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Procedia Engineering 15 (2011) 1668 – 1672

Procedia Engineering

www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Laser and infrared compatible stealth from near to far infrared bands by doped photonic crystal

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Abstract

Photonic crystals can realize broadband thermal infrared stealth based on its high-reflection photon forbidden band. By forming a "hole-digging" reflection spectrum of doped photonic crystals at military laser wavelength of 1.06μm and 10.6μm, compatible stealth of laser and infrared can be achieved. We selected lead telluride (PbTe) and cryolite (Na_3AlF_6), and designed a one-dimensional two-defect-mode photonic crystal based on principles of distributed Bragg reflector micro-cavity. The reflection and transmission spectra of the photonic crystals were calculated by transfer matrix method of thin-film optical theory. The calculation results show that the designed multi-cycle dual-hetero-junction photonic crystal has a high spectral reflectance in the near, middle and far infrared band, whose spectral reflectance is greater than 99% in 1~5μm and 8~14μm infrared bands, and spectral transmittance at 1.06μm and 10.6μm is greater than 96%. This will satisfy the laser and infrared compatible stealth in the near, middle and far infrared bands

Selection and/or peer-review under responsibility of [CEIS 2011]

Keywords:Laser stealth, infrared stealth, compatible stealth, photonic crystals, transfer matrix method(TMM)

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1. Introduction

Compatible stealth of laser and infrared is an urgent demand of modern battlefield, but the demand is ambivalent for conventional materials.[1,2] Infrared detection is a passive detection, which detect and identify targets by their infrared radiation. So for infrared stealth, the material with low thermal radiation

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doi:10.1016/j.proeng.2011.08.311

or high reflectance is needed. On the contrary, laser detection is an active detection, which detect and identify targets by own laser echo. For laser stealth, the material with low reflectance or high transmittance is needed. The operating wavelength of common military Nd^{+3}:YAG laser and CO_2 laser was 1.06μm and 10.6μm, corresponding to near-infrared and far infrared. To realize compatible stealth of infrared and laser, the best way is to form a "hole-digging" reflection spectrum [3], that is developing a new material, which has an extremely low reflectance only at very narrow band nearby 1.06μm and 10.6μm, while has a high reflectance in the other infrared bands. It may be possible in theory, but is very difficult to implement for the conventional materials. This problem can be solved by the defect level structure of doped photonic crystal [4,5].

Photonic crystals can realize broadband thermal infrared stealth based on its high-reflection photon forbidden band,[6-12] and by forming a "hole-digging" reflection spectrum of doped photonic crystals, high transmittance at wavelength of 1.06μm and 10.6μm of military laser can be achieved, so compatible stealth of laser and infrared can be achieved too. [13-16]

In this paper, we selected lead telluride (PbTe) and cryolite (Na_3AlF_6) as high refractive index and low refractive index material respectively, and designed a one-dimensional two-defect-mode photonic crystal based on principles of distributed Bragg reflector (DBR) micro-cavity. The calculation results show that the designed multi-cycle dual-heterojunction photonic crystal has a high spectral reflectance in the near, middle and far infrared band, whose spectral reflectance is greater than 99% in 1~5μm and 8~14μm infrared bands, and spectral transmittance at 1.06μm and 10.6μm is greater than 96%. This will satisfy the laser and infrared compatible stealth in the near, middle and far infrared bands.

2. Theory model and algorithm

A typical one-dimensional photonic crystal usually consists of two different materials alternately, which its refractive index is n1 and n2, and the thickness of the two materials is h1and h2 respectively, as shown in Figure 1. For one-dimensional photonic crystal, its optical characteristic can be calculated by transfer matrix method [17].

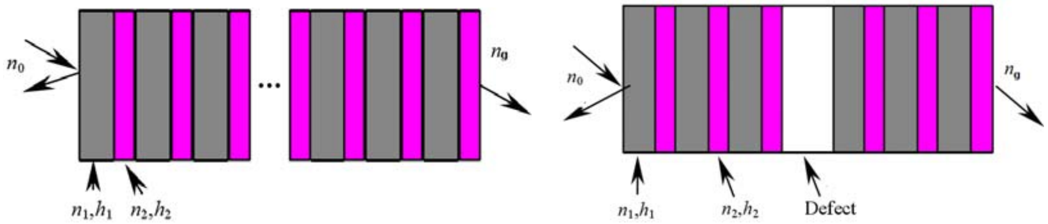

Fig. 1. (a) Schematic of 1-D photonic crystal; (b) Schematic of 1-D doped photonic crystal.

