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All-Optical Reconfigurable Interconnection for Free Space and Wavelength Division Multiplexing System

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Abstract

We suggest an all-optical interconnecter, which can be used in the spatial and wavelength division multiplexing system. This device can switch spatially-connected output channels according to multiplexed wavelength, and apply this operation to the whole spatial arrayed channels simultaneously and all-optically. We use photorefractive crystal as hologram material and examine the switching performance for the wavelength λ=514nm and λ=488nm.

1. Introduction

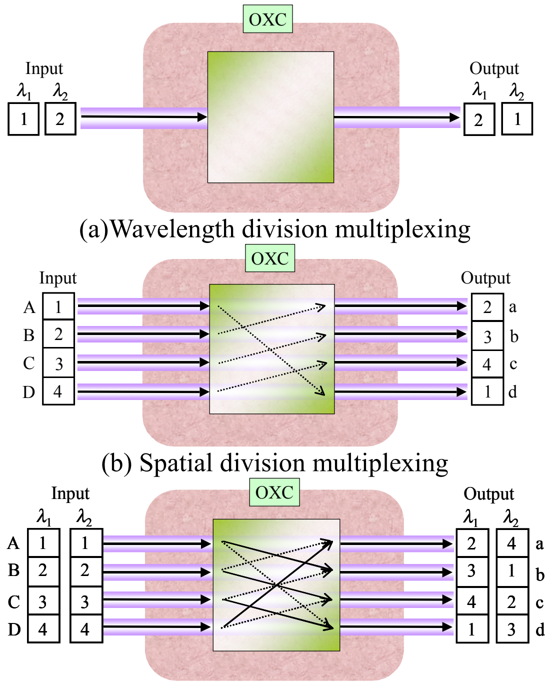
By taking advantage of optical spatial parallelism, the free space interconnection is useful in interconnecting between fibers, or between modules with several input and output (I/O) ports. Unlike such a conventional method, this study performs experiments to propose a new system, aimed at more multi-dimensional all-optical interconnection. Actually, signals interconnected in this experiment are spatially-arrayed or spatial division multiplexed signal, while each spatially-divided channel transmits WDM signal. Interconnection device, suggested in this study, can switch spatially-connected output channels according to multiplexed wavelength, and apply this operation to the whole spatial arrayed channels simultaneously and all-optically.

First of all, we explain the basic concept and the principle of the operation regarding multidimensional optical interconnection, then suggest new optical systems, which can be used in four spatial division and dual wavelength division multiplexing system. In the interconnection suggested, I/O signal arrays are aligned spatially in the form of linear array, while each I/O channel is multiplexed by means of two different wavelengths. In the OXC(Optical Cross Connector), input signal is divided into several wavelength components. As for each wavelength, spatial interconnection is conducted, and the resulting divided wavelength is transformed into wavelength multiplexing signals in each output channel. Also, in order to conduct these processes all-optically, it is necessary to rewrite interconnection patterns, by using light, not electrical signal. This study focuses on basic operational experiments, using photorefractive crystal as hologram material which can utilize two-dimensional control matrix signals, and examines wavelength dependency of materials.

2. Spatial and wavelength division multiplexing system

Fig. 1 shows block diagrams as for interconnection operation in several type of multiplexing systems. The figure (a) shows the WDM case, and demonstrates each element of input signal array corresponds to the wavelength divided in one fiber, etc. Regarding OXC, by switching wavelengths within WDM signals input, WDM signals reconstructed are output. The figure (b) illustrates the SDM case, and describes several spatially-aligned signals. In this case, OXC is associated with free space interconnection, but particularly when I/O signal array is two-dimensional, interconnecting makes an electrically difficult technology. Thus, advantages by optical interconnection are focused on instead. The figure (c) demonstrates the concept of multi-dimensional optical interconnection suggested in this study. I/O signal arrays are spatially-aligned in the form of linear array, with each I/O channel wavelength-multiplexed. In OXC, input signals are divided into several wavelength components. After spatial interconnection is conducted as for each wavelength, the resulting wavelengths are transformed into WDM signals in each output channel.

What we suggest in this study, by applying photorefractive crystal to hologram material as free space



(c) Multi-dimensional Division Multiplexing (Space and Wavelength)

Fig.1 Block diagrams as for interconnection operation in several type of multiplexing systems

