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參加國際性學術研討會議

會議名稱：

2012 International Conference on Applied Materials and Electornics Engineering (AMEE 2012)

服務單位：國立暨南國際大學

姓名︰科技學院 電機工程學系 孫台平 教授兼任院長

派赴國家：大陸 香港

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摘要

參加學術研討會是學術研究重要吸收專業知識機會，每年世界各地皆會舉辦大大小小研討會，對於本人研究領域於光電相關知識，研討會除了進行論文發表外，更舉辦優秀論文獎選拔、專家演講等項目進行，對於學術研究者吸收新知的場域與國際交流機會。本會議由International Association for Scientific and High Technology 和International Science and Engineering Research Center 舉辦，此會議涵蓋電子工程、材料應用、電子裝置、感測元件、生醫技術、雷射、影像、通訊技術等領域，會議論文將收錄於「Advanced Materials Research」，且部分優秀文章選擇於國際性期刊(SCI Journal)上，此行會難得機會與世界各地專家學者進行交流。

目錄

目的：

本會議為應用材料與電子工程領域，對於本人研究領域於光電材料與電子信息實務領域有所幫助，且此會議於中國香港舉辦，世界各地光電領域專家學者齊聚於會上，使本人所發表論文進行交流與探討，此次發表題目「Periodically one-dimensional photonic crystal filters applied on broadband quantum dot photodetectors」，主要是說明紅外線寬波段感測器材料特性突破與分析，透過研討會方式與世界材料專家學者進行交流，經評審專家將有機會收錄於國際性期刊(SCI Journal)上。

參加會議經過及記要：

本應用材料與電子工程會議由 International Association for Scientific and High Technology 和 International Science and Engineering Research Center 舉辦，每年於中國香港定期舉辦，今年舉辦地點於 1 月 18-19 日香港 Royal Park Hotel，會議時間為期 2 天，包含專家演講、論文發表等會議議程。此研討會主要分成兩大相關光科技領域，分別是 Electronics Engineering 與 Applied Materials，其中各個領域細分小章節，本人發表論文於 Semi-conductor and micro-electronic materials 領域，部分與紅外線感測器與影像系統範圍相關，此會議論文的主題很廣，包含應用材料、奈米電子、光電、感測器等，其中以光電製程方面研究論文較多。。

此論文發表方式於大會會議廳內張貼海報，並接受與會人員、國際學者觀摩與互動，並討論相關光電感測技術問題，匯集他方的意見及建議，也詢問本研究相關技術與創新性，以增進未來研究之深度及廣度。

Invited speaker Seoul National University Prof. Takhee Lee 報告 Organic Metal-oxide Dielectric for Thin Film Transistors and Non-volatile Memory Devices，主要報告內容以有機非揮發性記憶體應用於薄膜電晶體及非揮發性記憶體元件，經實驗數據可看出良好結果，且報告者探討單分子之傳導現象，更是深入分析物理機制，也有以低溫測量分析陷阱，更是促進自我研究專長領域啟發與感想。

感想與建議：

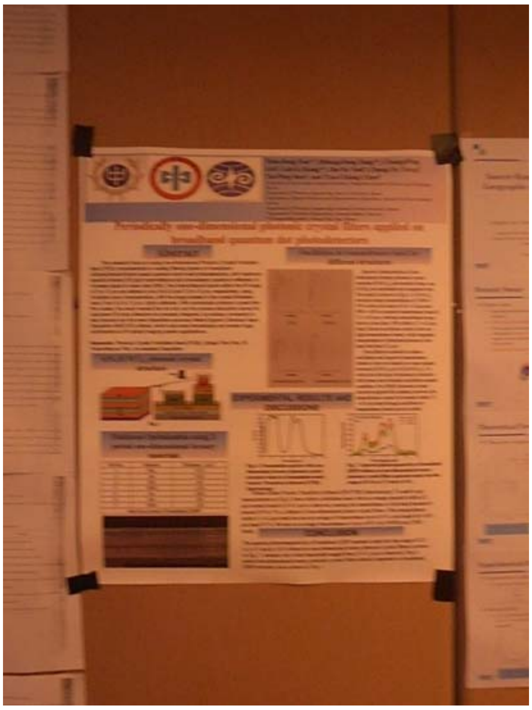
參與這次在香港舉行之 2012 International Conference on Applied Materials and Electornics Engineering (AMEE 2012)國際會議綜合了奈米科技、材料各個領域之研究及技術等方向，從中了解許多不同奈米材料製作技術之研究是可以結合光電製程技術領域，會議許多國際知名之教授，也有許多材料及半導體工程方面之專家與會，獲得相當多的啟發與技術新知，了解各個領域之專家如何製作新的製程方向並邁入更專精更寬廣之研究，並藉由其他學者所提出發問之內容，了解研究上所忽略之細節問題，為未來研究內容上能更詳細更寬廣。

攜回資料名稱及內容：

此次會議攜帶許多資料，包括了 2012 AMEE 會議論文集一本以及其他會議之相關資訊，藉由此會議得到許多相關領域期刊之會議徵稿，並參與於下年度的相關期刊會議，提升實驗室的研究與國際化研究方向。

