國科會專題研究結案報告

光纖通訊應用光電元件製作及數值模擬---總計畫

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Summary:

I. 光纖通訊應用之非線性光學光電元件

We have numerically demonstrated the retracing behaviors (RB) of quasi-phase matching (QPM) phase-matching curve, which are the key phenomena for broadband optical parametric processes. With QPM, vertical phase matching curves and hence broadband operations exist in collinear, non-collinear, and quasi-collinear configuration. Broadband operation is feasible only at the degenerate point in the collinear configuration with a specific pump wavelength, λ_{BC}. Such a constraint sets a significant limitation in application. Particularly, all the broadband signals of collinear phase-matched PPLN, PPKTP, PPKTA, PPLT, and QPM GaAs (the data are not discussed in this paper) are beyond the fiber communication wavelength range and biological window (650 – 1300 nm). With non-collinear or quasi-collinear phase matching configuration, the conditions and output signal ranges of broadband operation are much more flexible, particularly those useful for fiber communication and optical imaging of biological tissues.

Journal Publications:

1. Chih-Nan Lin, Yean-Woei Kiang and C. C. Yang, "Wavelength Switching in a Mixed Structure of a Long-period and a Bragg Fiber Gratings," to appear in Chinese Optics Letters. **(invited)**
2. Horng-Shyang Chen, Shun-Lee Liu and C. C. Yang, "Below-band-gap Linear and Nonlinear-optics Waveguiding Characteristics of a Weakly Index-guided Semiconductor Laser," SPIE Proceeding, Vol. 4905, 2002.
3. Chung-Yih Tang, Paoyi Tseng, Chung-Yih Chiu, Chih-Nan Lin, Yean-Woei Kiang, and C. C. Yang, "Long-period Fiber Grating Effects with Double-sided Loading on Fiber," SPIE Proceeding, Vol. 4904, 2002. **(invited)**
4. Horng-Shyang Chen, Shun-Lee Liu, and C. C. Yang, "Below-band-gap Waveguiding Behaviors of a Weakly Index-guided GaAs/AlGaAs Quantum Well Laser," accepted for publication in Optics Communications.
5. Chih-Wei Hsu, Chieh-Ting Chen, and C. C. Yang, "Retracing Behaviors and Broadband Generation Based on Quasi Phase-matched Optical Parametric Processes," J. Optical Society of America B, Vol. 19, No. 5, pp-1150-1156, 2002.
6. Yan-Ju Chiang, Likarn Wang, Wen-Fung Liu, and C. C. Yang, "Multipoint Temperature-independent Fiber-Bragg Grating Strain Sensing System Employing Optical Power Detection Scheme," Applied Optics, March 2002.
7. Nai-Hsiang Sun, Chih-Cheng Chou, Ming-Jen Chang, Chih-Nan Lin, C. C. Yang, Yean-Woei Kiang, and Wen-Fung Liu "Analysis of Phase-matching Conditions in Flexural-wave Modulated Fiber Bragg Grating," J. Lightwave Technology, Vol. 20, No. 2, pp. 311-315, February 2002.
8. Jyh-Yang Wang, Jiun-Haw Lee,

