Usage of Binary Optical Elements in Ultrafast All-optical Switching Modules and Their Applications to Novel Photonic Systems

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1. Introduction

It is indispensable in next generation photonic systems to satisfy large capacity and noise suppression requirements. All-optical switching devices are promising, being free from CR-bottleneck of electrical circuits. In order to realize compact, robust and mass-producible all-optical-switching-modules, we tried to use the technology of binary optical elements in free-space optical platforms. The all-optical demultiplexer modules for ultrafast TDM system were designed. The optical platform was fabricated using EB lithography and InGaAs MQW saturable absorber. Preliminary switching experiments were performed. As a novel application of time-gating module, we also discuss about the noise suppression by time gating. This approach is powerful for low duty ratio RZ codes, where signal is temporally localized and noise is non-localized.

In this paper we present our trial fabrication of all-optical switching module using binary optics. Then its preliminary evaluation as TDM demultiplexer is reported, followed by a discussion on time-gated noise suppression in low duty ratio systems.

2. All-optical Switching Module Using Diffractive Optical Elements (DOEs)

We proposed the basic principle of all-optical platform employing reflective multilevel zone plates and mirrors combined with MQW all-optical switch array [1,2]. The concept of the all-optical switching module designed for TDM demultiplexing is illustrated in Fig.1. A single mode fiber array launches both the pump and signal pulses into the optical platform. The light at the output port of the optical plat-form is coupled into a multi-mode fiber and detected by an optical power meter.

We designed and fabricated multilevel zone plates by applying binary optics technology. This technology has the advantageous features such as small size, light weight, high efficiency, small spot sizes close to diffraction limit, and the reproducibility in fabrication[3,4]. We used three masks process, namely eight-level zone plates. To meet the minimum feature size of 2 μm imposed by the available facility, the level number of the zone plates had to distribute between 2, 4 and 8[5]. In Fig. 2, the two-lens configuration is shown. The two-lens type is featured by 1:2 imaging from the input coupler to

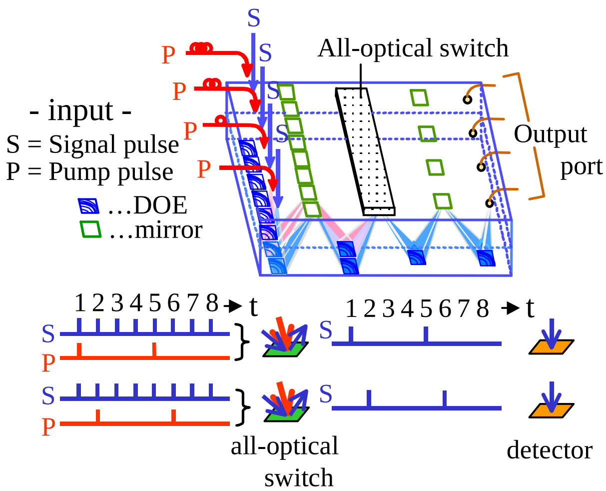


Fig.1 The concept of all-optical switching module

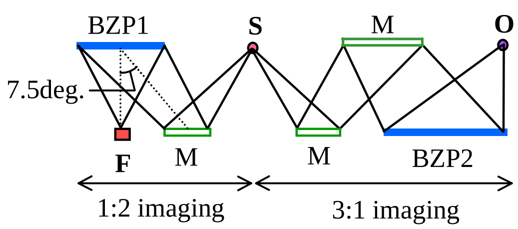
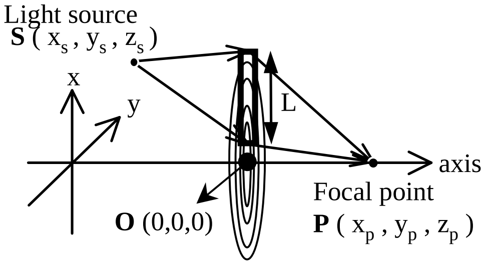


