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CONVERSION EFFICIENCY OF SECOND HARMONIC GENERATION IN ONE-DIMENSIONAL PHOTONIC CRYSTAL BASED ON ISOTROPIC MATERIAL

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The investigation of second-harmonic generation in a one-dimensional photonic crystal was carried out. The calculation of the $\chi^{(2)}$ – grating recording in a periodic system consisted of air and glass layers and second-harmonic generation in it was performed. The frequency conversion efficiency at different wavelengths of the first harmonic was estimated.

Keywords: one-dimensional photonic crystal, second harmonic generation, optical nonlinearity, conversion efficiency.

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1. Introduction

There is intense interest in the work on the second harmonic generation in isotropic media. Nonlinear materials traditionally used for frequency doubling optical radiation nonlinear materials are quite expensive and difficult to handle, although capable of converting radiation into the second harmonic with an efficiency of about 50–60%. At the same time, isotropic media allow you to create structures and objects of almost any complexity of forms and structures, but do not provide the efficient conversion of radiation into the second harmonic.

Second harmonic generation in one-dimensional photonic crystal has been well studied, but this study was done only for non-linear media. For example, in Ref. [1], second-harmonic generation was attained in a one-dimensional photonic crystal with a conversion efficiency of about 1%. In another study, the conversion efficiency was calculated for the second harmonic nonlinear in a photonic crystal [2]. The conversion efficiency was 10^{-2}–10^{-3}.

Second harmonic generation in isotropic media is difficult to realize because of the lack of such media in second-order nonlinearity, and because of implementation of phase-matching condition. At the same time, for the case of a one-dimensional photonic crystal, phase matching is realized automatically. In spite of the inversion symmetry in isotropic media, it is also possible to make an effective second harmonic generation. Second harmonic generation in an isotropic medium was first observed in 1981, when second harmonic generation was accidentally found via neodymium laser radiation in germanium-silicate fibers

[3,4]. In this case, the conversion efficiency was low and amounted to about 10^{-8}. Further, in 1987, a mechanism was proposed for explaining the emergence of second-order nonlinearity in isotropic media [5]. According to the theory, radiation propagation in a fiber at the first and the second harmonics occurs if ordered reorientation defects with $\chi^{(2)} \neq 0$, which subsequently causes second harmonic generation under irradiation only the first harmonic [6]. To test this hypothesis, an experiment was made with an optical fiber, which has achieved an efficiency of converting the radiation into the second harmonic of 0.03 %.

In this work, we offer a theoretical study of $\chi^{(2)}$ –grating formation in one-dimensional photonic crystal with the subsequent frequency conversion of this grating.

2. Second harmonic generation in one-dimensional photonic crystal

2.1. Making $\chi^{(2)}$ lattice in one-dimensional photonic crystal

According to ref.[5], second-order nonlinearity may appear in an isotropic medium if we have an electromagnetic wave with nonzero average cube field, <E3>≠0. If we illuminate an isotropic medium simultaneously by the first and second harmonic radiation, we get the total field with a nonzero average cube field, and in such an environment, we can create a $\chi^{(2)}$ grating with following amplitude:

$$\chi^{(2)}(R) = \alpha E_{2\omega}(R) E_{\omega}^{*}(R) E_{\omega}^{*}(R), \tag{1}$$

where the coefficient α must be determined experimentally and is much smaller than unity.

We have done a simulation of $\chi^{(2)}$–grating formation process in 1D photonic crystal using a software package MEEP [7]. The structure of one-dimensional photonic crystal "glass-and-air" was given. The refractive index of air was equal to 1.0, and refractive index of glass was equal to 1.5. The thickness of glass and air gaps layers was taken equal to 0.266 μm and $\lambda/6$=0.177 μm, which was taken equal to $\lambda/4$ and $\lambda/6$ for radiation with a wavelength of 1.064 μm – is the first harmonic of neodymium laser. A thickness ratio corresponding to the refractive index of glass is required to align the optical paths in the glass and in the air.

To generate a second order nonlinear coefficient ($\chi^{(2)}$) in the structure, we illuminate it simultaneously by the fundamental harmonic and doubled frequency radiation for different wavelengths. Calculated intensity distributions of both harmonics inside photonic crystal are shown on the Fig. 1. Two fundamental wavelengths were taken for an example: 1.060 μm and 1.266 μm.

One can see that the character of the distribution is quite different for first and second harmonics. If we know field distribution for both harmonics, we can calculate a $\chi^{(2)}$– grating inside a glass, according to formula (1). The resulting $\chi^{(2)}$–grating is depicted on the Fig. 2. Factor α in (1) was equal to 0.01.

