Chapter 8

Conclusions and Future Scopes

Recently, the studies on different nonclassical and non-linear effects are very much interesting and potentially impactful. These states have fundamental insight and also promising applications in quantum communication. Considering all these facts we have illustrated the practicability for generation of various nonclassical effects in optical and optomechanical systems. In chapter 3 and 4, nonclassicalities in single cavity and two cavity OMSs have been studied via solving system Hamiltonians both analytically and numerically. These nonclassicalities have potential applications in low noise signal production, cryptographic key distribution, macroscopic entangled state generation, state transfer etc. The possibility of the enhancement of nonclassicalities has been investigated via PT- symmetric micro-cavities setup, discussed in chapter 5. The PT-symmetry system has close inter-connection with OQSs. DPT is observed in the dynamics of OQS. Different nonclassicalities significantly varies during DPT. In chapter 6, we have reported the possible applications via optical bistability, sideband generation. Bistability is useful for optical memory, efficient optical switching and threshold power limiter. In chapter 7, other important applications are described by OIT and Fano resonance. In view of this investigation, we have enlisted the major outcomes of the work in next section.

8.1 Conclusions of the work

The main outcomes of the present work are epitomized as follows:

1. Different nonclassical effects are observed experimentally for different optical and optomechanical systems. The same has been theoretically established by using moment based nonclassical criteria.

2. The optical and optomechanical systems are studied here have some intrinsic advantage over other system which are useful for single photon source, generation of macroscopic nonclassical state via squeezing and entanglement.
3. The system Hamiltonian is solved analytically and numerically and nonclassical features in weak, moderate and strong coupling regime are studied.
4. The nonclassical properties studied here are of both lower and higher in order. Although, experimental evidence for higher order effects are very small till now. But higher order study has much importance than lower order. For lower order, degree of nonclassicalities is very weak and difficult to detect. For higher order studies it is found that degree of nonclassical states enhances significantly. Again, for higher order degree of nonclassicalities increases as order grows.
5. The degree of nonclassical effects is studied here for different optical and optomechanical systems, can be controlled by system parameters such as coupling strength, photon hopping strength, Kerr nonlinear strength, weight factor and phase of the input states and optical gain-to-loss ratio.
6. In quadratically coupled OMS, photon field mode shows Poissonian statistics, phonon mode shows super- Poissonian statistics but photon-phonon compound mode shows sub- Poissonian statistics i.e. antibunched states.
7. Mechanical squeezed state is observed for quadratically coupled OMS. In higher order degree of squeezing degree increases with order number but time period of fluctuations decreases. Due to nonlinearity of the dielectric constant of the membrane placed in the middle of the cavity, squeezing factors of the mechanical mode exhibits collapse-revival phenomena. The number of revival pattern increases with order number.

8. Difference and sum frequency generation are possible for quadratically coupled OMS via difference and sum squeezing. Spin squeezing is also possible for either S_x or S_y direction, which may be useful for reduction of noise in optical signal.
9. For couple cavity OMS nonclassical effects are observed only for compound mode but not for single mode (except single mode higher order squeezing). The degree of nonclassicality is prominent for intra-cavity compound mode rather than inter-cavity compound mode.
10. Three mode and four mode entanglement are observed in the dynamics of couple cavity system, the entangled state can be manipulated via phase of the input state. This would be useful for quantum metrology via phase precision. The generation of multimode entangled state also confirms the state transfer from intra-cavity modes to inter-cavity modes via photon hopping.
11. In parity-time symmetric coupled micro-cavity system, single mode squeezing is possible for passive cavity field mode which is also verified via principal and normal squeezing and also for passive-active compound mode. The degree of squeezing is enhanced for unbroken PT-symmetry regime as compared to broken regime. This study also opens new window for enhancement of squeezing effect via PT-symmetry architecture.
12. Entangled state generation is possible for PT-symmetry micro-cavity system. This study also shows that EPR steerable state signifies stronger correlation as compared to entangled states between two cavity field modes. The EPR steering shows asymmetric nature which will be useful for quantum computation, especially for quantum key distribution.

13. Higher order side band generation is possible for PT-symmetry micro-cavity system, which is established via FFT. The spectral power and number of side band can be tuned via photon tunnelling strength and Kerr nonlinearity.
14. Optical bistability is observed in PT-symmetry micro-cavity system. The bistable nature is controlled via photon tunnelling strength between the cavities. This effect is prominent at EP or PT-symmetry breaking point.
15. The steady state mean passive cavity photon number of PT-symmetry coupled micro-cavity system, shows symmetric nature around zero cavities detuning for weak Kerr-nonlinearity but shows asymmetric in nature for comparable Kerr-nonlinear strength. The zero window intensity can be tuned via photon tunnelling strength. This is useful for designing all-optical switch, memory element and optical sensor.
16. Optically induced transparency is studied in the dynamics of coupled micro-cavity system in over and critical cavity loading regime. The transmission profile exhibit symmetric dip-peak-dip spectral structure and transparency window can be tuned via photon tunnelling strength.
17. At over coupling regime and for passive-passive cavity configuration, the transmission profile shows a dip at zero probe detuning. The dip intensity is controlled by photon tunnelling strength and gain-to-loss ratio.
18. The forward transmission rate and backward reflection rate are more for passive-active cavity system as compared to passive-passive cavity system. So, one can tune both the rates via controlling gain-to-loss ratio.
19. The transmission spectra for passive-active cavity system shows sharp asymmetric line shape structure which indicates the presence of Fano resonance.

The line shape profile can be tuned via photon tunnelling. The contrast of the Fano line structure is so high to satisfy the optimum condition for Telecom system.

Specifically, our work provides a significant role in optical communications, quantum computation and different nonclassical state generation.

8.2 Future scopes of the work

In the present thesis work, we have reported the generation, enhancement of nonclassical and nonlinear effects in a theoretical framework. As methodology enlarged and techniques developed, the present study can be extended in various ways to demonstrate experimentally. Some future extensions of this work are as follow:

1. The study reported here is based on analytical and numerical solution. As different optical and optomechanical systems are experimentally realizable. So, there is a possibility to verify the results experimentally.
2. Possibility for entangled state generation at macroscopic regime.
3. Different nonclassical effects (EPR steering, Entanglement) can be studied for open system quantum formalism.
4. Possibility of designing optical sensor and optical switch.
5. Verifying optomechanically induced transparency (OMIT), optomechanically induced absorption (OMIA) and production of slow light in different OMSs.
6. Similar method can be adopted to study cavity-magnon system.
7. Magnon-induced transparency, Magnon-bistability can be investigated in detail for low power devices.