassicalities in PT-symmetric coupled micro-cavities	95
5.1 Introduction.....	96
5.2 Model Hamiltonian.....	97
5.3 Details of \mathcal{PT} -symmetry theory.....	99
5.4 Analytical solution.....	100
5.5 Numerical solution.....	102
5.6 Quadrature squeezing.....	103
5.6.1 Single mode squeezing.....	103
5.6.2 Compound mode squeezing.....	106
5.6.3 Principal and normal squeezing.....	107
5.7 Intermodal entanglement.....	112
5.7.1 Lower order entanglement.....	112
5.7.2 Higher order entanglement.....	116
5.8 EPR Steering.....	120
5.9 Summary.....	122
6. Optical bistability in coupled micro-cavities	124
6.1 Introduction.....	125
6.2 Physical system.....	126
6.3 Steady state solution.....	127

6.4 Optical bistability.....	128
6.5 Possibility of all optical switching.....	131
6.6 Optical memory.....	133
6.7 Power spectrum	134
6.8 Summary.....	136
7. Optically induced transparency and tunable Fano resonance in micro-cavities	138
7.1 Introduction.....	139
7.2 The Model.....	140
7.3 Quantum dynamics.....	142
7.4 Forward transmission and backward reflection spectra.....	145
7.5 Asymmetric Fano line shape.....	149
7.6 Summary.....	152
8. Conclusions and Future Scopes	154
8.1 Conclusions of the work.....	155
8.2 Future scopes of the work.....	159
Appendix A	160
Appendix B	161
Appendix C	162
Appendix D	163
Bibliography	164