Yean-Woei Kiang, and C. C. Yang, "Numerical Simulation on Pulsed Operation of an All-Semiconductor-Optical-Amplifier Nonlinear Loop Device," J. Lightwave Technology, Vol. 19, No. 11, pp. 1768-1776, 2001.
9. C. C. Yang, Yean-Woei Kiang, Jiun-Haw Lee, Jyh-Yang Wang, Horng-Shyang Chen, Chih-Wei Hsu, Ding-An Wang, and Chih-Chang Chen, "Nonlinear Optical Effects in Semiconductor Optical Amplifiers and Their Applications to All-optical Switching," SPIE Proceedings, Volume 4580, 2001. (invited)
10. C. C. Yang, Chih-Nan Lin, Chung-Yih Tang, Yan-Ju Chiang, Yean-Woei Kiang, Chih-Cheng Chou, Nai-Hsiang Sun, Chih-An Wei, Wen-Fung Liu, I-Ming Liu, Lung-Wei Chung, and Ding-Wei Huang, "Flexural Waves on Fiber and Fiber Bragg Gratings for WDM Switching and Gain Equalization of Erbium-doped Fiber Amplifiers," SPIE Proceedings, Volume 4579, 2001. **(invited)**
11. Yan-Ju Chiang, Likarn Wang, Wen-Fung Liu, Horng-Shyang Chen, Chih-Wei Hsu, and C. C. Yang, "Temperature-Insensitive Strain Measurement Using Two Fiber Bragg Gratings in a Power Detection Scheme," Optics Communications, Vol. 197, pp. 327-330, 2001.
12. Chih-Wei Hsu and C. C. Yang, "Broadband Optical Parametric Generation with Non-collinear Operation on Periodically Poled $LiNbO_3$," Optics Letters, Vol. 26, No. 18, pp.1412-1414, 2001.
13. Jiun-Haw Lee, Jyh-Yang Wang, C. C. Yang, and Yean-Woei Kiang, "All-Optical Switching Behaviors in an All-Semiconductor Nonlinear Loop Device," J. Optical Society of America B, Vol. 18, No. 9, pp. 1334-1341, 2001.

II. Research on Special-Type Optical Waveguides

Photonic crystal fibers (PCFs) or microstructured fibers are novel photonic structures that represent one successful application of the photonic crystal concept. In recent years many research efforts have been devoted to understanding the propagation characteristics of such fibers, based on different theoretical methods. In this research we have modeled and analyzed PCFs using the finite difference mode solver we developed. We demonstrate that the full-vectorial finite difference method that has often been employed to study waveguide modes of various dielectric waveguides can be efficiently used to obtain the propagation characteristics, including the effective indexes and field distributions, of different PCFs [1],[2]. We are able to calculate the dispersion properties of the original holey fiber. The dispersion properties are obtained by calculating the effective indexes of the guided modes over a range of wavelength. The actual index of the pure silica is taken into account by means of four-term Sellmeier formulas. The dispersion coefficient curve is then obtained by considering both the material and the waveguide dispersions, which is found to have very good agreement with reported experimental values.

We have previously established an efficient and highly accurate three-dimensional full-vectorial finite element numerical model (FEM-I) by introducing inhomogeneous elements to properly handle the boundary conditions at the interface between different dielectrics and at the corners of the dielectric structure [3], [4]. In this research we have employed the FEM-I to accurately calculate the propagation constants and the field distributions of the modes propagating in the MQW-based waveguides. Since the sparsity of the matrices of the final eigenvalue problem can be kept, the FEM-I can be used to analyze the MQW structure with a large number of wells. The accuracy of approximating the composite MQW region as a homogeneous region has been examined numerically by varying the MQW period. We conclude that replacing the MQW materials by a single homogeneous material with the root mean square value of the refractive index profile,

as has been used for planar MQW waveguides, is also useful for strip-loaded waveguides with a large number of MQW layers [5].

Publications:

[1] C. P. Yu and H. C. Chang, "Finite difference modal analysis of photonic crystal fibers," *Proc. Optics and Photonics Taiwan '01 (OPT '01)*, vol. I, pp. 178–180, Kaohsiung, Taiwan, R.O.C., December 13–14, 2001.

[2] C. P. Yu and H. C. Chang, "Research on photonic crystal fibers using finite difference electromagnetic analysis," *XXVIth General Assembly of the International Union of Radio Science (URSI) Proceedings CD-ROM*, paper 1197, Maastricht, the Netherlands, August 17–24, 2002.

[3] D. U. Li and H. C. Chang, "An efficient full-vectorial finite-element modal analysis of dielectric waveguides incorporating inhomogeneous elements across dielectric discontinuities," *IEEE J. Quantum Electron.*, vol. 36, no. 11, pp. 1251–1261, 2000.