附錄

註冊會場照片



發表論文照片

會場一偶

Periodically one-dimensional photonic crystal filters applied on broadband quantum dot photodetectors

Tien-Jung Fan[1,2], Shiang-Feng Tang[1,3], Chung-Ping Liu[2], Lai-Li Kang[1,4], Jia-Yu Tsai[5], Cheng-Yu Tseng[5], Tai-Ping Sun[4], and Tzu-Chiang Chen[5]

[1]*Materials & Electro-Optics Research Division, Chung-Shan Institute of Science and Technology, Taiwan*

[2]*Department of Photonics Engineering, Yuan Ze University, Taiwan*

[3]*Department of Applied Materials and Optoelectronic Engineering, National Chi-Nan University, Taiwan*

[4]*Department of Electrical Engineering, National Chi-Nan University, Taiwan*

[5]*Department of Electrical Engineering, National Defense University*

[1,3]*Corresponding author: Shiang-Feng Tang, Taiwan*

Corresponding author: Shiang-Feng Tang

Mailing Address: P. O. Box No. 90008-8-6, Lung Tan, Taoyuan, Taiwan

Telephones: +886-3-4712201ext357106 (office), +886-9-22237007 (Mobile)

Fax: +886-3-4711024

E-mail: shiangfengtang@yahoo.com.tw

Abstract: This research focus on using one-dimensional Photonic Crystal Forbidden Band (PCB) characteristics in coating filtering layers on broadband AlGaAs/GaAs/InGaAs based quantum-dot-in-well photodetectors, with maximum specific infrared (IR) light transmittance and unnecessary spectrum reflected, to increase signal to noise ratio (S/N). Two transmittance bands within the IR range of 3 to 12 μm are defined to be 3 to 5.2 and 7.2 to 12 μm, respectively, using forbidden band characteristics, with the range located in the crystal forbidden band, from 5.2 to 7.2 μm, highly reflected. With periodically photonic crystal thin-film coated, the result reveals that not only can the precise absorption bands for dual-band IR photo detectors be precisely designed, but epitaxy complexity is also reduced and the lower deposition-accuracy Metal-Organic Chemical Vapor Deposition (MOCVD) utilized, which cuts costs dramatically and render huge contributions to IR optical Imaging system applications.

Keywords: Photonic Crystal Forbidden Band (PCB), Optical Thin Film, IR Transmittance Film, Ion-assisted Deposition

1. INTRODUCTION

With IR having lower absorption than visible light within the atmosphere, dual-band IR sensors have its specific gain spectrum bands [1]. IR transparent materials in general are used for the infrared observation window. To cut back on noise, one additional filtering thin-film layer on the window is needed to have better ratio of signal to noise (S/N ratio), but it also augments optical system uncertainty. This study, based on forbidden characteristics of photonic crystal[2], investigates using materials of Ge, ZnS and YbF_3 as directly coating layers on of GaAs material of top contact layer on the detector structures to form periodic high, middle and low refractive-index thin-film photonic crystal layers, which, besides in-situ optical filtering, reduces complexity of wavelength-tuning and post lens assembly without optical filter. In this study, appropriate photo crystal thin films are designed and optimized, and two kinds of crystals, one-dimensional binary and one-dimensional ternary, are compared in terms of factors influencing filtering characteristics.

2. THEORY OF THE OPTICAL THIN FILM DESIGN

Based on applications for specific-wavelength detection, the appropriate coating material is selected on demand. The materials for fitting the design should be as transparent as possible in IR spectrum; furthermore, at least two types of material are needed following design principles for photonic crystal thin-film layers. Among those meeting above requirement are listed as Tab. 1, wherein we determine to adopt Ge as high refractive index material with symbol: H, ZnS as the middle one with symbol: M and YbF_3 the low one with symbol: L. The $0.5L(H\ M\ L)_2$ means half characteristic wavelength of low refractive index in addition with the two periodically characteristic wavelength thin-films composed of H, M and L refractive index materials. The above periodically photonic crystal thin-film layers are deposited on broadband QDIP structure shown in Fig.1. and similar fabrication of broadband QDIP is proposed from Tang, et al.[3]

To satisfy dual-band filtering function, one-dimensional periodically photonic crystal films is used for design. Photonic crystal thin-film technology, compared with regular films, brings features of fewer layers of films and small film thickness resulting in low hetero-structured strain. Using optical transformation matrix method, the formula is listed as follows [4]:

$$M_i(d) = \begin{bmatrix} \cos\beta & -(i/p)\sin\beta \\ -ip\sin\beta & \cos\beta \end{bmatrix} \quad (1)$$

,in which d is the dielectric layer thickness, $\beta = \mathbf{k_0 nz\cos\theta}$, $\mathbf{p} = \sqrt{\varepsilon/\mu}\cos\theta$ k_0 is the wave number in vacuum, ε is the dielectric constant, μ is the permeability (all materials examined are non-magnetic, μ = 1), refractive index , $n = \sqrt{\varepsilon\mu}$ and θ is the incidence angle between incident light and perpendicular direction on the dielectric surface. That said, the multi-layer eigen matrix can be represented as:

$$M_i(d_N) = \sum_{i=1}^{N} M_i = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \tag{2}$$

thus, thin-film photonic crystal reflectance and transmittance are:

$$R = |r^2| = \left| \frac{(m_{11} + m_{12}p_R)p_L - (m_{21} + m_{22}p_R)}{(m_{11} + m_{12}p_R)p_L + (m_{21} + m_{22}p_R)} \right|^2 \tag{3}$$

$$T = \frac{p_R}{p_L}|t^2| = \frac{p_R}{p_L}\left| \frac{2p_L}{(m_{11} + m_{12}p_t)p_L + (m_{21} + m_{22}p_R)} \right|^2 \tag{4}$$