This figure shows that the $\chi^{(2)}$ grating is formed non-uniformly along the entire length of the photonic crystal and is absent in air gaps, because of absence of $\chi^{(3)}$-nonlinearity.

2.2. Conversion efficiency of second harmonic generation in one-dimensional photonic crystal

After the $\chi^{(2)}$ – grating is formed in the photonic crystal structure, we simulate a second harmonic generation if we have at the input only fundamental harmonic radiation. Fig. 3(a-b) and Fig. 4(a-b) show the ration of second-harmonic intensity at the output of the photonic crystal to the input intensity of first harmonic on different wavelengths, for example 1.266, 1.246, 1.226, 1.206 μm. The frequency of 0.08 in MEEP units corresponds to the first harmonic.

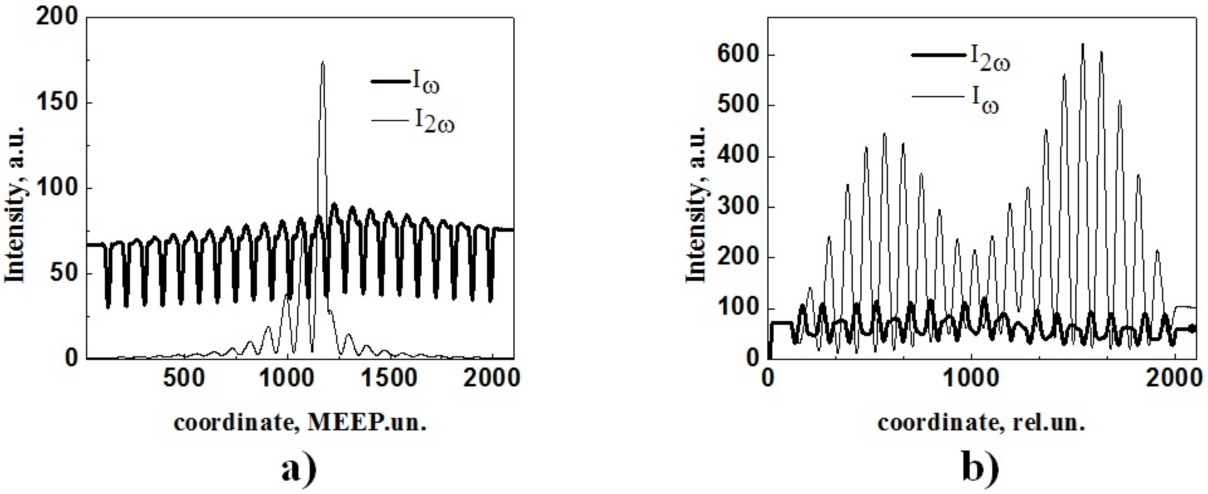

FIG. 1. The intensity distribution of the first and second harmonics of the one-dimensional photonic crystal at the wavelengths of the first harmonic: a) 1.060 μm and 0.530 μm b) 1.266 μm and 0.633 μm

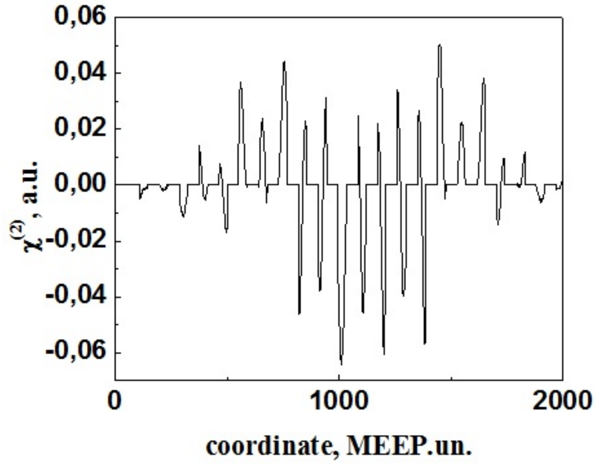

FIG. 2. Sample distribution of the quadratic nonlinearity in one-dimensional photonic crystal

3. Conclusions

As can be seen from Fig. 3-4, the SHG efficient generation is observed for different wavelengths of the incident radiation of the first harmonic. At the first harmonic wavelength, equal to 1.226 μm, we see not only the second generation, but the third harmonic, which arose from the summation of frequencies of the first and second harmonic. In this case, the SHG efficiency was 0.2 %.

