Study on MgO: APLN Crystal for Multi-Optical Parametric Oscillation

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Abstract. In this paper, the expression of polarization structure for superlattice materials with phase mismatch and relative coefficient is established. Based on this method, a MgO:APLN crystal with two reciprocal lattice vectors is designed to generate 1.47μm, 3.84μm and 1.57μm, 3.3μm parametric light pumped by 1064 nm fundamental frequency light. Comparing the Fourier coefficients of MgO:APLN crystals with different structures, it is found that the Fourier coefficients of the two reciprocal lattice vectors are equal when the relative coefficient is 1:1. Based on this crystal, the experiment of external cavity MgO:APLN-MOPO is carried out to optimize the output transmittance of parametric optical coupling. With 20kHz high repetition rate 1064nm laser pumping, 1.57μm and 3.84 μm are achieved and the average power are 4.1W and 3.7W, respectively. The corresponding light-to-light conversion efficiency are 17.1% and 15.4%.

1. Introduction

Superlattice materials can be made by serval reciprocal lattice vectors in a single crystal and compensate for phase mismatches to achieve multiple quasi-phase matching processes. The multi-optical parametric oscillator based on superlattice material obtains the same spectral region and multi-wavelength tunable laser output [1-7], which has broad application prospects in military multi-band laser interference countermeasure, optical difference-frequency THz, dual-comb spectroscopy, environmental multi-component gas high precision synchronous detection and other frontier scientific and technological fields [8-10]. The polarization structure of superlattice materials directly affects the performance of multi-optical parametric oscillators. Common polarization structural design methods, such as Fibonacci binary projection method has a large gap of non-linearity coefficient for reciprocal lattice vectors [11-13]; simulated annealing algorithm has a large amount of iteration calculation and is difficult to optimize [14] and phase-reversal sequence method has the same interval, which is not adaptability [15].

In order to adjust the width of the reciprocal lattice vectors and effective nonlinearity coefficients freely, the expression of the polarization structure with the phase mismatch and relative coefficients is proposed based on the Fourier transformation. Based on this method, a MgO:APLN crystal with reciprocal lattice vectors is designed to realize simultaneous oscillation of 1.47μm, 3.84μm and
1.57μm, 3.3μm parametric light pumped by 1064nm fundamental frequency light. Comparing the Fourier coefficients of MgO:APLN crystals with different structures, it is found that the Fourier coefficients of the two reciprocal lattice vectors are equal when the relative coefficient is 1:1. Based on this crystal, the experiment of external cavity MgO:APLN-MOPO is carried out to optimize the output transmittance of parametric optical coupling. With 20kHz high repetition rate 1064nm laser pumping, 1.57μm and 3.84 μm are achieved and the average power are 4.1W and 3.7W, respectively. The corresponding light-to-light conversion efficiency are 17.1% and 15.4%.

2. Theoretical Analysis

There are two reciprocal lattice vectors in MgO:APLN crystal, so two groups of signal and idle light can oscillate simultaneously. The phase mismatch corresponding to each parameter oscillation process is

$$\Delta k_1 = k_p - k_{s1} - k_{i1}$$

$$\Delta k_2 = k_p - k_{i2} - k_{s2}$$

Where \(k_p\) is the pump light wave vector, \(k_{i1}\), \(k_{s1}\) are the idle light and signal light wave vector produced by parametric oscillation 1, \(k_{i2}\) and \(k_{s2}\) are the idle light and signal light wave vector produced by parametric oscillation 2.

The effective nonlinearity coefficient of MgO:APLN crystal \(d(\Delta k)= g(z) d_\delta\) is a function of the propagation distance \(Z\) in the crystal, where \(d_\delta\) is the nonlinearity coefficient of the crystal, and \(g(z)\) is the polarization periodicity function of the crystal, with a value of only 1 or - 1, representing the positive and negative domains.

The expression of crystal polarization structure based on Fourier transform is as follows

$$G(\Delta k) = \frac{1}{\Delta k} \int_{-\infty}^{\infty} g(z) \exp(i\Delta k z) d(\Delta k)$$

Where,

$$G(\Delta k) = \frac{1}{\Delta k} \int_{0}^{\Delta k} g(z) \exp(-i\Delta k z) dz$$

There is a Fourier transform relationship between the reciprocal lattice vectors and the polarization structure of the crystal, that is, the polarization structure of the crystal can be obtained by inverted Fourier transform of reciprocal lattice vectors.