,wherein $\mathbf{p_L} = \sqrt{\varepsilon_L/\mu_L}\cos\theta_L$, $\mathbf{p_R} = \sqrt{\varepsilon_R/\mu_R}\cos\theta_R$. εL, μL, εR and μR are photonic crystal left and right dielectric constants and permeability, respectively. θ_L and θ_R are the angles between the perpendicular direction of the dielectric surface and incidence light, transmitting light, respectively.

3. OPTICAL THIN FILMS COMPARISON IN PHOTONIC CRYSTAL

Spectral characteristics of one-dimensional ternary photonic crystal structure $(H\ M\ L)_2$ and another binary one $(H\ M)_5$ are calculated and compared with. The result is shown in Fig. 2—$(H\ M\ L)_2$ structure keeps transmittance of 100%～87% within the band of 4.0～5.3μm and 99%～82% in another transmittance band of 7.2～8.9 μm, whereas transmittance drops down to less than 10%

within 5.7～6.5 μm band. Severe oscillation exists in the two high-transmittance bands, which degrades transmittance of absorbed photons in the band less than 5.3 μm. One effective method to reduce oscillation and improve transmittance further in the two bands is to tune original structure $(H\ M\ L)_2$ to $0.5L(H\ M\ L)_2$ [4], in which the first layer thickness is halved to shift phase and eliminate oscillation-caused condition. For (HM)5 photonic crystal structure applied this method, however, the transmittance cannot be boosted within 7.2～8.9 μm band though oscillation in transmittance bands can be curbed.

4. ANALYSIS OF FACTORS INFLUENCING OPTICS SPECTRAL CHARACTERISTICS

4.1 IMPACT OF PERIODIC THIN-FILM FILTER ON PERFORMANCE

The period of photonic crystal structure has a large impact on characteristics of forbidden bands, and when target spectral characteristics can be satisfied, filters of fewer periods are advantageous in terms of practical processing. We calculated spectral characteristics of filter structures, 2-period $0.5L\ (H\ M\ L)_2$, 3-period $0.5L\ (H\ M\ L)_3$ and 4-period $0.5L\ (H\ M\ L)_4$, all using 0° incidence angles (along –y direction) as examples. The results are shown in Fig. 3, wherein we find the period influences the whole band spectral performance, high transmittance characteristics can meet our demand within 4.0～5.5 μm band at two periods, and steep spectral characteristics change at 5.5 μm and 7.0 μm locations can better benefit spectral control. Nonetheless, further more periods brings in worse oscillations in high-transmittance band, which is harmful to spectral control.

Therefore, separate band spectral characteristics and the whole IR detection system both need considering. From analysis we conclude: Based on filter design of dual transmittance bands of 4.0～5.2 μm and 7.2～9.0 μm as a precondition, the oscillation in the two bands should be reduced as much as possible via selection of optimal periodic numbers. Shown as Fig 2, 2-period filter structure bears better spectral performance.

4.2 INFLUENCE OF THIN-FILM THICKNESS DEVIATION ON FILTER PERFORMANCE

In practical processing for coating thin films, the real thickness for each layer (Fig. 4 shown and taken by Cross-sectional Transmission Electron Microscopy, X-TEM) may be somewhat different from designed ones (Tab 2). There exists an acceptable influence of deviation of layer thickness on filter spectral characteristics, thus, it still meets the requirements on demand.

We assumed each layer thickness has the same percentage of deviation, and to facilitate calculation, took the deviation to be 5% higher and lower than designed values and used incidence angle of 0° as input parameters for evaluating the impact of thickness deviation. The analysis result indicates the layer thickness deviation mainly impacts spectral characteristics within 3.0～5.5 μm band, especially for high and low refractive index layers. To clearly clarify issues, Fig. 5 offers transmittance characteristics in 4.0～5.5 μm band caused by layer thickness deviation for high and low refractive index layers. From Fig. 5, thickness deviation of Ge and YbF_3 layers will both induce right or left shift and transmittance dramatic oscillation in corresponding high-transmittance bands. Optimized layer thickness value for each layer will have a smoother transmittance spectrum, and Ge layer has a greater influence on spectral performance than YbF_3 if the two layers have the same absolute deviation. Deviation for each layer should be reduced as much as possible to guarantee spectral efficiency in coating thin-film filters practically.

