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Multi-channel reading in free space for WDM signals with photorefractive connection module

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Abstract

We propose a multi-channel reading method of desired channel data in free space for WDM (Wavelength Divided Multiplexing) signals with a PRCM (Photorefractive Connection Module). We estimate the output efficiency and the amplification for the number of multiple reading channels. We analyze the output efficiency for phase mismatching angle and the optimum separation angle between control beams for each wavelength.

1. Introduction

We have proposed a free space WDM system with a PRCM (Photorefractive Connection Module).[1][2] PRCM is an optical module with CPFWM (Cross Polarized Four-Wave Mixing) and PBS (Polarization Beam Splitter), and works as optical amplifier and distributor without the need for electricity conversion in free space. WDM technology is the ability to simultaneously transmit signal data on multiple wavelengths.[3] By using WDM signals, PRCM exponentially improves the performance of the WDM system because SDM (Space Divided Multiplexing) signals can be connected with this module directly. By now, we had simulated and experimented the method that only one channel data is branched in this module.

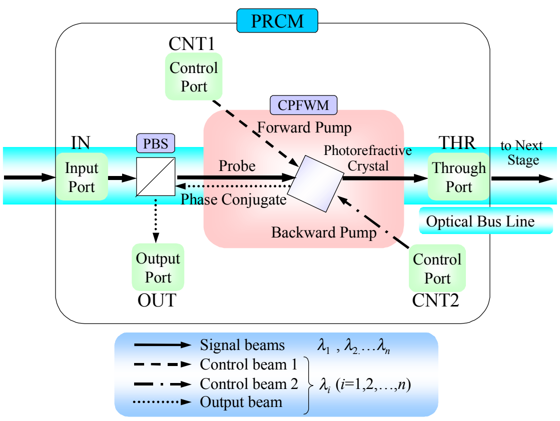

Fig. 1 The conceptual design of PRCM

In this report, we analyze the output efficiency and the amplification for the reading channel number. As multiple output beams is read, the cross talk is generated because the phase mismatching condition is insufficient for other channel beams. By adjusting a different angle of the control beams in several wavelengths, the cross talk is suppressed. We analyze the output efficiency for the phase mismatching angle, and investigate the optimum separation angle between control beams for each wavelength.

2. Multi-channel reading method in PRCM

The schema of PRCM with WDM signals is illustrated in Fig. 1. PRCM is an optical module included CPFWM (Cross Polarized Four-Wave Mixing) and PBS (Polarization Beam Splitter), and it has three signal ports and two control ports. The relationships between each port of the PRCM and the optical waves that contribute to CPFWM are as follows: the IN, OUT, CNT1 and CNT2-Port correspond to the probe beam, the phase conjugate beam, the forward pump beam and the back pump beam, respectively. WDM signal beams are incident from the IN-Port and transmitted from the THR-Port to the next PRCM stage, respectively. The angles of the signal beam, the control beam 1 at the CNT1-Port, and the control beam 2 at the CNT2-Port are adjusted to satisfy the phase matching condition in several wavelengths, and these beams have different angles to not satisfy the phase matching condition for other channels in several wavelength. The channel data are read by the control beam 1 and the control beam 2 of the desired channel, and is extracted from OUT-Port. By illuminations of the control beams of multiple wavelengths, multi-channel reading can be realized in this module.

3. Output efficiency and amplification of signal

In this chapter, we calculate the output efficiency and the amplification of the signal for the number of multiple reading channels in the PRCM. The optical geometry of CPFWM, which is core of the PRCM, is illustrated in Fig. 2. A_{1i}, A_{2i}, A_{3i} and A_{4i} (i=1,2…n) denote the complex field amplitudes of the signal

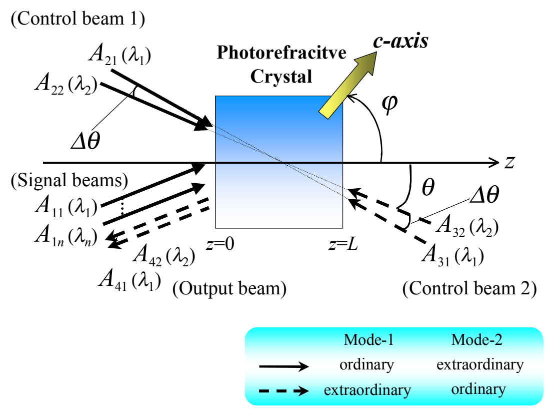

Fig. 2 The optical geometry of CPFWM

beams, the control beam 1, the control beam 2, and the output beams, respectively. Wavelength of these beams is λ_i. θ is the angle of the control beam 2, and $\Delta\theta$ is the separation angle between the control beams. φ is the angle between c-axis and z-axis, and z=0 and L are the boundaries of the crystal. The energy of each beam flows to the orientation of the c-axis. PRCM has two modes, which are Mode-1 and Mode-2. In Mode-1, the polarization of the signal beams and the control beam 1 (writing beams) are the ordinary waves, the control beam 2 and the output beams (reading beams) are the extraordinary waves. In Mode-2, the writing beams are the extraordinary waves and the reading beams are the ordinary waves. We can take advantages of the efficient generation of the output beams in Mode-1 and the amplification of the signal beams in Mode-2.[4]