Similarly, the reciprocal lattice vectors \(G(k)\) is rewritten to

$$G(\Delta k) = A_1 \cdot \sin[(\Delta k_1 + C_1 \cdot z) \cdot z] + A_2 \cdot \sin[(\Delta k_2 + C_2 \cdot z) \cdot z]$$

Where \(A_1\) and \(A_2\) are the relative coefficients of phase mismatch \(\Delta k_1\) and \(\Delta k_2\), \(C_1\) and \(C_2\) are the corresponding chirp coefficients. The polarization structure \(g(z)\) is simplified by Fourier transform,

$$g(z) = \text{sign}\{A_1 \cdot \sin[(\Delta k_1 + C_1 \cdot z) \cdot z] + A_2 \cdot \sin[(\Delta k_2 + C_2 \cdot z) \cdot z]\}$$

Where sign denotes a symbolic function. The values of \(A_1\) and \(A_2\) can actively adjust the effective non-linear coefficients of the reciprocal lattice vectors, and optimizing \(C_1\) and \(C_2\) can control the width of the reciprocal lattice vectors.
3. Simulation and Analysis

In order to obtain two groups of 1.47µm, 3.84µm and 1.57µm, 3.3µm parametric light output from 1064 nm pumped light, MgO: APLN crystal needs to provide two phase mismatches which can compensate for 0.2041µm⁻¹(1.57µm, 3.3 µm) and 0.2138µm⁻¹(1.47 µm, 3.84 µm). The polarization structures and corresponding Fourier coefficient are simulated by using the upper section design method in Figure 1. The parameters of MgO: APLN crystals are shown in Table 1.

Table 1. The parameters of MgO: APLN

| Number | Relative coefficients of reciprocal lattice vectors | Chirp |
|--------|----------------------------------------------------|-------|
| a      | 1:1                                                | No    |
| b      | 1:1                                                | Yes   |
| c      | 0.9:1                                              | No    |
| d      | 1:0.9                                              | No    |

Figure 1. The polarization structure of MgO: APLN
The FIG. 1. shows that four polarization structures can compensate 0.2041µm⁻¹ and 0.2138µm⁻¹ at the same time. Comparing figure a, c and d, three polarization structure can be found without chirp. The Fourier coefficients of reciprocal lattice vectors are proportional to the relative coefficients, i.e. the bigger the relative coefficients, the bigger the Fourier coefficients. Figure b include chirp polarization structure. Compared with the figure a, the polarization structure B has the same Fourier coefficient of polarization structure A of 0.2041µm⁻¹, and the width of reciprocal lattice vectors increased for chirp of 0.2138µm⁻¹. Comparing the parameters of each crystal synthetically, polarization structure A is the optimum.

4. Experiment
The external cavity MgO:APLN-MOPO device is shown in FIG. 2. The crystal size of MgO:APLN is 3×3×50mm. The 1064nm pump light is coupled to the MOPO cavity composed of M3 and M4 by polarization conversion and beam shape adjustment. The M3 and M4 mirror matrices are calcium fluoride with curvature radii of 150mm and 100mm, respectively. All mirrors are coated as shown in Table 2.

![Diagram of external cavity MgO:APLN-MOPO](image)

**Figure 2. The diagram of external cavity MgO:APLN-MOPO**

| Name | Coating parameter |
|------|-------------------|
| M3   | 1064nm@HT(T=100%) |
|      | 1.47µm@HR(R=100%), 1.57µm@HR(R=100%) |
|      | 3.3µm@HR(R=100%), 3.84µm@HR(R=100%) |
|      | 1064nm@HR(R=100%) |
| M4-1 | 1064nm@HR(R=100%) |
|      | 1.47µm@AR(T=80%), 1.57µm@AR(T=60%) |
|      | 3.3µm@HT(R=100%), 3.84µm@HT(T=100%) |
| M4-2 | 1064nm@HR(R=100%) |
|      | 1.47µm@AR(T=60%), 1.57µm@AR(T=60%) |
|      | 3.3µm@HT(R=100%), 3.84µm@HT(T=100%) |

**Table 2. A table with coating parameter**

![Graph of output power and efficiency](image)

**Figure 3. The output power and efficiency of external cavity MgO:APLN-MOPO**
FIG. 3. shows the output power and conversion efficiency of the external cavity MgO:APLN-MOPO experimental device. Under the maximum pumping power of 1064nm at 24W 20kHz, the average power of 1.57μm and 3.84μm are 4.1W and 3.7W by using M4-1. The corresponding optical-optical conversion efficiency are 17.1% and 15.4%, which is significantly better than that of M4-2 at 10.2% and 12.9%. This phenomenon shows that the conversion efficiency of 3.84μm and 1.57μm increases significantly with the increase of 1.47μm transmission.

5. Conclusion
The expression of polarization structure for superlattice materials with phase mismatch and relative coefficient is established. Based on this method, a MgO:APLN crystal with two reciprocal lattice vectors is designed to generate 1.47μm, 3.84μm and 1.57μm , 3.3 μm parametric light pumped by 1064 nm fundamental frequency light. The experiment of external cavity MgO:APLN-MOPO is carried out to obtain 1.57μm and 3.84μm output. With 20kHz high repetition rate 1064nm laser pumping, 1.57μm and 3.84 μm average power are 4.1W and 3.7W, respectively. The corresponding light-to-light conversion efficiency are 17.1% and 15.4%.

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