5. OPTICAL THIN FILM FABRICATION

Optical thin films are fabricated using LH-1100 vacuum coater made by Leyblod corp, which machine equips with dual electron-beam guns. The electron-beam gun has a stable vaporization rate and does coating automatically combined with quartz monitors. The substrate is cleaned first by blended solution of ethyl alcohol and ethyl ether, then the gripper is put on the substrate hold. Close the door of the chamber, turn on the switch to begin vacuuming the chamber, and set the baking temperature at 100 ℃ to avoid the cracking of substrates due to non-uniform material stress caused by too high temperature. When vacuum level reaches 4×10^{-3} Pa, ionic source is turned on and the Argon gas in-flow rate is controlled to keep the vacuum chamber pressure at around 1×10^{-2} Pa. The ionic source can bombard the substrate to decompose hydrocarbon complex polluted on the substrate surface, and provide surface activation layer to facilitate thin film formation. All done, electron guns are turned on and vaporization process follows defined thin-film deposition procedures.

In above process, ZnS evaporation rate should be stepped up to keep at 1.2 nm/s considering its easiness to be decomposed, and contrarily, the rate of evaporating YbF3 needs to be kept at 0.25 nm/s to bypass film drop-off phenomenon. We utilize the thickness control technology which combines the quartz oscillation and the photoelectricity-limit-value methods, wherein optical wavelength is controlled and changed in the photoelectricity-limit-value method to monitor and control the film thickness and quartz oscillation is used to control evaporation rate.

6. EXPERIMENTAL RESULTS AND DISCUSSIONS

6.1 OPTICAL THIN-FILM FILTER CHARACTERISTICS TEST AND ANALYSIS

Perkin-Elmer Fourier Transform Infrared (PE-FTIR) Spectroscopy [5] is used to get measurements as Fig 6, from which a forbidden band with an average spectral width of 2 μm located inside 6.2~8.5 μm is observed, causing the transmittance in the band descend to around 50 %~5 %, a feature of one-dimensional photo crystal filters. Film transmittance inside 4.1~6.1μm band can see an average of transmittance up to 93 %, and inside 8.6~10.6 μm band 87 %. We have an average transmittance of up to 90 % for MWIR and LWIR bands.

6.2 CHARACTERISTICS EVALUATION OF IR PHOTODETECTOR AND OPTICAL THIN-FILM FILTER COMBINED

The spectral photoresponsivity of broadband QDIP operated under the bias range of 2.0 to 2.4 V and at 10 K without an one-dimensional ternary photonic crystal filters is shown in Fig. 7, wherein very wider bandwidth ranged from 3.5~11 μm is observed. The 2-period one-dimensional ternary photonic crystal filters directly deposited on broadband QDIP structure just as shown in Fig. 1. The spectral photoresponsivity of broadband QDIP deposited with an one-dimensional ternary photonic crystal filters is shown in Fig. 8. Separate dual-band of 4.1~6.4 μm and 8.6~10.5 μm is observed clearly, which well agrees with our estimation.

7. CONCLUSION

Based on band-gap engineering, normal IR dual-band photodetector utilize structure with two different-periodically hetero-epitaxy which demands precise design. It demands a super-high vacuum solid-state MBE technology to grow periodic stacking-layer structure for dual-band IR photodetector. Offering a new dual-band IR detector, this paper proposes using a broadband IR AlGaAs/GaAs/InGaAs based quantum-dot photodetector covering the 3~12 μm band, and concentrates on increasing the responsivity in LWIR and MWIR bands without necessarily designing quantum well depth and width precisely. Modulation design of the absorption band begins with selection of IR-transparent material, using optical transformation matrix method to do the one-dimensional thin film design via modulating film thickness and periods, increasing band transmittance, reducing oscillation in high-transmittance bands, and bombarding substrates to deposit thin films with ionic beams to grow epitaxial structures. As such, accurate IR dual-band absorption bands can be achieved, effectively simplifying epitaxy process complexity with lower-precision

MOCVD method [6] substituted to further reduce the epitaxy cost.

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Figures and Tables

Table 1. Proposed semiconductor film materials

Table 2 Thickness Optimization using 2-period one-dimensional ternary materials

Fig. 1. 0.5L(H M L)$_2$ photonic crystal structure

Fig. 2. Oscillation in transmittance band for different structures

Fig. 3. Transmission v.s. wavelength as the function of periodic numbers of PBC filters on spectral characteristics

Fig.4. Cross-sectional transmission electron microscopy photograph with 2-period one-dimensional ternary materials

Fig. 5. (a) to (d) Transmission and their enlarged spectra obtained under thick deviations on layers with high, mid- low refractive indexes for mid-wavelength band

Fig. 6 Transmission spectra with one-dimensional ternary photonic crystal structure taken by transmission-mode Fourier Transform Infrared (FTIR) Spectroscopy

Fig. 7. Spectral photoresponsivity of broadband QDIP without an one-dimensional ternary photonic crystal filters operated under the bias range of 2.0 to 2.4 V and at 10 K

Fig. 8. Photoresponsivity of separate dual-band of 4.1~6.4 μm and 8.6~10.5 μm

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Table 1. Proposed semiconductor film materials

Material	Characteristic Wavelength/nm	Refractive index	Transmittance range (μm)
Ge	500	4.0	1.8~23
ZnS	500	2.3	0.4~14
YbF3	800	1.52	0.25~14

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Table 2. Thickness Optimization using 2-period one-dimensional ternary materials