[4] D. U. Li and H. C. Chang, "Full-vectorial finite element modal analysis of bounded and unbounded waveguides," *Proc. 2001 Asia-Pacific Microwave Conference*, vol. 1, pp. 376–379, Taipei, Taiwan, R.O.C., December 3–6, 2001.

[5] H. C. Chang and D. U. Li, "Full-vectorial finite-element analysis of multiple-quantum-well semiconductor waveguides," *2001 Asia-Pacific Radio Science Conference Digest (AP-RASC'01)*, p. 89, Chuo University, Tokyo, Japan, August 1–4, 2001.

III. 半導體光放大器元件內非線性現象與放大自發放光雜訊之數值研究

Because of the required functions of wavelength reuse and dynamic routing in a wavelength-division-multiplexing fiber communication network, all-optical wavelength conversion has been an issue of research focus for years. Besides four-wave mixing either in a semiconductor optical amplifier (SOA) or in fiber, the most commonly used methods are based on cross-gain and/or cross-phase modulation in an SOA. Recently, it has been experimentally and numerically shown that an SOA with a directional coupler configuration can improve the functions of wavelength conversion based on the cross-phase modulation. The directionally coupled SOA scheme has advantages over a conventional SOA wavelength converter in several aspects, including extinction ratio and response speed.

In this study, we report the results of numerical studies on wavelength conversion based on cross-gain/phase modulation in a multimode-interference (MMI) SOA. Although an MMI SOA can be regarded as a directional coupler of zero gap and its linear coupling phenomenon is similar to that of a directional coupler, their nonlinear coupling behaviors based on gain saturation and the associated phase modulation can be different. With our MMI SOA configuration, we found that the switching speed could be higher with about the same switching contrast, when compared with the operation in a directional coupler configuration. We also evaluated the effects of additive noise on the signal-to-noise ratio of wavelength conversion output.

Publication:

1. Nai-Jen Kuo, Yean-Woei Kiang and C. C. Yang, "Simulation of wavelength conversion in a multimode-interference semiconductor optical amplifier," Optics and Photonics Taiwan 2002, Taipei, December 2002.

IV. 含氮化合物半導體的磊晶成長與元件應用

在本計畫的含氮化合物半導體研究中，我們以加裝射頻電漿源的氣態源分子束磊晶機來成長含氮材料，在研究的方向上大致可分為發光波長 1.3 微米之 InGaAsN 及 2.2 微米以上 InAsN 長波長半導體材料研究與雷射製作。

對於少量含氮之氮砷化銦鎵長波長半導體雷射研究，因其巨大的能帶彎曲效

應的材料特性，當把少量的氮成份加入砷化銦鎵之中形成氮砷化銦鎵，將可見其晶格常數隨著氮含量的增加而縮小，但能隙變化卻也一起下降，可將以往於砷化鎵成長的光學元件操作波長由 1 微米，延伸至 1.3 微米、1.55 微米甚至更長的波段，是以此材料於近年來極受重視。我們在對磊晶成長參數最佳化後，已成功以射頻輔助氣態源分子束磊晶法，達成了 1.3 微米氮砷化銦鎵量子井雷射研製，雷射元件的內部量子效率可達 72% ，內部損耗為 6.8 cm^{-1}，在無鏡面損失下之臨界電流密度為 1,460 A/cm^2，已具有相當良好的特性。

