Chapter VI

Conclusions

In this thesis we have investigated the effects of nonlinear interactions of light with matter on the coherence properties of the light fields in some specific examples. The examples studied in this thesis have immense application potentials.

In Part A of the thesis we considered the classical propagation of electromagnetic pulses through a one-dimensional nanostructure of a nonlinear photonic crystal and the effect of the nonlinearity on the spectrum of the propagating pulses. The novel properties of photonic crystals to prohibit light of certain frequencies, or allow it in certain directions only at certain frequencies, or localize light in specific areas or at specific frequencies have made them indispensable for the development of optical devices. They hold a lot of promise in the use of light as information carrier instead of electrons, making it possible to provide higher data bit transmission in a faster and more reliable way than the current opto-electronic devices. Other potential applications of photonic crystals point to a fast control of light-by-light (as in a nonlinear mirror and/or an optical switch) and ultimate miniaturization of microdevices down to nanoscales. By breaking the symmetry in the periodicity of a photonic crystal, one can create a microcavity wherein strong localization of light and hence lasing action can be obtained.

The specific structure studied in Chapter II has both the second- and third-order susceptibilities present. Our model for nonlinear interactions is similar to the one developed by Hashizume et al. [N. Hashizume, M. Ohashi, T. Kondo, and R. Ito, J. Opt. Soc. Am. B 12, 1894-1904 (1995)], but is fully vectorial with each component of the field analyzed separately and allows the treatment of propagation of short pulses of finite bandwidth through the structure. Our results [A. K. Hafiz and R. Ghosh, to be published] show interesting nonlinear spectral modifications under appropriate conditions in the reflected and transmitted pulses. In the absence of nonlinearities in the structure we see phase-shifts in the reflected and transmitted fields due to the grating structure of the one-dimensional photonic
crystal (1-dPC). The presence of a strong external pump at the second harmonic frequency (SHF) results in large phase-shifts and field amplification of the fundamental frequency (FF) through a third-order nonlinear interaction between the two fields inside 1-dPC. In the case when only a strong FF beam is incident on the structure, phase-shifts in the reflected and transmitted FF pulses are seen as an outcome of a second-order second harmonic generation process (SHG) followed by a third-order interaction of the FF with the generated SHF. The experimentally observed shifts [R. Ghosh, A. K. Hafiz, P. Monnier, C. Cojocaru, F. Rainery, A. Levenson, and R. Raj, “Blue shift in a one-dimensional photonic crystal due to interference of second- and third- order nonlinearities”, in Proceedings of the Seventh International Conference on Optoelectronics, Fiber Optics and Photonics: Photonics-2004, Kochi, India, December 2004] in the spectra of a pulse reflected off an AlGaAs/AlOx nonlinear 1-dPC match very well with that in our simulated spectra. Investigations of these structures have been performed in the classical domain so far. Quantum nonlinear optics in photonic crystals is also very promising. These nonlinear structures can serve as sources of light with nonclassical properties, as predicted by Sakoda [K. Sakoda, J. Opt. Soc. Am. B 19, 2060 (2002)]. The SHG process in a planar nonlinear waveguide with a corrugation on the top of the waveguide can be used to control squeezing of the FF [D. Tricca, C. Sibilia, S. Severini, M. Bertolotti, M. Scalora, C. M. Bowden, and K. Sakoda, J. Opt. Soc. Am. B 21, 671 (2004)], where the corrugation reproduces a photonic band-gap structure.

In Part B of the thesis we studied the nonlinear light-matter interactions in the problem of the spectrum of a multimode laser. Though the laser emission above threshold is “intense” and hence may be treated as a classical field, the coherence properties of the field have quantum origins. We have probed the effects of mode competition in the statistical properties of the light in the two modes in the simplest example of a multimode laser. The two-mode lasers have found numerous applications in optical transmission and signal-processing systems. Generation of high-repetition-rate optical pulses can be made possible by using a dual wavelength light source, or two discrete laser diodes, where the beating of the two wavelengths generates a high frequency sinusoidal signal [P. V. Mamyshev, S. V. Chernikov, and E. M. Dianov, IEEE J. Quant. Electron. 27, 2347 (1991)]. This signal can then be
compressed into short optical pulses using the nonlinearity and dispersion in an optical fibre. Such pulses can be made use in developing ultrafast optical switches in signal-processing systems. Further, in the case of a two-mode laser, the phase noise and the linewidth can be controlled by means of the degree of cross-coupling between the modes.

In Chapter III, we considered a two-mode laser system in which the population inversion in the active medium is eliminated adiabatically [A. K. Hafiz and R. Ghosh, J. Opt. B: Quantum Semiclass. Opt. 6, 276 (2004)]. Our approach rigorously applies only to class-A lasers (gas lasers) for which the inversion dynamics is sufficiently fast. From the quantum Master equation for the field density matrix we obtain the mean-value equations for the field amplitudes and the steady-state solutions for the fields under the semiclassical approximations. On linearizing the Master equation in the vicinity of the steady-state solutions we get the Master equation in terms of the fluctuating fields. From the linearized Master equation we construct the quantum Langevin equations for the fluctuating fields. We then compute the spectrum of the laser by taking the Fourier transform of the cross-correlation of the two fields with the assumption of random fields. The numerical results show that the fundamental heterodyned linewidth varies inversely with the nonlinear cross-coupling between the two-modes for constant gain when the output power of each mode is held constant by decreasing the self-saturation coefficient. Then at long times the two-mode laser does not behave as a free-running laser as the phase fluctuations tend to saturate because of the non-linear cross-coupling. The heterodyned linewidth shows the usual decrease when the output power of each mode increases with increase in the gain, while the nonlinear self-saturation and cross-coupling coefficients are held constant. The linewidth increases with increasing the cross-coupling term when both the gain and self-saturation coefficients are held constant and hence the output power in each mode decreases, or when the gain is keeping the output power and self saturation of each mode constant. The beat-note linewidth is also calculated analytically and it shows complete agreement with the numerical results.

In Chapter IV, we calculated the spectrum of fluctuations in the intensity difference of the two-mode laser. Starting from the two-time correlation function for the difference in intensities of the two output modes we derive the spectrum using the approach given by

The spectrum of fluctuations in the intensity difference of the two modes shows *squeezing* of noise. The squeezing strongly depends on the cross-coupling between the two modes. The suppression in the noise increases with the increase in the cross-coupling term. It is also seen that the squeezing of noise increases with the increase in the gain and output power while the cross-coupling is held constant. A corresponding noise augmentation is seen in the spectrum of fluctuations in the intensity-sum of the two output modes with the increase in the gain and output power. When the power of the two modes is held constant by compensating the increase in the cross-saturation term with an equal decrease in the self-saturation terms, the squeezing of noise again increases.

In Chapter V, we formulated the problem for the analysis of the effect of the atomic-memory on the two-mode laser system. In a three-level model we included the atomic decay and the pumping in the Master equation for the combined atom-field density matrix. The Raman-type two-photon interaction is also taken into account. We calculated the steady-state values of the fields and atomic polarization in the linear regime. It is possible to compute the spectrum of the laser using this formulation [A. K. Hafiz and R. Ghosh, to be published].

Our theoretical predictions in Part B of the thesis can be tested in appropriate experiments.