Film No.	Material	Thickness（μm）
1	YbF_3	0.75
2	Ge	0.55
3	ZnS	0.9
4	YbF3	1.55
5	Ge	0.55
6	ZnS	0.9
7	YbF3	1.55
GaAs top contact of broadband QWIP		

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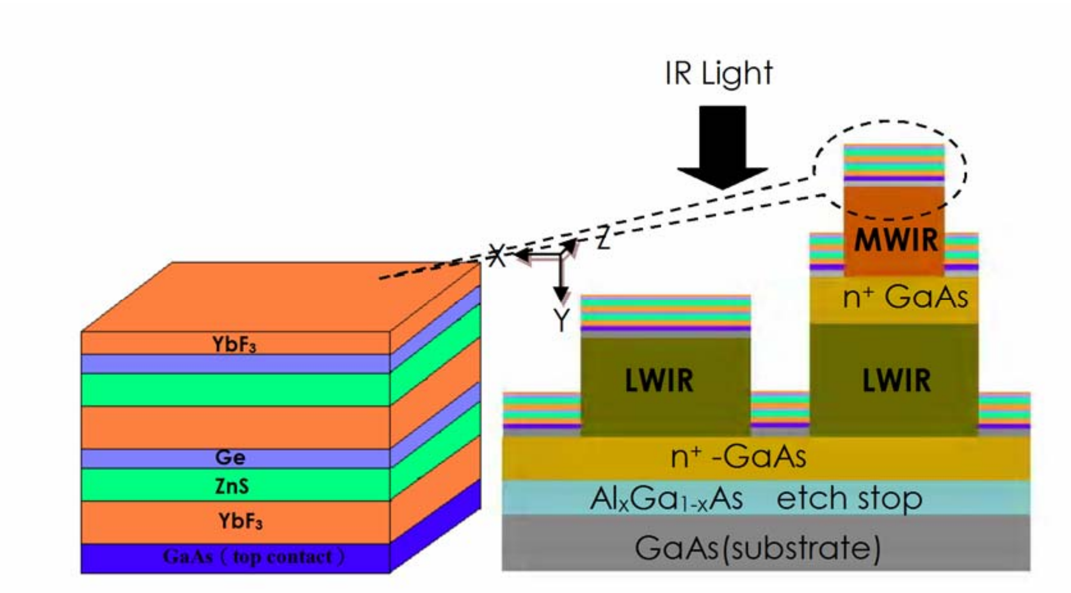

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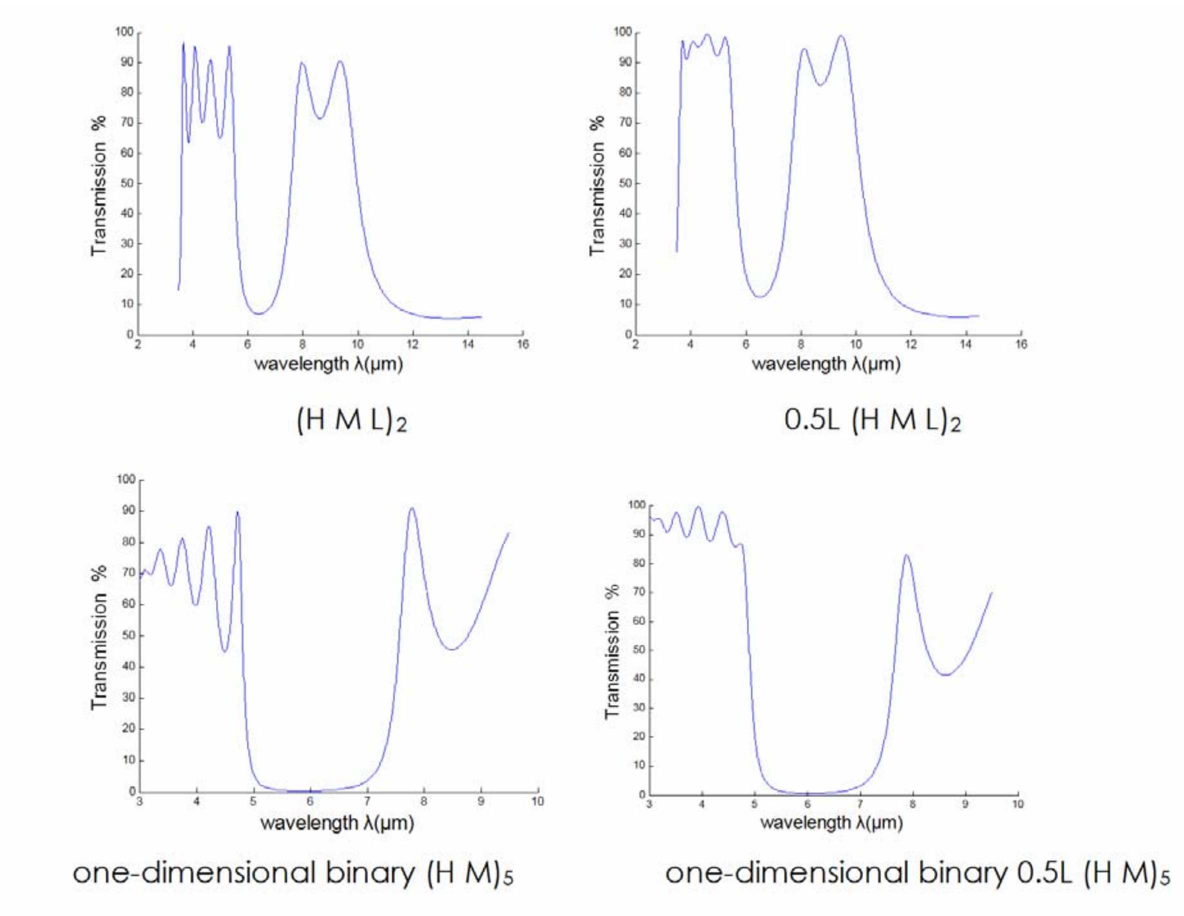