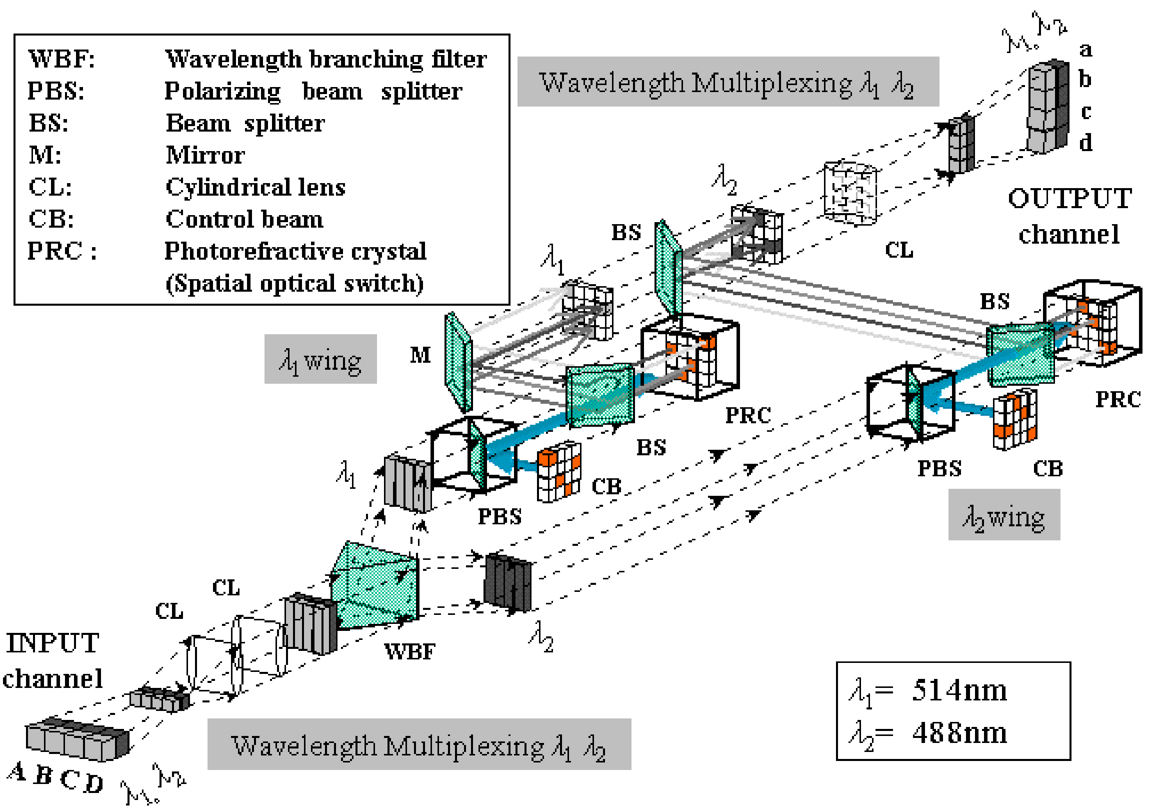


Fig.2 Reconfigurable interconnecter based on twin photorefractive self-pumped phase conjugator. Dual wavelength multiplexed spatial arrayed signal can be connected with this device and the connection pattern is pure optically controllable.

interconnector, is to adopt a method, which enables all-optical multi-dimensional optical interconnection above mentioned. The actual example is illustrated in the Fig. 2. In this figure, signals are four spatial multiplexing, that is to have four spatial channels. On the other hand, each spatial channel is multiplexed by two wavelengths. The input signal array, which incomes to OXC from the left side of the figure, is first divided into two wavelengths by the wavelength branching filter. After each wavelength component is put through the 4×4 free space interconnection device to be spatially interconnected, it is reconstructed according to each spatial channel. As a result, several input signals, which originally are included in the same spatial channel, are allocated into spatial channels different in wavelength, and connected to spatial channels on the side of output.

The free space interconnection by photorefractive crystals consists of vector multipliers which use anamorphic optical systems[1]. The input signal array, which is expanded into two dimensional matrixes by cylindrical lens, incomes to the photorefractive crystal, along with control light determining interconnection pattern. In photorefractive crystal, diffraction beam of input signal occurs by self-pumped four-wave mixing. However, the part illuminated by the control beam finds no diffraction beam, thus it is possible to control all-optical interconnection, by using spatial intensity pattern given to the control beam.

3. Experiment

We perform the basic experiments on the optical multiplier, which is core of the all-optical multi-dimensional interconnecter. The experimental setup of the 4×4 free space vector multiplier is shown in Fig.3, that is correspondent to λ=514 [nm] wing of Fig. 2.

The sizes of the signal beam pattern SP and the erase beam pattern EP are 10 [mm]×10 [mm], respectively, and the incidence angle of the beam to the crystal surface is approximately 30°. Assuming that f_i (i=1～4) is the focal length of L_i, f_1, f_2, f_3 and f_4 are 10 [mm], 200 [mm], 1000 [mm] and 100 [mm], respectively. The size of photorefractive $BaTiO_3$ crystal is 5 [mm]×5 [mm]×5 [mm]. Fig.4 is the photographs of the input, the control and the output channels that taken at 1, 2 and 3 in Fig.3, respectively. The left side of the figure shows a connection from 'A' to 'a', and the right side is from 'A' to 'c'. It was shown to be reconfiguable by the pure optical control pattern. The observed output intensity of output port 'a' was 27.4[μW], and that of 'c' was 22.0[μW] for the input of 336[μW].