在 InAsN 材料研究工作上，我們成長一系列位能井寬度 3 nm 的 $InAs_{1-x}N_x/InGa_{0.53}As_{0.47}$、週期單或 10 週的量子井結構。藉由光激螢光實驗方式得到其位能井中能隙躍遷值後，接著我們使用有限深方型位能井模型對這些 InAsN 量子井實驗數據進行理論分析及計算，計算過程中一併考慮材料應變、量子侷限及因氮原子加入所引發的 band anticrossing 等效應，計算所用到的 InAsN band anticrossing model 理論參數值是由我們過去 InAsN 塊材上得到的(band-anticrosssing model 應用在 InAsN 材料上的耦合參數 C_{NM}=1.68 eV 及高侷限態的氮能階 E_N 位在相對於砷化銦價電帶頂端 1.48 eV 處)。結果每一 $InAs_{1-x}N_x$ 量子井的實驗數據皆與我們的理論分析值相當吻合，並證明之前在 InAsN 塊材分析上所得的理論參數值是合理的。我們的理論分析也預測量子井中的電子有效質量將因氮的引入而變大，這與我們在對單週 InAsN/InGaAs 量子井所進行 Shubnikov-de Hass (SdH) 振盪實驗的結果定性上吻合。SdH 實驗結果顯示當 InAsN 量子井中的氮含量為 0.4%時、殘餘載子濃度為 $2.85\times10^{11}cm^{-2}$ 時其電子有效質量劇增為 $0.1\pm0.01\ m_0$。

Journal Pulications:

1. W. K. Hung, K. S. Cho, M. Y. Chem, Y. F. Chen, D. K. Shih, **H. H. Lin**, C. C. Lu, and T. R. Yang, "Nitrogen induced enhancement of the electron effective mass in $InAs_xN_{1-x}$, " *Appl. Phys. Lett., Vol. 80 (5),* pp. 796-799, (2002).
2. Y. Y. Ke, M. H. Ya, Y. F. Chen, J. S. Wang, and **H. H. Lin**, "Photoluminescence study of hydrogen passivation in $InAs_xN_{1-x}$/InGaAs single quantum well on InP, " *Appl. Phys. Lett., Vol. 80 (19),* pp. 3539-3541, (2002).
3. L. W. Sung, **H. H. Lin**, and C. T. Chia "Cubic GaN Grown on (001) GaAs substrate by RF plasma assisted gas source MBE, " *J. Crystal Growth., Vol. 241(3)* pp. 320-324, (2002).
4. D. R. Hang, C. F. Huang, W. K. Hung, Y. H. Chang, J. C. Chen, H. C. Yang, Y. F. Chen, D. K. Shih, T. Y. Chu, and **H. H. Lin**, "Shubnikov-de Haas oscillations of two-dimensional electron gas in an InAsN/InGaAs single quantum well, " *Semicond. Sci. Technol, 17,* pp. 999-1003, (2002).
5. D. K. Shih, **H. H. Lin**, L. W. Sung, T. Y. Chu, and T. R. Yang, "Band Gap Reduction in InAsN Alloys, " *Jpn. J. Appl. Physic.*, in press.
6. G. R. Chen, **H. H. Lin**, J. S. Wang and D. K. Shih, "Optical properties of $InAs_{1-x}N_x/In_{0.53}Ga_{0.47}As$ single quantum wells grown by gas source molecular beam epitaxy, " *J. Electronic Mat.* accepted.
7. D. K. Shih, **H. H. Lin**, and Y. H. Lin, "Strained InAsN/InGaAs/InP multiple quantum well structures grown by RF-plasma assisted GSMBE for mid-infrared lasers applications, " *IEE Proceedings – Optoelectronics,* accepted.
8. Li-Wei Sung, Hao-Hsiung Lin, and Chih-Ta Chia, "V-III ratio effect on Cubic GaN Grown by RF Plasma Assisted Gas Source MBE", *Mat. Res. Soc. Symp. Proc.*, 693, I3.22, 117, (2002).
9. Ding-Kang Shih, Hao-Hsiung Lin, Tso-Yu Chu, and T. R. Yang, "InAsN Grown by Plasma-Assisted Gas Source MBE", *Mat. Res. Soc. Symp. Proc.*, 692, H2.5, 61, (2002).

