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
子計畫一：光纖通訊應用之非線性光學光電元件

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含出席國際會議報告

中文摘要：
本研究主要針對週期區域反轉鈮酸鋰材料內的相匹配曲線迴轉行為探討，討論其可用於光通訊波長附近之大頻寬放大之用，另外，我們也在週期區域反轉鈮酸鋰材料上製作波導，並產生二倍頻及三倍頻。其他方面，我們也探討數個光纖及半導體光放大器之問題。

Abstract:
Broadband operations, based on retracing behaviors (RB) of the phase-matching curves, in various quasi phase-matched materials with collinear, non-collinear, and quasi-collinear phase-matching schemes are theoretically studied. 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. With a non-collinear or quasi-collinear phase matching configuration, the conditions and resultant output signal ranges of broadband operations are much more flexible, particularly those useful for fiber communications and optical imaging of biological tissues. In a signal-resonated (idler-resonated) optical parametric oscillator (OPO) with non-collinear or quasi-collinear configuration, RB and hence broadband operation can be observed only for pump wavelength shorter (longer) than λ_{BC}. Also, broadband operation for an idler-resonated OPO with pump wavelength longer than λ_{BC} can be obtained only at the degenerate point. Nevertheless, broadband phenomena for a signal-resonated OPO with pump wavelength shorter than λ_{BC} can be observed either at degenerate points or away from the degenerate points.

Summary:
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.

In a signal-resonated (idler-resonated) OPO with non-collinear configuration, RB and hence broadband operation can be observed only for pump wavelength shorter (longer) than λ_{BC}. Also, broadband operation for an idler-resonated OPO with pump wavelength longer than λ_{BC} can be obtained only at degenerate points. Nevertheless, broadband phenomena for a signal-resonated OPO with pump wavelength shorter than λ_{BC} can be observed either at degenerate points or away from the degenerate points. These rules are also true for quasi-collinear configurations. They are actually quite general for all concerned QPM crystals and are valid for the BPM configuration.

Besides these trends, a few common phenomena for broadband operation based on QPM crystals deserve mentioning. First, as pump wavelength approaches λ_{BC}, the phase-matching angle for implementing broadband OPO becomes smaller (closer to the collinear case). In this situation, the broadband signal wavelength range is closer to the degenerate point and signal bandwidth becomes larger. Second, the phase-matched QPM period for broadband OPO in quasi-collinear configuration is always smaller than that in a non-collinear scheme. With a shorter pump wavelength, the difference in QPM period becomes larger. Third, the phase-matching angles for broadband OPO in quasi-collinear cases become quite large, particularly with short pump wavelengths. With a shorter pump wavelength, the angle between idler and pump becomes larger. In this situation, the overall efficiency will be reduced.

In the cases of non-collinear and quasi-collinear configurations, broadband generation can be obtained at the expense of nonlinear conversion efficiency. In both cases, the advantage of increasing crystal length for enhancing conversion efficiency in the collinear configuration does not exist. Considering the operation of difference-frequency generation, the conversion efficiency depends on the overlap degree of the incident pump and signal/idler beams. For the quasi-collinear case, if a waveguide structure is fabricated, the conversion efficiency is actually not degraded when compared with the typical collinear configuration with a waveguide structure. This is so because usually the fabricated waveguide cannot guide the idler, resulting in the similar situation to the quasi-collinear configuration.

From the results reported above, one can see that the suitable pump wavelengths for broadband generation are always shorter than 900 nm. Such high-coherence pump sources are available on the market. For instance, widely tunable narrow-bandwidth Ti:sapphire laser (with a ring cavity) should be useful for such operations. When a compact setup is required, such as for the application to fiber communications, highly coherent laser diodes based on GaAs/AlGaAs or GaAs/InGaAs quantum well structures should be developed first.

Also, in experiments with non-collinear OPG on PPLN, we have theoretically predicted retracing behaviors of phase matching and experimentally demonstrated the generation of broadband signal and idler beams. The broadest signal spectrum covered the wavelength range from 1.66 through 1.96 μm. The corresponding idler wavelength ranged from 2.328 through 2.963 μm. Note that the OPG output bandwidth reported can be reduced if an OPO is implemented because of the propagation direction confinement of either signal or idler.

Meanwhile, we report the reduced waveguiding efficiency for the signals around 1560 nm as the injection current of an GaAs/AlGaAs multiple quantum well laser diode (lasing wavelength at 840 nm) with a ridge-loading waveguide configuration increased. This reduction trend stopped when the injection current reached the threshold condition of the laser diode. The decreased waveguide transmission and the more expanded mode profile indicated the variation of the effective refractive index gradient in the lateral dimension with injection current. This variation was due to the refractive index decrease with increasing carrier density even below band gap. A slab waveguide model was used to simulate the lateral mode profile variation with injection current. The refractive index differences between the guiding layer and claddings in the slab waveguide model provided estimates of refractive index contrasts of the laser diode at a concerned wavelength under various injection conditions.

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.