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IN PHYSICS BACKWARD FREQUENCY CONVERTORS BASED ON QUASI-PHASE MATCHED CRYSTALS

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Abstract

This paper reports on the use of quasi-phase matched (QPM) crystals to implement forward and backward second harmonic generation (BSHG). Recently, the latter and other types of frequency conversion processes have become the subject of widespread research. This is due to many new phenomena and technological advances in the production of short-lived nonlinear lattices,

in a periodically polarized nonlinear crystal (PPNC) the theory of second harmonic generation (SHG) is developed in the approximation of fixed intensity of CW fundamental radiation.

Key words

quasiphase, second harmonic generation, frequency, nonlinear gratings, fixed intensity.

Annotatsiya

Ushbu maqolada, kvazifazali mos keladigan (QPM) kristallari oldinga va orqaga ikkinchi garmonik avlodni (BSHG) amalga oshirish uchun ishlatilishi haqida ma'lumotlar berilagan. So'nggi paytlarda chastotani o'zgartirish jarayonlarining oxirgi va boshqa turlari keng tarqalgan tadqiqotlar mavzusiga aylandi. Bu ko'plab yangi hodisalar va qisqa muddatli chiziqli bo'lmagan panjaralarni ishlab chiqarishdagi texnologik taraqqiyot tufayli,

vaqti-vaqti bilan qutblangan chiziqli bo'lmagan kristallda (PPNC) ikkinchi garmonik avlod (SHG) nazariyasi CW fundamental nurlanishining sobit intensivligini yaqinlashtirishda ishlab chiqilgan.

Kalit so'zlar

kvazifaza, ikkinchi garmonik avlodni, chastota, chiziqli bo'lmagan panjaralar, sobit intensivlik.

Абстрактный

Кристаллы квазисинхронизации (QPM) могут использоваться для реализации как прямой, так и обратной генерации второй гармоники (BSHG). В последнее время последний и другие виды процессов преобразования частоты стали предметом широких исследований. Это связано с множеством новых явлений и техническим прогрессом в изготовлении короткопериодных нелинейных решеток.

Теория генерации второй гармоники (ГВГ) в периодически поляризованном нелинейном кристалле (ППНК) развита в приближении фиксированной интенсивности непрерывного фундаментального излучения.

Ключевые слова

квазифаза, генерация второй гармоники, частота, нелинейные решетки, фиксированная интенсивность.

Enter

The quasi-phase matched (QPM) crystals can be used to realize both forward, and backward second harmonic generation (BSHG) [1]. Recently, the latter and other types of frequency conversion processes have become a subject of widespread studies [2]. This is owing to a wealth of novel phenomena [3, 4] and the technological progress in the fabrication of short period nonlinear gratings [5].

Quasi-phase-matching (QPM) makes it possible to design domain engineered nonlinear crystals for highly efficient and multitasking nonlinear frequency conversion. However, finding the optimal crystal domain arrangement in a meaningful time is very challenging sometimes impossible by classical computing. In this paper, we proposed a quantum annealing computing method and used D-Wave superconducting quantum computer to design aperiodically poled lithium niobate (APPLN) for coupled third harmonic generation (CTHG). We converted the optical transformation efficiency function to an Ising model which can be solved by D-Wave quantum computer. The crystal design results were simulated by using nonlinear envelope equation (NEE), which showed very similar conversion efficiencies to the crystals designed by using simulated annealing (SA) method, demonstrating that quantum annealing computing is a powerful method for QPM crystal design.

The wavelength generated from a laser depends on the energy level structure of the activated ions and is often limited in a small tuning range. A well-known Tisapphire laser has a tuning range of 650–1100 nm, but this is almost the widest span we can obtained in near infrared . However, research in fields such as spectroscopy often requires wavelengths from the deep ultraviolet to the mid-infrared from a laser system as simple and efficient as possible. For example, currently there is no mature technology to obtain ultrashort 234 nm optical pulses directly from a laser for Al^+ cooling in an optical clock. Therefore, nonlinear frequency conversion is an important technique to obtain lights at various wavelengths flexibly.

Quasi-phase matching is a very popular second-order nonlinear frequency transformation technology. It avoids critical phase matching in a nonlinear crystal with a specific orientation and a specific polarization state. By artificially modulating the direction of each optical superlattice in a QPM crystal periodically or quasi-periodically, the nonlinear interaction can satisfy the phase matching condition where the crystal has the highest coefficient. Periodically polarized nonlinear crystals, such as periodically polarized lithium niobate (PPLN), and periodically polarized potassium titanyl phosphate (PPKTP), are commonly used in quasi-phase matching second-order harmonic generation (SHG), sum-frequency generation (SFG), differential-frequency generation (DFG), and so on. However, a periodically polarized crystal normally only satisfies a specific frequency conversion with single process and narrow bandwidth. For nonlinear conversion of femtosecond laser pulse, especially when multiple nonlinear processes are expected in a single system, a more sophisticated design of QPM crystal should be employed.