PbTe was selected as a high refractive index material, whose refractive index is 5.6 at the wavelength of 5μm, and transparent band is between 3.4~30μm; meanwhile, Na_3AlF_6 was selected as a low refractive index material, whose refractive index is 1.35, and transparent band is between 0.2~14μm[18]. During the calculation, we presume that the incident angle is zero, and the medium dispersion and absorption can be neglected.

To achieve dual-wavelength of 1.06μm and 10.6μm "hole-digging" reflection spectrum, the photonic crystal is bound to be dual-doped. But there is an interaction between the two defect modes generated by traditional dual-doped method, which can lead to mode splitting, channels interference, independent adjustment of channel positions and changes of the band structure, and peak transmission of defect modes and so on [19-21]. Based on DBR micro-cavity principle, we designed a two-fixed-position defect mode photonic crystal at the wavelength of 1.06μm and 10.6μm firstly, and then expanded the band gap by superimpose different cycle photonic crystals between two photonic crystal micro-cavities [22-23]. The calculation results show that the compound photonic crystal has achieved high reflectance in the most of 1~14μm infrared band, and high transmittance at the wavelength of 1.06μm and 10.6μm.

3. Results and discussion

Firstly, we designed a symmetry DBR micro-cavity A with central wavelength λ_0 is10.6μm, and designed the optical thickness of each layer is $\lambda_0/4$. The structure can be expressed as follow: Air/$[HL]^2H[HL]^2H$/glass,where H represents PbTe, L represents Na3AlF6, the same below). Its reflection spectrum has shown in Figure 2.

Then we designed a symmetry DBR micro-cavity B with central wavelength λ_0=1.06μm as same structure as micro-cavity A, and its reflection spectrum has shown in Figure 3.

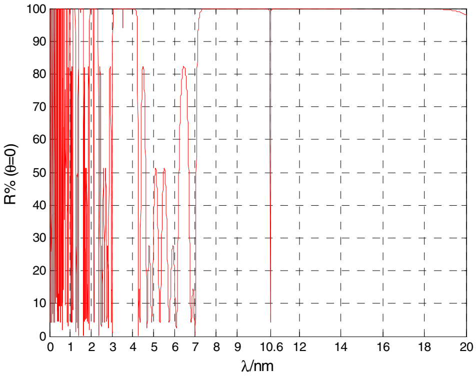

Fig.2 The reflection spectrum of DBR microcavity A

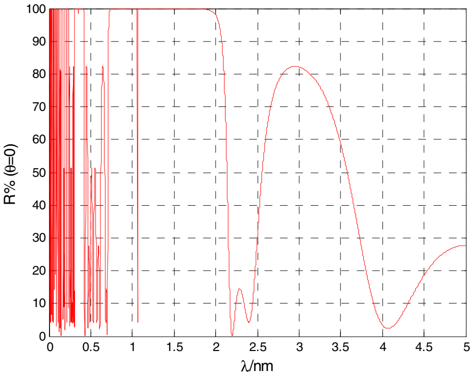

Fig.3. The reflectance spectrum of DBR microcavity B

And then, we stacked up the above two micro-cavities. The structure can be expressed as follow, Air/$[HL]^2H[HL]^2H[HL]^2H[HL]^2H$/glass. Its reflection spectrum has shown in Figure 4, and two "holes" at 1.06μm and 10.6μm can be seen clearly.

