Near-infrared spectral region photonic crystal band gaps and KTP defect

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Abstract: Photonic crystal defect formed by the introduction of the defect was amplified in the gain medium and formed laser. To further clarify the laser characteristics of the defect, the matrix of the photonic crystals was theoretically analyzed and the characteristics of the photonic band gaps was obtained: the width of the optical band gaps increased as the number of cycles does, and a certain value exceed a certain amount of cycles was reached; the higher the value which determined by the width of the optical band gaps constant, the higher refractive index ratio; superposing different centers of the photonic crystal wavelength can effectively expand the optical band gaps range. The experimental result from the band gaps analysis reveals one-dimensional photonic crystals in the KTP, which negatively affects the photonic band structure of the wavelength response curve; the refractive index of the KTP increases as temperature increases, and then the direction of the long wavelength defect mode changes. The results of this study contributes to the theoretical and practical development of small light sources.

Key words: photonic crystals; defect; laser; band gaps; refractive index
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近红外光谱区光子晶体禁带与 KTP 缺陷研究

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摘 要: 光子晶体引入缺陷后形成的缺陷模在增益介质中将被放大形成激光,为了进一步明确缺陷的激光特性,首先从理论上分析了光子晶体的特征矩阵,接着得出了以下光子禁带特性:光带隙宽度随着周期数的增加而增大,但在周期数达到一定数值后其光带隙宽度是确定不变的;折射率比值越大,光带隙宽度越大;叠加不同中心波长的光子晶体可以简单、有效地拓展光带隙范围。在一维 KTP 光子晶体的禁带特性实验分析中得到了 KTP 缺陷的光子能带结构的波长响应曲线;随着温度的上升,KTP 的折射率随之增大,进而缺陷模向长波长方向移动。上述研究对于微小光源的发展具有一定的理论和实际意义。

关键词: 光子晶体; 缺陷; 激光; 禁带; 折射率

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0 Introduction

The concept of "photonic crystal" was proposed by S. John and E. Yabloncvitch in 1987 [1-2]. Shanhui Fan of the Massachusetts Institute of Technology produced a two-dimensional photonic crystal using thin films in 1997[3]. The integrated circuit revolution has extended to the field of ultra-wideband optical signal, thus advancing ultra miniaturized optoelectronics further. In 1999[4-5], Cregan extended the study of Knight et al. and produced an air-core photonic crystal fiber (i.e., photonic band gaps fiber), which is a photonic crystal fiber in its true sense. In 2004[6-7], Blaze released a new PCF, which is optical fiber for Nd^{3+} microchip lasers and is optimized and specifically designed to produce ultra-continuous spectrum[8-10]. In 2005, A. Ortigosa and Blanch of the England Bath University used a 200 fs supercontinuum pump pulse generated from the PCF. As new micro-cavity lasers, photonic crystal lasers have attracted widespread attention in recent years[11-12]. A one-dimensional photonic crystal is characterized by a dielectric constant of different materials. Defect formation in photonic crystals by the gain medium resulting from the introduction of defects is amplified to form laser[11]. Adjusting the refractive index of a defect layer changes the defect mode resonance, which outputs wavelength drifts. Methods such as finite difference time-domain, plane wave method, and transfer matrix method (TMM) are used to study the characteristics of a micro-cavity[13]. Based on the overview provided above, the one-dimensional photonic band gaps and KTP crystal defects is studied.

1 Photonic crystal band analysis

1.1 Feature matrix

In thin film optics, a feature matrix on a medium is given by

$$M=\begin{pmatrix} \cos[-h(k_x\tan\theta_{r1}+k_z)] & -j\cdot\sin[h(k_x\tan\theta_{r1}+k_z)/\sqrt{\varepsilon/\mu}\,] \\ -j\cdot\sin[h(k_x\tan\theta_{r1}+k_z)/\sqrt{\varepsilon/\mu} & \cos[-h(k_x\tan\theta_{r1}+k_z)] \end{pmatrix} \quad (1)$$

where M is a normalized basic cycle matrix that determines the electromagnetic waves and wave propagation characteristics in a medium. For a limited layer of dielectric photonic crystals (e.g., n-layer dielectric) that consists of matrix, M may be calculated n times to obtain the characteristics of the media matrix.

$$\begin{bmatrix} E_1 \\ H_1 \end{bmatrix}=\left\{\prod_{i=1}^{k} M_i\right\}\begin{bmatrix} E_{k+1} \\ H_{k+1} \end{bmatrix} \quad (2)$$

For a periodic structure with n repetitions of one-dimensional photonic crystals, a characterized matrix is designated as $M'=M^n$.

The band gaps properties of photonic crystals based on the characteristic matrix M' are determined according to the M' matrix. In this way, the reflection coefficient r and the refractive index of one-dimensional photonic crystals are obtained.

$$r=\frac{E_{r1}}{E_{i1}}=\frac{m_{11}\eta_0+m_{12}\eta_0^2-m_{21}-m_{22}\eta_0}{m_{11}\eta_0+m_{12}\eta_0^2+m_{21}+m_{22}\eta_0} \quad (3)$$

$$t=\frac{E_{tN+1}}{E_{i1}}=\frac{2\eta_0}{m_{11}\eta_0+m_{12}\eta_0^2+m_{21}+m_{22}\eta_0} \quad (4)$$

Reflectance $R=r^*$, where r is the conjugated form of the same token. The transmission rate $T=t^*$.