In order to achieve CTHG from a single gain medium, Gu et al. demonstrated APPLN as a frequency conversion crystal, and used SA algorithm to realize the design of the APPLN. The idea of this method is to set a small calculation step (a domain) in which the optical property is unified, select an appropriate objective function, and search the optimal domain orientations by using the SA algorithm. Since each crystal domain can take positive or negative polarization direction, the calculation may result in a crystal with different numbers of positively orientated domains adjacent and different numbers of negatively orientated domains adjacent, formed an APPLN with different lengths of positive and negative superlattices. For an APPLN with N domains, there are 2^N types of crystal domain arrangements, so increasing the number of calculation domains to obtain finer optical superlattice design and higher conversion efficiency is generally not practical by using SA algorithm.

Some other algorithms were also presented for APPLN design, including genetic algorithm, Lagrange multiplier method and so on. These algorithms do not essentially solve the complexity problem, and can only obtain an approximate optimization result. Searching for optimal crystal domain orientations is essentially a combinatorial optimization problem. To solve this problem, it is necessary to improve the computing hardware essentially. Quantum computers are designed to solve such complex combinatorial optimization problems. Recent studies have shown that a large number of combinatorial optimization problems in the fields of medicine design, very-large-scale integrated circuit design , traffic planning, financial investment can be solved using quantum computers. We are trying to adopt these methods to APPLN superlattice design, and to solve such combinatorial optimization problems in polynomial time.

In this paper, we demonstrated an APPLN design for CTHG by using the *D*-Wave superconducting quantum computer, which can only solve the minimum of the real number Ising model. We first convert the CTHG efficiency function into a complex Ising model, and then use the *rotation-projection* method to convert it into a series of real Ising models for D-Wave. The results show that with superconducting quantum computers, we can find fairly good solutions in a relatively short time. The method provides new ideas for the design of APPLN by using quantum computing.

Theoretical analysis

The quasi-phase matching technique compensates the phase mismatch in a nonlinear process by changing the sign of the nonlinear coefficient of the crystal within a coherent length, thereby realizing an effective and efficient nonlinear frequency transformation. As shown in , the APPLN crystal is divided into numbers of domains of the same size, and each domain can have two polarization directions, either “up” or “down”.

The theory of second-harmonic generation (SHG) in the periodically poled nonlinear crystal (PPNC) is developed in the approximation of the fixed intensity of the CW fundamental radiation [6]. The SHG at a wavelength of 0.8 µm by 50- and 10-fs pulses with and without phase modulation (PM) was systematically studied in LiNbO3 crystals with regular domain structure and linearly varied domain thickness [7]. The maximum conversion efficiency for the SHG by PM pulses is achieved at a certain optimum chirp step in the crystal domain length, which depends on both the value and sign of frequency modulation. It is numerically found that the conversion efficiency of about 90 % can be achieved by doubling the frequency of 50-fs laser pulses without PM in the LiNbO3 PPNC. A theoretical analysis of the degenerate parametric frequency conversion in a LiNbO3 crystal with a regular domain structure and a linearly varying domain thickness (chirped crystal) is presented [8]. The pump energy is effectively converted into subharmonic energy when the pump carrier frequency decreases with time.

Since the first demonstration of the backward optical parametric osculation [9], there have been extensive theoretical and experimental studies on various types of backward frequency conversion processes. For the first time, the theory of BSHG in quadratic nonlinear optical media was presented in detail in [10]. The self-pulsing instabilities , cavity-less oscillation in the presence of gain , gap solution propagation [3], multiple frequency, under counter-propagated wave interacting have been studied relatively recently. Other unique possibilities of QPM waveguides, when one part of devise is closed by a mirror, owing to what energy conversion of BSHG may be effectively increased with relatively low pump energy, was also reported in . Optical bistability and limiting in backward nondegenerate three wave mixing through an index corrugation and second harmonic pulse compression by means of BSHG were also studied. Experimental demonstration on BSHG by lower order of QPM waveguides has been also reported in periodically poled lithium niobate crystal , in periodically potassium titanyl phosphate .

Up to now unlike the forward case, BSHG has been generated with very low energy conversion in various experimental conditions. This is caused by a few factors. Among them main one is, the generating of the BSHG requests relatively short period of QPM grating. Present time, BSHG could be only generated with a few order of QPM grating. Second one is, in order to obtain high effective BSHG it is necessary to use higher intense laser source. In most cases the latter one could be achieved using pulsed laser sources. However, because of the fundamental and BSH waves propagate in opposite directions; the group velocity mismatch (GVM) exerts an essential influence on efficiency of the nonlinear frequency conversion process, in contrast to the forward second harmonic generation. Third one is, to our knowledge, a randomly error of domain sizes, which occurs during fabricating QPM crystals with relatively short period (see e.g. in). Since the random deviation of domain sizes of QPM grating from their ideal size, which generates BSHG, could be large enough to destroy the QPM condition. In other word, QPM waveguides with relatively short period of domains request relatively high resolution on their sizes.

In this paper we report on our numerical and analytical studies of BSHG during the influences of GVM and GVD for Gaussian profiled fundamental pulse. We develop a numerically effective iterative algorithm, based on a numerical solution of the coupled-wave equations with a shooting approach. Thanks to the algorithm we were able to design temporal profile of backward frequency doubling, generated by transform-limited incident pulse in various conditions, closer to experimental results.

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