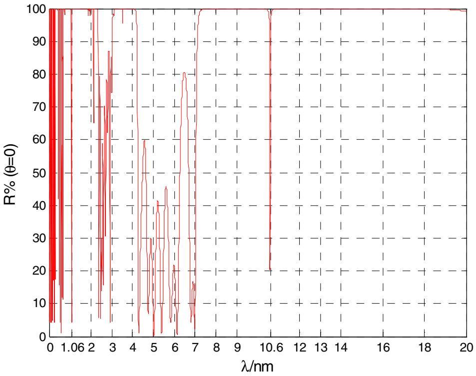

Fig.4 The reflectance of two-stacked DBR microcavities

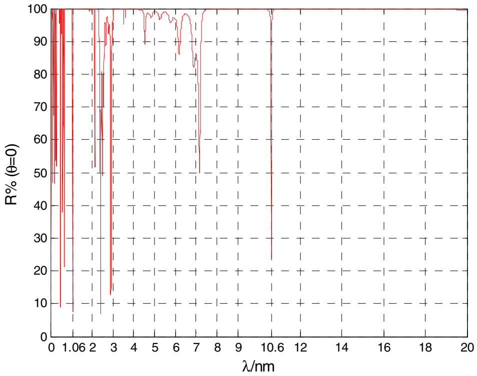

Fig.5 The reflectance spectrum of 1-D photonic crystals

Then, we inserted a photonic crystal (PC1) with central wavelength λ_0 is 3.85μm into the middle of the two DBR microcavities to extend the 3~5μm mid-infrared band gap. The structure can be expressed as: air/$[HL]^2H[HL]^2H[HL]^2[LH]^2[HL]^2H$/glass, and its reflection spectrum has shown in Figure 5.

Finally, we inserted another photonic crystal (PC2) with central wavelength λ_0 is 2.5μm between the microcavity B and PC1, to widen the near-infrared band gap. The structure is: air/$[HL]^2H[HL]^2H[HL]^2[LH]^2[HL]^2H[HL]^2H$/glass. The designed multi-cycle dual-heterojunction photonic crystal has a high spectral reflectance in the near, middle and far infrared band, whose spectral reflectance is as high as 99% in 1~5μm and 7.4~20μm infrared bands, and a high spectral transmittance greater than 96% at 1.06μm and 10.6μm, as shown in Figure 6. This will satisfy the laser and infrared compatible stealth in the near, middle and far infrared bands.

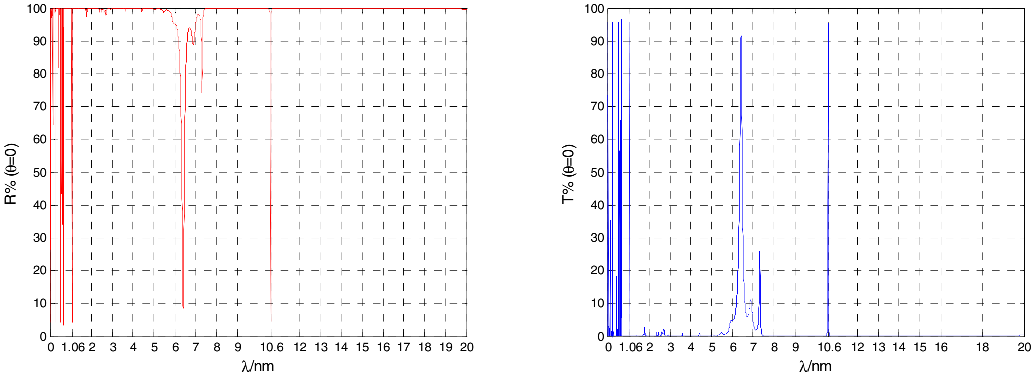

Fig.6 The reflection and transmission spectra of multi-cycle dual-heterojunction photonic crystal

4. Conclusions

In summary, we selected PbTe and Na_3AlF_6 and designed a one-dimensional two-defect-mode photonic crystal based on principles of DBR micro-cavity. The photon forbidden band was broaden to 1~20μm by constructing two hetero-junction photonic crystals. The reflection and transmission spectra of the photonic crystal were calculated by transfer matrix method of thin-film optical theory. The calculation results show that the designed multi-cycle dual-heterojunction photonic crystal has a high spectral reflectance in the near, middle and far infrared band, whose spectral reflectance is greater than 99% in 1~5μm and 8~14μm infrared bands, and spectral transmittance at 1.06μm and 10.6μm is greater than 96%. This will satisfy the laser and infrared compatible stealth in the near, middle and far infrared bands.

Acknowledgements

We gratefully acknowledge financial support by the key Innovation Exploration project of Xi'an Research Inst. of Hi-Tech [No. XY2010JJA01].

References

[1] ZHOU Jian-xun, LIU Shi-cai. Research on performance of infrared and laser composite stealthy coating. *Infra. & Laser Tech.* 1992; **2**:30-32.

[2] WU Ling-zhi, XIE Guo-hua,WU Rui-bin, ZHANG Wei-dong. Prospect analysis for compatible stealth coatings in laser and infrared. *Astro. Mater.Tech.* 2001;**2**:1-3.

