PHOTONIC BAND GAP STRUCTURES IN PLANAR NONLINEAR WAVEGUIDES: APPLICATION TO SECOND HARMONIC GENERATION

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Abstract

The properties of photonic band gap structures are discussed in view of their applications to second harmonic generation.

In integrated optics, waveguides offer the advantages of lateral confinement of the field and mode dispersion for phase-matching adjustment using different polarisations for the fundamental and second harmonic fields [1]. However, inter-modal dispersion generally leads to poor mode overlap in the transverse direction, thus making this phase mismatch compensation technique convenient only for materials with large nonlinear coefficient [2].

The use of a medium with periodic linear properties in the form of photonic band gap (PBG) structures can present some advantages. The linear properties of photonic band-gaps (PBG's) can be used to design efficient second-order interaction schemes. The main properties of interest for this kind of application in bulk are the possibility to use the dispersion of the structure to obtain perfect phase matching and the increased density of modes (DOM) that the structures exhibit at transmission resonance peaks when the spatial pulse length is much longer than the length of the structure. These properties have been discussed in a number of papers [3] and we will only briefly discuss them.

Fig. 1 shows the DOM as a function of frequency with the transmission spectrum superimposed, for a structure made alternating two layers of refractive index \( n_1 = 1 \) and \( n_2 = 1.5 \) and thicknesses \( d_1 = \lambda_0/4 \) respectively with \( \lambda_0 = 1 \mu m \). Simple inspection shows that the DOM has maxima at the frequencies corresponding to peaks of transmission. The DOM maximum is larger corresponding to the first transmission peak before a stop band. At the successive transmission peaks away from the stop band, DOM exhibits maxima which decrease with the position of the peak moving away from the stopband. The effective nonlinear coefficient can be shown to be proportional to the DOM [4] and is therefore higher at transmission peaks.

The second very interesting property of the structure is the possibility to add to the dispersion of the material with which the layers are made, the dispersion due to the geometry of the structure (form dispersion). Because in general the material dispersion increases with increasing frequency while the form dispersion decreases, it is possible in
a number of situation to compensate for material dispersion realizing perfect phase-matching. It has been shown [4] that the structure dispersion can be easily derived from the phase of transmission as can be calculated, for example, by using the transfer matrix formalism (6). An effective index can be derived for a finite structure (composed by a finite number of layers) so that the phase matching condition corresponds to equalize the effective indices for the fundamental and second harmonic wave in correspondence of peaks of transmission, so that

\[ n_{\text{eff}}(\omega) = n_{\text{eff}}(2\omega) \]  

Relation (1) can be expressed using the Bloch phase \( \beta(\omega) \) corresponding to the infinite structure (7) according to the relation

\[ 2\beta(\omega) = \beta(2\omega) \]  

It is therefore very easy to design structures which maximise phase-matching in correspondence of peaks of transmission where also the DOM has maxima.

A few examples can show how to use this strategy. Fig. 2 shows the situation that one must realize to have efficient second-order interaction. The transmission spectrum is shown which has the first maximum at the frequency corresponding to the fundamental frequency and the second maximum before the second stop-band at the frequency corresponding to the SH wave. Efficient SH generation can be predicted in this case. An experiment has been performed in which a GaAlAs/AlAs structure has been designed to have a reasonable \( \chi^{(2)} \) coefficient growing the crystal in the (100) direction and

\[ \text{Figure 1: DOM}(N_0) \text{ (upper curve) and transmittance } (T) \text{ (lower curve) as a function of the normalized frequency.} \]