수치분산관계식에 의한 광자결정의 광학적 컬 비선형성 분석

Analysis of Optical Kerr Nonlinearity in Photonic Crystals by Numerical Dispersion Relation

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The characteristic propagation of an electromagnetic (EM) wave inside a photonic bandgap (PBG) structure is determined by the energy-momentum dispersion relation. For example, the electric field-enhancement at PBG edges is understood in terms of low group velocity and dispersion anomaly of propagating EM wave. While an analytic expression of dispersion relation, providing a Bloch index, is readily available for an infinite period structure of PBG, a dispersion relation is numerically obtained from the measured transmission coefficient in case of a finite period PBG structure. In practice, the numerical dispersion relation (NDR) is very useful in tailoring PBG structures when we are interested in efficient nonlinear optical (NLO) harmonic generations in a PBG structure, since NDR allows us to find the spectral locations of fundamental and harmonics near bandgap edges to achieve a phase matching.[1] In fact, Galisteo-López *et al.* compared the dispersion relation measured by a white light interferometry and the calculated NDR of a three-dimensional PBG structure, and found that the agreement was remarkable.[2] The NDR analysis is further extended to obtain an explicit relation between the real and the imaginary components of an EM wave emerging from a PBG structure by use of a Kramers-Krönig relation.[3]

While all-optical switching at bandgap edges [4],[5] and defect mode, [6],[7] originating from optical Kerr related nonlinearity, has been demonstrated experimentally in a PBG structure, NLO analysis of the beam propagating properties based on the NDR was not pursued, mainly due to the difficulty in obtaining an analytical dispersion relation. In this paper, we utilize the NDR to investigate the optical Kerr changes in two 1-D finite period photonic bandgap structures, namely, a Bragg reflector (BR) and a photonic crystal microcavity (PCMC). The BR is a 1-D finite period photonic bandgap structure without a defect layer, and the PCMC is in a structure of two identical BRs sandwiched symmetrically with a defect layer-between, hence exhibiting an optical defect mode. We report three important findings. First, the singularity predicted to occur at bandgap edges of a BR by a Bloch index is removed. Second, the optical properties, based on the dispersions of linear and nonlinear refractive indices, of a defect mode and bandgap edges in a PCMC are properly described. In particular, optical Kerr nonlinearity is found to be more enhanced at defect mode than at bandgap edges, which is understood when the density of modes and the EM field localization are taken care of in describing a third order nonlinear optical process in a periodic structure. Third, the NLO transmission property associated with the optical Kerr nonlinearity is investigated and compared for the bandgap edge of a BR and the defect mode of a PCMC. The NLO refractive index change required to achieve for a transmission change from 100 % to 10 % is numerically simulated.(Fig.1)

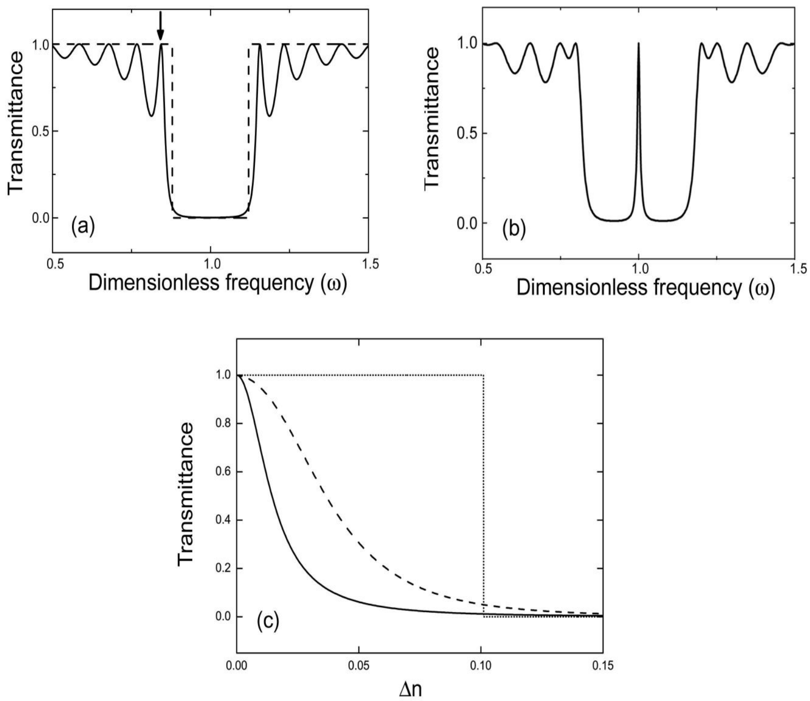

Fig.1 Numerically simulated transmission spectra of (a) a finite BR (solid curve) & an infinite BR (dashed curve), and (b) a finite PCMC. Numerically simulated transmission changes at the low-energy bandgap edge of the BR (dashed curve) & the defect mode of the PCMC (solid curve). As a reference, that of the infinite BR is shown as the dotted curve.

This work was supported by the Brain Korea 21 project at Ewha Womans University.

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