V. A New MEMS-Based Tunable External-Cavity Semiconductor Laser For Fiber-Optic Communication

A corner mirror, composed of two orthogonal surfaces, can be used to reflect incident light back to its incoming direction. In this report an array of micromachined corner mirrors is first reported to manipulate light beam in free space. Through MEMS technology, the corner micromirror allows to provide actuation on one of the reflective planes, causing destruction of preset orthogonal planes. Incorporated with a grating and other optical components, the corner mirrors are preset to maintain reflective light to its incoming direction, or may be actuated to destruct mirror verticality in order for free-space wavelength selection or intensity variation. In addition, the use of the corner mirrors may not need a lens for collimation in an appropriate optical configuration, thus simplifying the optical system and reducing alignment problems in assembly. A corner micromirror requires two orthogonal planes with virtually flat and mirror-like surfaces. The addressable micromachined corner mirror is constituted by three elements: a vertical mirror, a movable horizontal mirror, and a bottom electrode.

The addressing corner mirror array is able to be batch fabricated. The microstructures of the flat mirror and bottom electrode were anisotropically micromachined from Si(100) wafers. The thin gold film was evaporated onto the mirror surfaces and electrodes. The electrostatically switchable flat mirror was then assembled by anodically bonding both elements on the same glass carrier. Meanwhile, the gap for electrostatic actuation is critical, and thus requires a precise control in process and assembly. In the fabrication of vertical mirrors, the crystal plane was also bulk micormachined, but from a Si (110) wafer. The gold film was deposited for high reflection. To constitute the addressable corner mirrors, the patterned polymer BCB was heated in joining the fixed vertical mirror onto the flat mirror substrate. Consequently, the corner mirror array was achieved in final assembly.

The optical properties of mirror surface roughness and flatness were inspected through the atomic force microscope (AFM) and instrumental interferometer, WYKO MHT III. In the roughness of both virtually orthogonal planes, the vertical and horizontal surfaces were measured in root-mean-square (RMS) value to be 3.32 nm and 4.18 nm, respectively, which demonstrates insignificant surface scattering.

The addressable corner mirror array lies at the path of the first-order diffractive light after the emitted light is incident on the grating (700 lines/mm). Although no collimated lens was used in the experiment, the reflected light beam was detected from the corner mirror array.

We also demonstrate that, with the actuation of one corner mirror, the structure configuration failed to maintain its right angle, thus destructing the light path back to the incoming direction. The signal at the wavelength of 634 nm was not detected. The results significantly ensure the feasibility of the corn mirror array for wide optical applications.

行政院國家科學委員會補助延聘「博士後研究」人才
研究工作報告表

（本表請填送一式三份）

受聘者姓名	中文：許怡仁 英文：I-Jen Hsu	☑男 ◎女	聘　期	90 年 8 月 1 日至 91 年 7 月 31 日
研究計畫名稱	總計畫：光纖通訊應用光電元件製作及數值模擬		計畫主持人	楊 志 忠
補助延聘編號	NSC 90-2811-E-002-040			
研究工作全程經過概述（由博士後研究填寫，篇幅以三～四頁為原則）	研究工作全程經過概述： 許博士在前一期聘任期間（其國防役第三年），主要是善用其於固態雷射及光學實驗的專長，掌管本實驗室五套超快固態雷射，用以做各種元件及材料的光學特性，尤其，他架了一套光學同調斷層掃描系統，可以量測各種材料及元件的結構及色散特性，尤其，他利用光子晶體光纖及截面漸變之光纖，以超快雷射產生頻寬高達 300 nm 之寬頻光源，成果相當好。 其詳細內容請見附頁之說明。			