In the numerical analysis, we assume that the photorefractive medium is a $BaTiO_3$ crystal, the phase matching condition of every wavelength is satisfied, and the optical absorption loss in the crystals is negligible. The coupled wave equations are described as

$$\frac{\partial A_{1i}}{\partial z} = -\gamma_\xi \frac{A_{1i}A_{2i}^* + A_{3i}A_{4i}^*}{I_0} A_{2i} \tag{1}$$

$$\frac{\partial A_{2i}}{\partial z} = \gamma_\xi \frac{A_{1i}^* A_{2i} + A_{3i}^* A_{4i}}{I_0} A_{1i} \tag{2}$$

$$\frac{\partial A_{3i}}{\partial z} = \gamma_\eta \frac{A_{1i}A_{2i}^* + A_{3i}A_{4i}^*}{I_0} A_{4i} \tag{3}$$

$$\frac{\partial A_{4i}}{\partial z} = -\gamma_\eta \frac{A_{1i}^* A_{2i} + A_{3i}^* A_{4i}}{I_0} A_{3i} \tag{4}$$

where I_0, which is the total beam intensity, is described as

$$I_0 = \sum_{i=1}^{n} I_{1i} + \sum_{k=2}^{4} \sum_{l=1}^{j} I_{kl} = \sum_{i=1}^{n} |A_{1i}|^2 + \sum_{k=2}^{4} \sum_{l=1}^{j} |A_{kl}|^2 \tag{5}$$

where j (=1,2…n) denote the simultaneous reading channel number. The subscripts ξ and η represent

"o" and "e" in Mode-1, and the subscripts represent "e" and "o" in Mode-2, respectively. Subscripts "o" and "e" represent ordinary and extraordinary beams. γ_o (γ_e) is the coupling coefficient. We define the output efficiency as E ($=I_{4i}(0)/I_{1i}(0)$) and the amplification of the signal as m ($=I_{1i}(L)/I_{1i}(0)$). The control ratio p and the signal ratio q are defined as $I_{3i}(L)/I_{2i}(0)$ and $I_{1i}(0)/I_{2i}(0)$. Wavelengths of λ_1 and λ_2 are 514.5nm and 633nm. We assume that two different wavelength beams don't interfere to one another. We have already analyzed that this module can multiplex signal beams about 50 degrees theoretically,[2] and so assume that the degree of multiplexing signal beams is 50. We also provide L=3[mm], and p=1, q=3 φ=270° and θ=10° in Mode-1 and p=0.1, q=0.1 φ=45° and θ=2.5° in Mode-2.

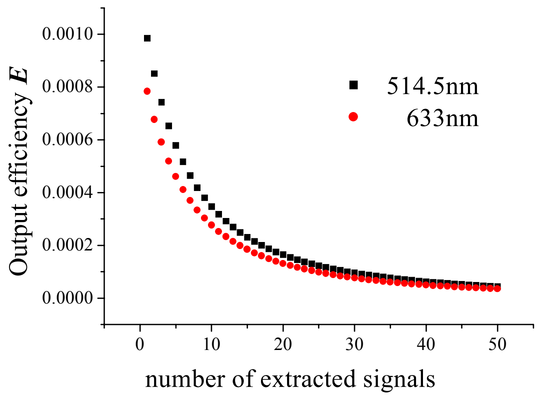

Fig. 3 The output efficiency for the multiple reading channel number

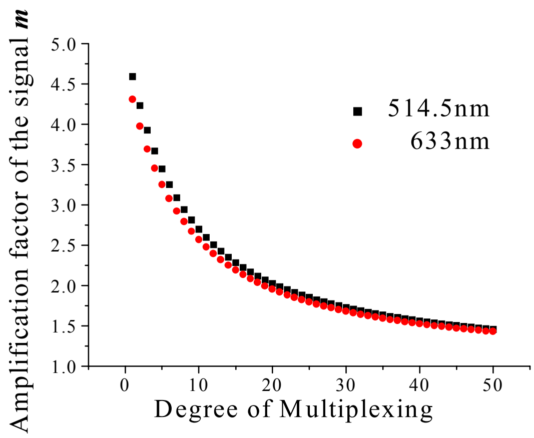

Fig. 4 The amplification factor of the signal for the multiple reading channel number

Fig. 3 shows the output efficiency of 514.5nm and 633nm signal beams for the number of multiple reading channels in Mode-1. As the channel number increases, the output efficiency decreases because the index grating is erased by the other channel beams.