We also investigate the optimum incident angle of the signal beam on the crystal by using λ=514 [nm] and 488[nm] light. We use an Ar^+ ion laser whose wavelengths are 514 [nm](=λ_1) and 488 [nm](=λ_2). θ is the incident angle of the signal beam respected with the crystal surface. The incident beam intensity is 4.95 [mW] for λ_1 and λ_2. Fig.5 shows the experimental result. We can obtain the large output efficiency, that is over 35%, by adjusting the incident angle θ= 56 [deg] in case of λ_1. The efficiency

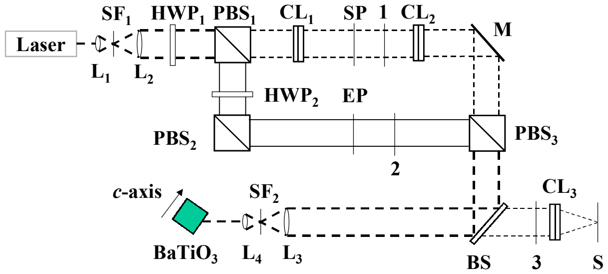


Fig. 3 Experimental setup of λ=514 [nm] wing

decreases as the incident angle deviates from this optimum angle. On the other hands, the output efficiency is about 14% by adjusting the optimum angle $\theta = 58$ [deg] in case of λ_2. This value is small compared with that of λ_1, but it is obtained stably in large angle range. We use the two crystals for each wavelength of the signals in Fig. 2, but we can construct the two multipliers in single crystal by illumination of λ_1 and λ_2 from the different angle.

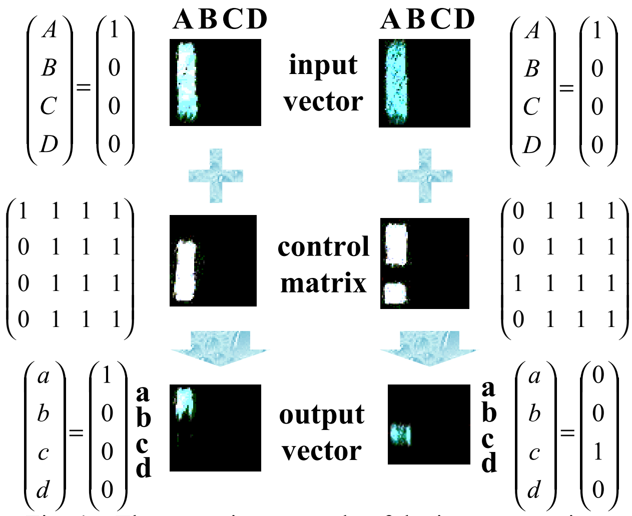


Fig. 4 The operation example of the interconnection. The left side shows a connection from 'A' to 'a', and the right side is from 'A' to 'c'.

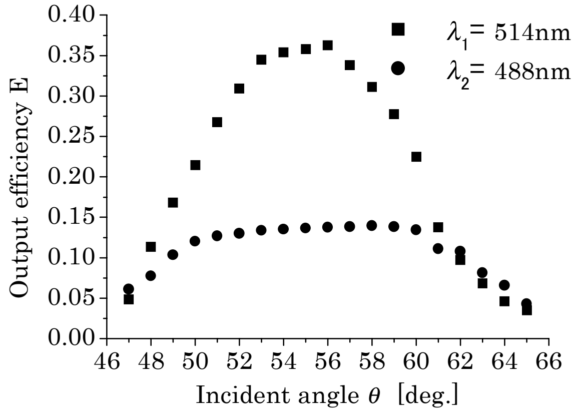


Fig. 5 Output efficiency E for incident angle of signal beam

4. Conclusion

This report suggests such devices as conducting all-optical interconnection as for spatially-aligned several WDM signals according to wavelength, and conducts the experiment to confirm the validity of its principle. The photorefractive crystal adopted in this experiment has some problems with response time rates under connection switching. Despite such an obstacle, it can still be used as a protection switch, etc. in fault-tolerant system, which causes no frequent change in routing. However, once interconnection is determined, the resulting signal transmission speed reaches light velocity, making optical transmission with Tbit/s class possible. Improvement in response time under connection switching is heavily dependent on the future material development. But, if we try to achieve transformation of ATM into light on the basis of a similar idea of using conventional electronic circuit, we will face some problems, such as synchronization of digital signal and difficulties in temporary memory of information using light. Therefore, new ideas are expected to be come up with, by taking advantage of optical properties. Also, in terms of free space system, if it is applied to optical wireless system which transmits optical signal in the atmosphere, there remains a possibility of expecting dramatic increase in transmission rate in spatial division multiplexing. We will continue to examine its possibility.

Reference

[1] Yugo Aizawa, Atsushi Okamoto, and Kunihiro Sato : "Optical Interconnection with Cat Conjugator Using an Erase Beam", IEICE of Japan, **J81-C-I**, 9, pp.533-543 (1998)