Thus, the $\chi^{(2)}$–grating recording process is simulated in the one-dimensional photonic crystal made from glass and air. Second harmonic generation is predicted for different wavelengths. A conversion efficiency of about 0.2% was obtained for the 1.226 μm wavelength.

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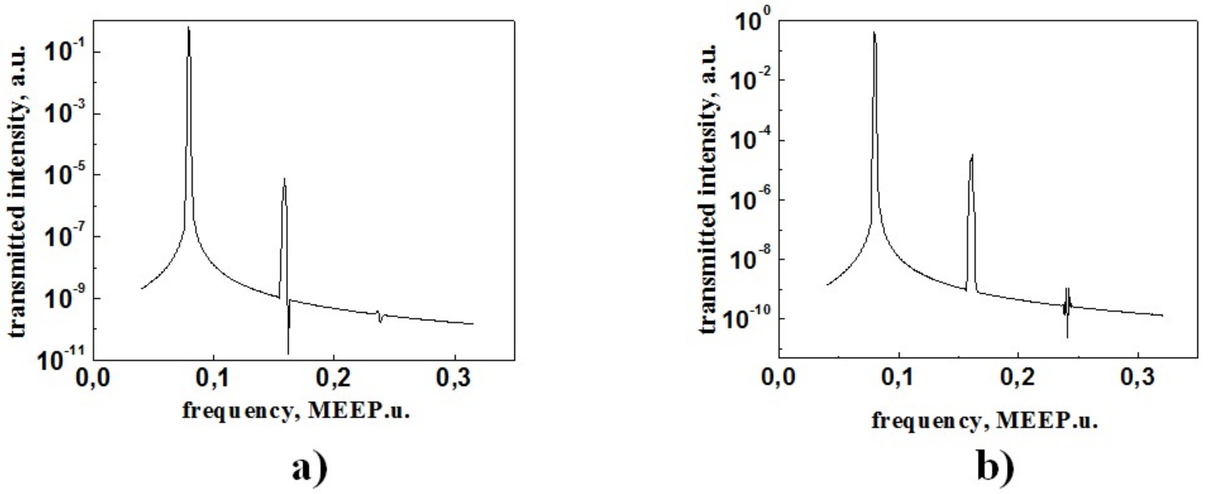

FIG. 3. SHG in one dimensional photonic crystal. Wavelength of fundamental harmonic by recording process is equal to: a) 1.266 μm b) 1.246 μm.

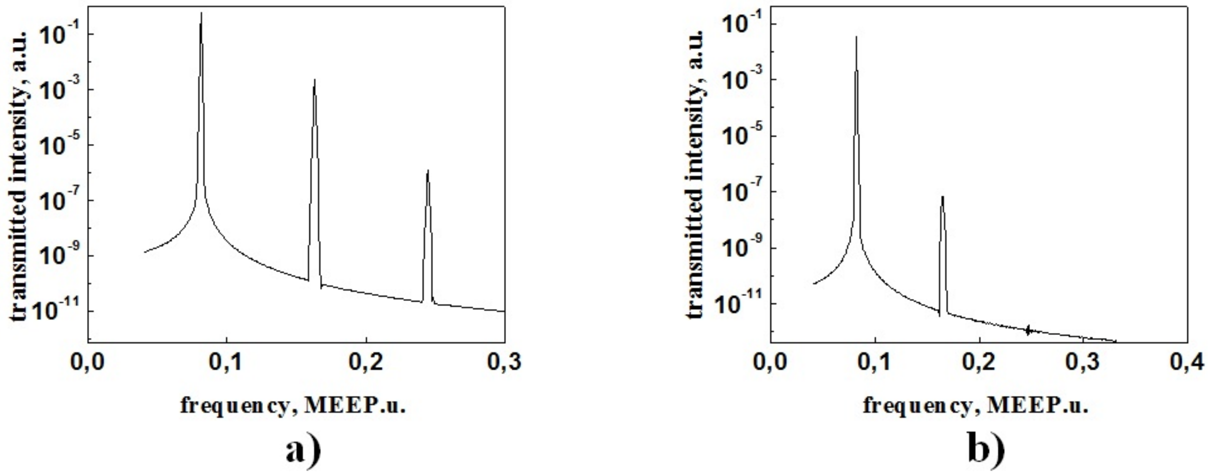

FIG. 4. SHG in one dimensional photonic crystal. Wavelength of fundamental harmonic by recording process is equal to: a) 1.226 μm b) 1.206 μm.

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