Fig. 4 shows the amplification factor of the signal for the number of multiple reading channels in Mode-2. As the channel number increases, the amplification of the signal decreases because the index grating is erased by the other probe beams and energy transfer from the forward beam to the probe beam is restrained. The amplification factor is about 1.4 in 514.5nm and 633nm when the degree of multiplexing is 50. We note that the output efficiency and the amplification factor of 514.5nm are larger than that of 633nm. The reason is that the coupling coefficient of 514.5nm is larger than that of 633nm.[5]

4. Separation angle between channels

As multiple signals is read, the cross talk, which is the component of other signals when the desired output signal is extracted, is generated because the phase mismatching condition is insufficient for other channel beams. This matter can be solved by adjusting the angles of control beams in several wavelengths. In this chapter, we analyze the output efficiency for the phase mismatching angle to investigate the optimum separation angle between control beams for each wavelength. We assume that we extract the multiple channel data wavelengths of which are 488nm, 514.5nm and 633nm.

To numerous analysis, the coupled wave equations applied 2 wave mixing approximation with consideration of phase mismatching are described as

$$\partial A_{1i} / \partial z = -\gamma_{\xi} \left(A_{1i} A_{2i}^{*} \right) A_{2i} / I_0 \quad (6)$$

$$\partial A_{2i} / \partial z = \gamma_{\xi} \left(A_{1i}^{*} A_{2i} \right) A_{1i} / I_0 \quad (7)$$

$$\partial A_{3i} / \partial z = \gamma_{\eta} \left[A_{1i} A_{2i}^{*} \exp(-i\Delta kz) \right] A_{4i} / I_0 \quad (8)$$

$$\partial A_{4i} / \partial z = -\gamma_{\eta} \left[A_{1i}^{*} A_{2i} \exp(i\Delta kz) \right] A_{3i} / I_0 \quad (9)$$

where *Δk* is the amount of phase mismatching. The output efficiency is derived

$$R = \frac{I_{3i}(L)}{I_{1i}(0)} \sin^2 \left[-\gamma_e \eta \int_0^L \frac{\cos(-\Delta kz')}{2\cosh\left(\gamma_o \eta z' + \ln\sqrt{q}\right)} \right] \quad (10)$$

where

$$\eta = \{ I_{1i}(0) + I_{2i}(0) \} / I_0 \quad (11)$$

Fig. 5 shows the output efficiency normalized by the maximum output efficiency of each wavelength for the deviation angle from the phase matching angle, where we provide *L*=3[mm]. The amount of the phase mismatching angle is larger, the normalized output efficiency is smaller. In case that the phase matching angles is 0.015[deg.], 0.012[deg.] and 0.011[deg.] for 633nm, 514.4nm and 488nm, the normalized output efficiency is about 0. The wavelength of the extracted channel becomes shorter, the output efficiency declines more sharply for the deviation angle from the phase matching angle, that is, the separation angle between the control beams required to necessary to decrease the cross talk, is smaller. Besides, the interaction length is larger, the deviation angle can be smaller because the phase mismatching is proportional to the interaction length.

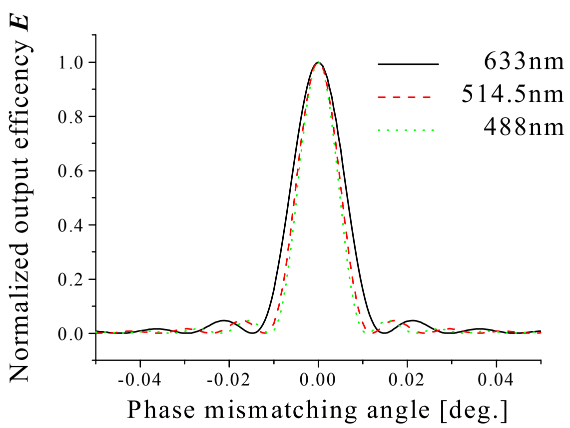

Fig. 5 The normalized output efficiency for the different angle from the phase matching angle

5. Conclusion

In this report, we proposed a multi-channel reading method of desired channel data from WDM signals in the PRCM. The wavelength of the extracted channel becomes shorter, the separation angle between the control beams becomes narrower. In case of a multiple reading of 50 channels, extracting performance of data seems to become 50 times. This method can improve the output performance of signal data.

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