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Topic: Light Matter Interaction in Periodic Nanostructures

Abstract:

This thesis is an attempt to understand the effects of interactions of light with matter in periodic nano structures. One dimensional photonic crystals (1-D PCs) are choice of interest for specific linear and nonlinear interactions. 1-D PCs are well recognised for their potentials for confining and guiding light in periodic nano/micro structures.Nanophotonics is fast emerging area of research around the world. For the past couple of decades, researchers have shown keen interest both theoretically as well as experimentally in the field of light-matter interaction inside photonic crystals (PCs). With the advancement in the existing technologies, development of accurate photonic structures has become possible. The role of PCs in the optical networks makes them indispensable for communication technology. The study on the nonlinear interactions inside PCs is highly important from the perspective of all-optical device design. The substitution of electronic elements with all-optical devices will lead to high data bit rate transfer, low data loss and faithful signal processing. PCs offer fast control of light by light based on the slow group-velocities. The focus of our research has been on the understanding of the nature of interaction between the propagating short electromagnetic pulses and one-dimensional nonlinear photonic crystals (1D NPC).

In Chapter 1 of the thesis we give a concise description of the different types of periodic nanostructures with a brief history on the development of photonic bandgap structures. Various theoretical approaches to analyze the propagation of electromagnetic waves across PCs are discussed. Nonlinear properties of the medium and spectral characteristics of the incident pulse are briefly described.

In Chapter 2 we probe the propagation of the electromagnetic waves through one dimensional photonic crystal and analyse the nature of interaction. The transfer matrix method (TMM) is used to understand propagation of light through the structure. TMM has excellent ability to solve the complex nature of photonic crystal by computing transmittance and reflectance of the layered structures in a wide range of wavelengths and at very thin dimension. We elaborately discuss the formation of TMM in general together with the vector model of transfer matrix and effective index method to understand various structural properties as well as complex linear and nonlinear interactions.

In Chapter 3 we present a specific linear structural property of 1-D PC in the form of omnidirectional reflector. Understanding of the reflection and transmission properties for any incident angle and for both transfer-electric (TE) and transfer-magnetic (TM) polarizations lead to the design of an omnidirectional reflector (ODR) using one-dimensional photonic heterostructure. Chromatic linear dispersion in the constituent material in the desired wavelength range is one of the biggest obstacles in ODR designing using bi-layer photonic crystal. We probe the influence of dispersion on the structural properties first and then formulate a simple solution to achieve the ODR at the wavelength range of interest. We consider an ambient medium for our studies which is dispersive at the desired wavelength range. Taking material combinations of SiO_2 and GaSb as

low and high index medium and realistic material parameters a perfect ODR is designed in the 1480-1680 nm wavelength range.

Chapters 4-6 deal with the nonlinear interaction of coherent light pulse with 1-D PCs. We focus on the interaction of ultra short pulses inside 1D PCs with second and third order nonlinearities. We analyse the spectra of the reflected and transmitted pulses that may exhibit nonlinear second harmonic generation, phase distortions and other modifications, with potential applications in all-optical signal-processing.

In Chapter 4 we investigate the second order nonlinear properties of a quadratic photonic crystal in the process of efficient second harmonic generation. The ultra-short pulse propagation and nonlinear second harmonic generation under the undepleted pump approximation in a quadratic nonlinear photonic crystal (NPC) is probed. The double resonance condition emerged as an effective way of achieving phase matching in photonic crystals. This condition is explained with the help of effective index approach. Selecting unique set of material combination GaInP/InAlP as alternating nonlinear and linear layers and implementing double resonance condition as an effective way of achieving perfect phase matching condition, optimized parameters for high conversion efficiency is accomplished. The sensitiveness of these parameters is also well analyzed.

Chapter 5 deals with the cascaded nonlinear interactions arising from second order nonlinearities in a 1D - Photonic crystals. The cascaded second order processes have attracted the researchers as an alternative to third order nonlinearities. A weak signal pulse operating at a particular frequency is seeded with a strong pulse operating at second harmonic (SH) frequency in GaInP/InAlP photonic crystal. The structure is designed in such manner so that the interaction of both pulses takes place at a particular phase mismatch condition. The intensity of SH pulse controls the excitation of signal pulse and at particular input SH intensity the signal pulse start to exhibit pulse compression. The dependency of pulse compression on the structural dispersion, group velocity mismatch and the input intensity are well examined.

Finally, in Chapter 6 we study the interaction in third-order nonlinear medium. We analyse the spectral characteristics of an ultra-short pulse as it propagates through a Kerr one-dimensional nonlinear photonic crystal. The self-interaction of the pulse with the nonlinear periodic structure leads to the self phase modulation at a precise wavelength and at a high peak input. As_2-S_3/Bi_2S_3 nonlinear 1-D PC is selected for the study. The As_2-S_3 is a Chalcogenide material possessing very high nonlinearity as compared to other semiconducting materials. The spectra of the transmitted and reflected pulses at different wavelength regimes in the photonic crystal with and without material dispersion exhibits rapid oscillation. This effect in the spectrum originates from the two photon absorption process resulting in the intensity dependent self phase modulation in a narrow spectral regime. We have also investigated the possible applications for the observed effects.