延聘博士後研究成效評估（由計畫主持人填寫）	一、是否達到延聘之預期目標？ 許博士在國防役第三年（即上期延聘）確實達到聘任目標，他不只自己在自己的研究上成果豐碩，而且，他協助研究生利用超快固態雷射，從事許多研究，充分發揮博士後的功能。 二、研究的方法、專業知識及進度如何？ 因許博士在本實驗已有三年，其研究方法與專業知識多有累積，進度如預期。 三、受聘人之研究對該計畫(或貴單位)助益如何？ 許博士在過去一年協助本實驗室解決許多光學量測問題，助益極大。 四、受聘人於受聘期間對增進其研究能力及經驗之助益如何？ 許博士自己在研究上的能力及專業知識進度極大，達到了服國防役累積學識及經驗之目的。 五、具體工作績效或研究成果：（篇幅不足部分，請另紙繕附） 過去一年內許博士以投稿於 SCI 專業期刊有兩篇乃第一作者，這兩篇文章都已經修改，將被接受發表，其成果詳見附件。 六、是否納編或移轉至其他單位或產業界？ 許博士於明年國防役期滿後，將進入產業界。

研究成果報告

許怡仁 91.7.19

本人於民國九十年八月一日至九十一年七月三十一日間，於國立臺灣大學電機資訊學院光電工程學研究所楊志忠教授研究群組擔任博士後研究員，參與國科會研究計畫「總計畫—光纖通訊應用光電元件製作及數值模擬」（NSC90-2215-E-002-041）之研究工作。在此期間，研究工作的主要內容可分為三部分。一為設計應用於光纖通訊上之光電元件，而以數值方法模擬光於此類元件當中之行為，進而完成適於光纖通訊應用之元件製作。

另一部分的研究為探討超短脈衝雷射於不同的光纖中所產生的非線性效應。由於超短脈衝雷射於光纖中具有高功率密度的特性，其藉由自相位調變、拉曼散射與四波混合等非線性效應，結合脈衝於光纖中所具有的色散性質，能使光源產生頻寬與頻譜形狀上的改變。此等作用無論在光通訊或者諸如光學同調掃描系統等之應用，均有相當大的研究價值。在研究當中，分別以脈衝寬度為 100 毫微微秒及 12 毫微微秒，中心波長為 800 毫微米的鈦寶石雷射，耦合至光纖當中。所使用的光纖則有 800 毫微米的單模光纖以及經特殊製作的拉細光纖。隨著耦合強度的增大，所產生的輸出光不但有中心波長偏移的現象，頻譜的寬度也明顯的隨著耦合強度而增大。在實驗當中，我們已可以此方法獲得波長範圍自綠光延伸至紅外光，半高全寬超過 300 毫微米的輸出光。

第三部分的研究則是應用超短脈衝雷射所產生的寬頻光源於一光學同調掃描系統上，並藉由色散補償的作用，提高系統的解析度。另外，更發展一套演算法，藉以減低系統所產生的贋像，並且進一步提高系統的解析度。研究結果已分別在國內與美國所舉行的國際會議當中發表，並投稿至國際期刊。由於在光學同調掃描系統當中，系統的縱向解析度與光源的頻寬成反比，因此由超短脈衝雷射經由光纖所產生的寬頻光源，對於提高系統的解析度有絕對的幫助。但當光源的頻譜非為高斯分布時，其自相關函數，或產生的干涉波包，將隨著頻譜形狀的改變而變化。另外，對於此類光源，若在系統的參考光與探測光的路徑中加入玻璃等介質，使光在兩者之間產生色散偏差，則其自相關函數將會受到進一步的影響。

在我們的研究當中發現，如果所使用的光源具有適當的頻譜形狀，其所產生的干涉波包有可能比來自高斯分布的頻譜具有更窄的半高全寬。而在適當的色散補償之後，干涉波包的寬度將可以進一步的壓縮。不過將伴隨著在干涉波包兩側的雜訊，而將造成造影上的贋像。對於此點，我們發展了一套利用反覆運算的演算法，以重建真實的影像。這些研究結果，已分別發表於去年在新加坡所舉行的「光電及應用—生物光電研討會」，在國內所舉行的「台灣光電科技研討會」、「生物醫學工程科技研討會」，今年一月在國內舉行的「生物光電研討會」，以及在美國聖荷西所舉行的「2002 生物光電研討會」，並將發表於今年十月在上海所舉行的「亞洲光電研討會」以及在日本札幌所舉行的「第一屆亞洲生醫光學研討會」。