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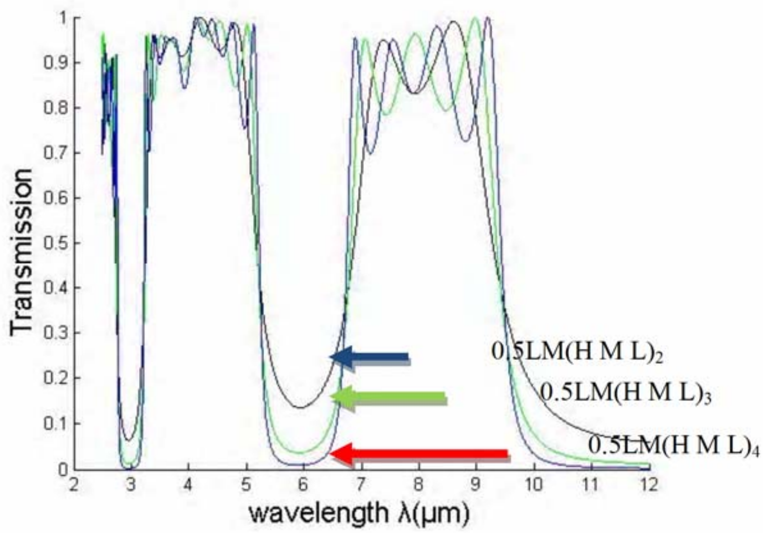

Fig.3. Transmission v.s. wavelength as the function of periodic numbers of PCB filters on spectral characteristics

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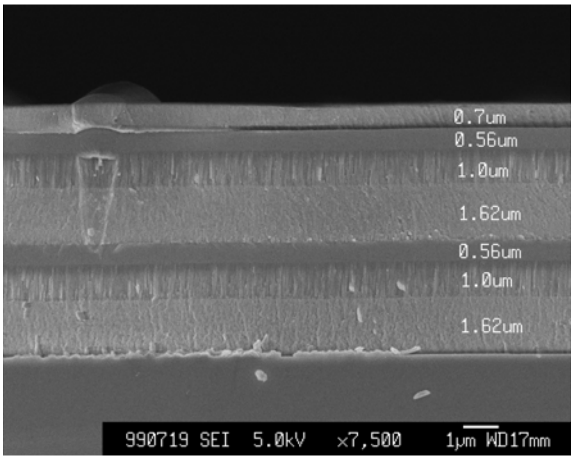

Fig.4. Cross-sectional transmission electron microscopy photograph with 2-period one-dimensional ternary materials

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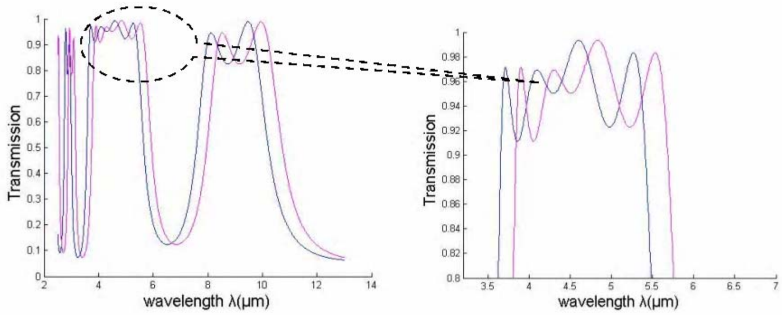
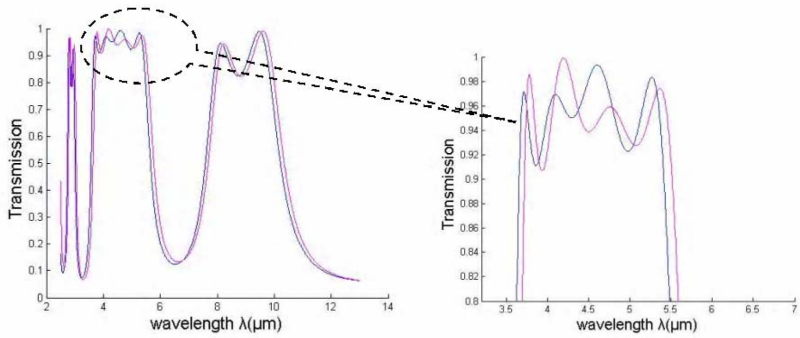
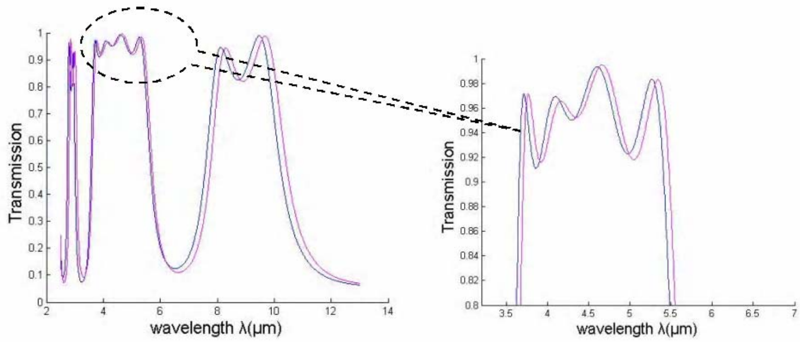