[3] DAI Song-tao, ZHANG Guang-yin, ZHANG Cun-zhou. Hole-digging mechanism of solid reflection spectrum. *J. Infra. Millim. Waves* 1997; **16**(2):126-129.

[4] E. Yablonovitch. Inhibited spontaneous emission in solid state physics and electronics. *Phys. Rev. Lett.* 1987; **58**(20):2059-2062.

[5] Sajeev John. Strong Localization of Photons in Certain Disordered Dielectric Superlattices. *Phys. Rev. Lett.* 1987; **58**(23): 2486-2489.

[6] C.M. Cornelius and J. P. Dowling. Modification of Planck blackbody radiation by photonic band-gap structures. *Phys. Rev. A* 1999; **59**: 4736.

[7] Shawn-Yu Lin, J. G. Fleming, E. Chow. Enhancement and suppression of thermal emission by a three-dimensional photonic crystal. *Phys. Rev. B* 2000; **62**:2243.

[8] J. G. Fleming, S. Y. Lin, I. El-Kady. All-metallic three-dimensional photonic crystals with a large infrared band-gap. *Nature* 2002; **417**:52-55.

[9] Lin S Y, Moreno J, Fleming J G. Three-dimensional photonic crystal emitter for thermal photovoltaic power generation. *Appl. Phys. Lett.* 2003; **83** (2):380.

[10] S. Enoch, J.-J. Simon, L. Escoubas. Simple layer-by-layer photonic crystal for the control of thermal emission. *Appl. Phys. Lett.* 2005; **86**:261101.

[11] David L. Chan, Marin Soljačić, and J. D. Joannopoulos. Thermal emission and design in one-dimensional periodic metallic photonic crystal slabs. *Physical Review E* 2006; **74**:016609.

[12] Wang Z J, Zhang J, Xu S H et al., "1D Partially oxidized porous silicon photonic crystal reflector for mid-infrared application", *J Phys D: Appl. Phys.* 2007;**40:**4482-4484.

[13] Stanley R P, Houdre R, Oesterle U. Impurity modes in one-dimensional periodic systems: The transition from photonic band gaps to micro-cavities. *Phys Rev A* 1993; **48**(3):2246-2250.

[14] A. Mir, A. Akjouj, E. H. Boudouti et al. Large omnidirectional band gaps and selective transmission in one-dimensional multilayer photonic structures. *Vacuum* 2001; **63**(1):197-203.

[15] LIU Bi-liu, SHI Jia-ming, ZHAO Da-peng, ZHANG Wei, XU Bo. Analysis on the camouflage application of photonic crystals. *Laser & Infra.* 2009; **39**(1):42-45.

[16] GAO Yong-fang, SHI Jia-ming, ZHAO Da-peng. Analysis on far infrared and laser band compatible camouflage of one-dimensional doped photonic crystals. *Infra. Tech*. 2010; **32**(4):235-238.

[17] M. Born, E. Wolf. *Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light.*7th ed. Cambridge University Press;1999.

[18] E. D. Palik, *Handbook of Optical constants of Solids*. San Diego:Academic Press, 1998.

[19] GENG Ji-guo, SHI Zong-hua, YAN Ke-zhu. Study of band-gap structure of photonic crystals with two defects. *J. Opto-elect & Laser* 2006; **17**(12):1497-1501.

[20] LI Wen-sheng, FU Yan-hua, ZHANG Qin, SHI Du-fang. Characteristics of defect mode of quasi-periodic 1-D photonic crystal containing double defects. *Semi. & Opto-elect* 2010;**31**(2):241-244.

[21] TIAN Guo-xun, WU Yong-gang, WANG Zhan-shan. Design and modification of double channel of one-dimensional photonic crystal", *ACTA OPTICA SINICA* 2005;**25**(5):661-664.

[22] WANG Li, WANG Zhan-shan, WU Yong-gang et al., "Enlargement of the non-transmission frequency range of multiple-channeled filters by the use of heterostructures", *J. Appl. Phys.* 2004; **95**(2):424-426.

[23] WANG Xin, HU Xing-hua, LI Yi-zhou et al. Enlargement of omnidirectional total reflection frequency range in one-dimensional photonic crystals by using photonic heterostructures. *Appl.Phys.Lett.* 2002;**80**(23):4291-4293.