1.2 Effect of number of cycles

The number of cycles N (N=3,5,7,10) of a basic structure with uniform thickness can be expressed as (HL)N. This parameter can be calculated according to the theoretical formula of the corresponding film based on reflectance R (Fig.1).

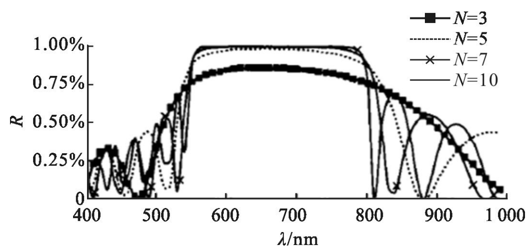

Fig.1 Affect number of a cycle diagram and other thick lines reflectivity

The following conditions are observed in Fig.1. First, the reflectivity at wavelength 1 of the incident wave gradually concentrates in the center when the number of cycles N increases. The center wavelength

λ_0 is a wavelength band (550 nm to 800 nm) in the so-called light band gaps. The band gaps wavelength of the wave propagation in the film layer is prohibited. Second, when N is greater than 7, the width of the optical band gaps diagram increases for both sides, and the number of oscillations does not increase significantly. Thus, for a given basic cycle of crystals, the number of cycles of the optical band gaps width is determined. However, the width of the number of cycles to reach a certain minimum number of cycles (the number of cycles in Fig.1) is uniquely determined. In other words, certain periodic one-dimensional photonic crystals are characterized as follows: optical band gaps width increases when the number of cycles increases; however, the value of the optical band gaps width becomes constant after a few cycles.

1.3 Effect of refractive index ratio

High and low refractive index seen by film theory optical band gaps width and film-based one-dimensional photonic crystals in the ratio of the relevant material. Figure 2 shows the minimum number

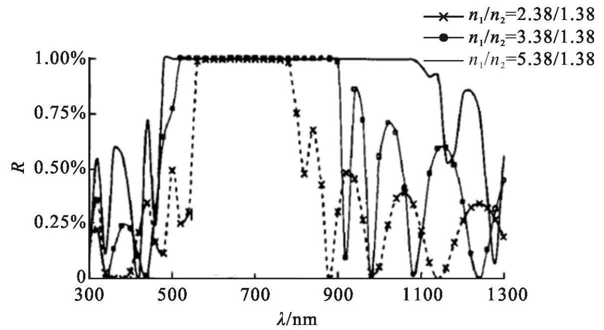

Fig.2 Refractive index ratio on membrane-based reflectance

of cycles and the center wavelength (i.e., 650 nm and 10, respectively) of a film based on refractive index ratios at various reflections. The ratio of the high and low refractive index may be increased to expand the optical band gaps width. A relatively broad optical band gaps can be obtained by increasing the refractive index ratio of the two kinds of film materials. However, materials of practical value are present in the visible region, where in the maximum refractive index does not exceed 2.6 and minimum is not lower than 1.3. Meanwhile, the maximum refractive index in the infrared region does not exceed 6. Therefore, in expanding the optical band gaps width of one-dimensional photonic crystals, using height alone to increase the ratio of the refractive index of the film is not feasible. Thus, optical band gaps width of a one-dimensional photonic crystal is high if the high and low refractive index ratios are also high.

1.4 Effect of center wavelength

The center wavelength of the optical thickness of a film directly affects the change in the fundamental period of the membrane system. Figure 3 shows the center wavelengths of 650 and 550 nm, which were obtained for the reflected film system (HL). The ratio of the reflectance is taken as 10 2.38/1.38. According to Fig.3, the center wavelength of the optical band gaps is approximately 550 nm in a film system of 450 nm to 700 nm. Moreover, the center wavelength of a 650 nm membrane system that corresponds to the range of the band gaps is 550 nm to 800 nm. Different central wavelengths corresponding to different wavelength bands are not acceptable. Therefore, a selected center wavelength of a corresponding one-dimensional photonic crystal is prepared to obtain a range of optical band gapss in accordance with set requirements.

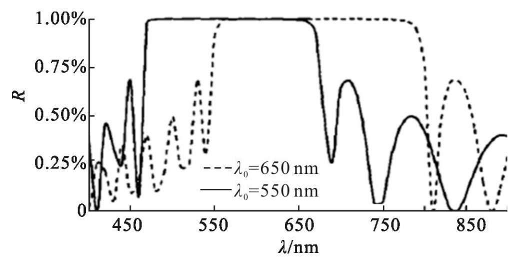

Fig.3 Center wavelength of influence (such as thick lines reflectivity)