a. Transmission spectra under each layer thickness having the same percentage of deviation



b. Transmission spectra obtained under thick deviation on layers with high refractive index. Inset indicates transmission spectra at mid-wavelength band



c. Transmission spectra obtained under thick deviation on layers with mid-refractive index. Inset indicates transmission spectra at mid-wavelength band

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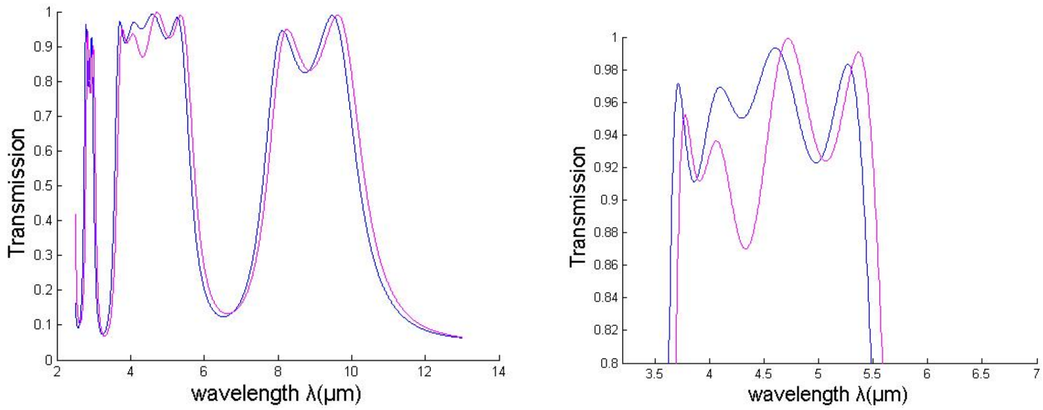

d. Transmission spectra obtained under thick deviation on layers with low refractive index. Inset indicates transmission spectra at mid-wavelength band

Fig. 5. (a) to (d) Transmission and their enlarged spectra obtained under thick deviations on layers with high, mid- low refractive indexes for mid-wavelength band

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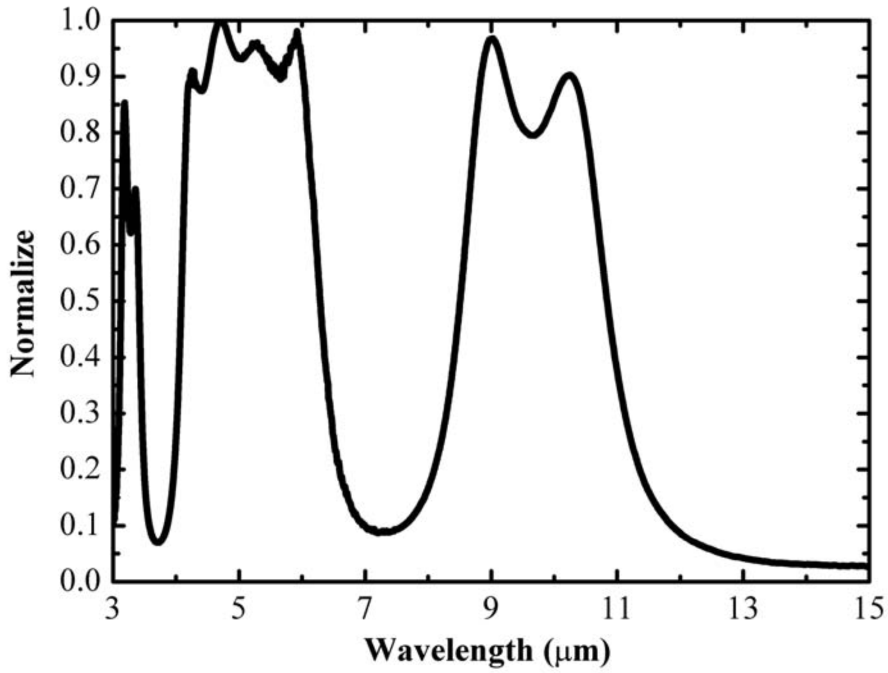

Fig. 6. Transmission spectra with one-dimensional ternary photonic crystal structure taken by transmission-mode Fourier Transform Infrared (FTIR) Spectroscopy