Figure 3 also shows the difference between the two lines of the center wavelength of a membrane; however, the basic structure of the high and low refractive index and the ratio of the minimum number of cycles are identical, and both optical band gapss exhibit similar width. The optical band gaps can be expanded by superimposing two different center wavelengths on the photonic crystal. The overlay requires two centers of the photonic crystal wavelength to be staggered so that both of the optical band gaps boundaries overlap. In this way, the optical band gaps width of the synthetic photonic crystals is broadened. Figure 3 shows that two film systems are superimposed to produce a new film system that can be expressed as(H1L1) 10 (H2L2) 10. The reflection conditions are shown in Figure 4. The superimposed

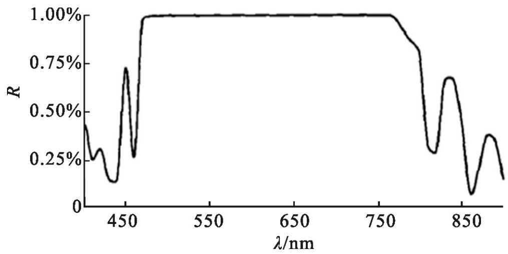

Fig.4 Center wavelength of 550 nm, respectively, and the film reflectance of the superimposed lines 650 nm

optical band gaps range of the new membrane system is expanded to a range of 500 nm to 800 nm. The superposition of different center wavelengths of visible photonic crystals may easily and efficiently expand the optical band gaps range. The optical band gaps range can be increased by superimposing different center wavelengths of a one-dimensional photonic crystal optical band gaps; however, additional layers form in the membrane system when the number of superimposed crystals increases. For instance, the original thickness of a periodic structure (e.g., 10 cycles produce a 20-layer film system) is twice that of the original value when the films of two crystals are superimposed. An increase in thickness is not favorable to the crystal layers because waste materials are generated. Other factors that do not change may be considered to improve the basic periodic structure and consequently expand the optical band gaps. In a recently proposed method, a slowly varying periodic structure, a complex periodic structure, and a one-dimensional photonic crystal structure with a metal insert layer may be used to widen the range of band gaps width using a small number of cycles. This method may be used in a wide range of applications. Therefore, to determine the regional center wavelength optical band gaps. After superimposing different center wavelengths on the photonic crystal, the corresponding band gapss of their respective boundaries overlap each other. The synthesis of a wide band gaps effectively expands band gaps width.

Can be calculated using the transfer matrix method in a one-dimensional optical transmission spectrum of KTP photonic crystal structure transmittance to obtain the photonic band structure of the wavelength response curve (Fig.5).

2 Band gaps properties of one-dimensional photonic crystal KTP analysis

2.1 One-dimensional photonic crystals transmission spectra of KTP

Can be calculated using the transfer matrix method in the one-dimensional optical transmission spectrum KTP photonic crystal structure transmittance obtain photonic band structure of the wavelength response curve shown in Figure 5.

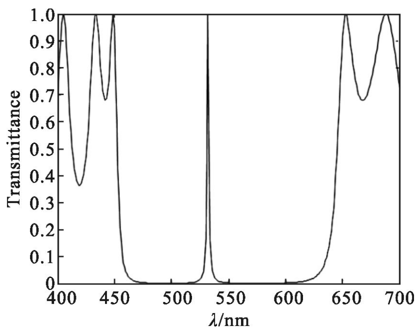

Fig.5 Doped defective transmission spectra of one-dimensional photonic crystals

2.2 Temperature characteristics

The change in temperature of the transmittance structure (Fig.6 -7) is calculated based on the aforementioned photonic crystal structure and on the significant temperature coefficient of the refractive index of an optical indicator. The index of refraction of the KTP increases as the temperature increases up to 850 ℃; thus, the defect mode moves to a longer wavelength direction.

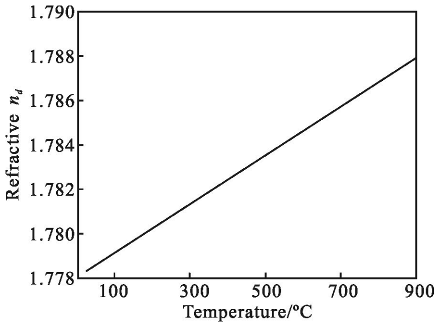

Fig.6 Temperature changes affect the KTP crystal refractive index

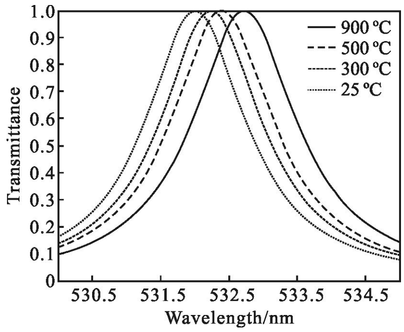

Fig.7 Effect of temperature change on the micro-cavity transmittance

3 Conclusion

In summary, the study theoretically analyzes the characteristics of the photonic crystal matrix based on the one-dimensional photonic band gaps properties of crystals. The micro-cavity laser structure of a doped KTP crystal constitutes a one-dimensional periodic photonic crystal with symmetrical structure, and its output wavelength, which is tunable around a center wavelength, and which can range up to several tens of nm. The simulation results have implications for the theoretical and applied manufacturing of tunable photonic crystal lasers and passive optical components.

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