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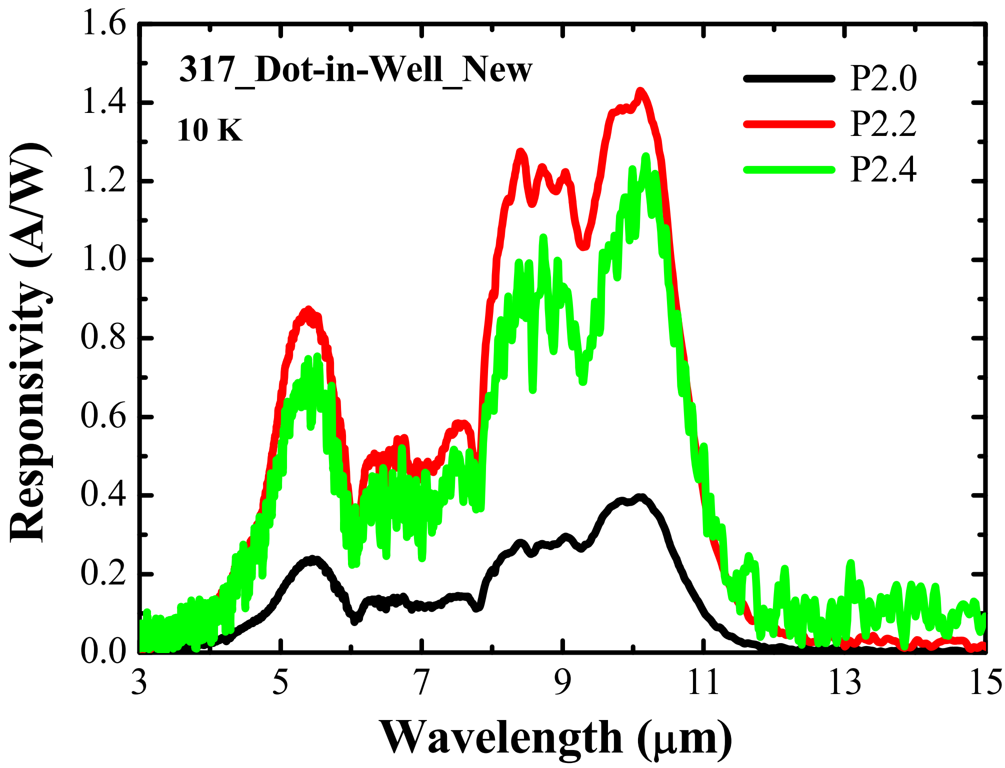

Fig. 7. Spectral photoresponsivity of broadband QDIP without an one-dimensional ternary photonic crystal filters operated under the bias range of 2.0 to 2.4 V and at 10 K

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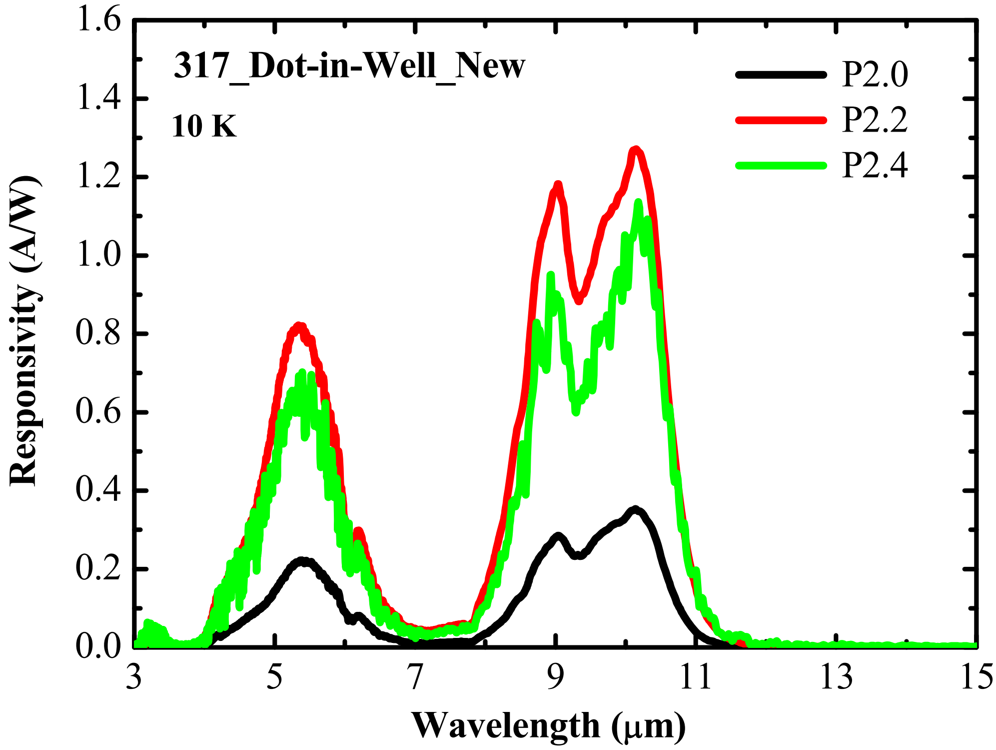

Fig. 8. Photoresponsivity of separate dual-band of 4.1~6.4 μm and 8.6~10.5 μm