Fig.2 The lense configuration

the switch, and 3:1 imaging from the switch to the output port. The design parameters of two-multi-level zone plates are shown in Fig. 3. In order to avoid the complexity of geometry in arrayed all optical switches, we designed the non-collinear configuration of off-axis illumination optics. Two plates of module with the thickness of 2.5 mm are adhered with the index-matched epoxy-resin. Fig. 4 shows the intensity profiles at the surface of the optical switch plotted for different wavelengths. At the wavelength of 1.55 μm the overlap between the two beams is quite satisfactory. With the deviation of the wavelength by 20 nm the two beams become separate. The wavelength dispersion is related to the focal lengths of the zone plates. Typical insertion losses were 3.8 dB and 6.2 dB, from the input fiber to the switch and to the output port, respectively. The diffraction efficiency amounts 60 to 70 %, and is mostly responsible for the insertion loss. In order to further decrease the loss, it is necessary both to refine the design procedure as well as to employ lithography of improved resolution.



BZP No.	1	2
S (x_s , y_s , z_s)	(1.25,0.425,-5.20)	(2.475,0.6375,-15.0)
P (x_P , y_P , z_P)	(0,0,10.0)	(0,0,5.00)
L [mm]	850	1275
f [mm]	3.50	3.76

Fig.3 The lense configuration and design parameters

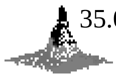
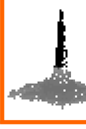
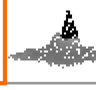
Wavelength [μm]	1.53	1.55	1.57
Spots profile (3D) & Spot size ($1/e^2$) [mm]	 35.0	 22.5	 30.0

Fig.4 Optical intensity profiles at the surface of all-optical switch

3. Application of All-optical Switch Module to TDM Demultiplexer

The switching function of the InGaAs MQW saturable absorber was examined by pulsed 1.55 μm LDs. The time gating characteristics is important for all-optical demultiplexing in O-TDM systems. Two laser diodes for signal pulse and pump pulse generation are driven at a repetition frequency of 100 MHz by the comb generators to operate them with gain-switching mode, where the pulse width amounts to 25 ps. Stronger pump pulse power resulted in higher on-off ratio.

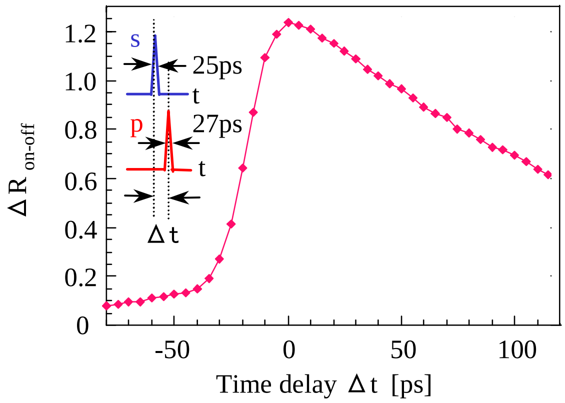


Fig.5 Switching recovery characteristics

The switching recovery characteristics were evaluated by changing the relative temporal position by means of an optical delay line installed in the pump pulse path. The plots shown in Fig. 5 the reflectivity change (ΔR) as a function of the relative time difference between signal and pump pulses. The origin of the time position t=0 represents zero time gap between signal and pump pulse where the change in reflectivity becomes maximized. In this case ΔR is equal to 1.1. The rise time of 25 ps is governed by the pulse width itself, while the recovery time of 200 ps is mostly limited by the carrier recombination lifetime. It is possible to aim at a higher speed response by improving the performance of all-optical switch, and then the time width of the window can be reduced.

4. Simulation of Time-gated Noise Suppression in Low Duty Ratio Transmission System

As another application of all-optical platform, we proposed a time window generator for the noise suppression system[6)]. As shown in Fig. 6, in analogy with the standard filtering in frequency domain, we can equivalently suppress the noise in the time domain by time windowing, if the signal is temporally localized and the noise is non-localized. We show here the schematics of the proposed detection system in Fig. 7.

At the sender side the pulse-position-modulated-codes are generated by the combination of a branching switch and a delay unit. At the receiver side the signal is pre-amplified with the semiconductor optical amplifier. The photodiode and subsequent electronics with a modest bandwidth detect the optical signal.

We have performed a model analysis of the bit error rate improvement by narrowing the time window. We assume that the signal pulse width is τ, the gate pulse width is τ_G, and the bit interval is T. We also assume that the CR time constant of the detection electronics is much larger than τ, so that the detection electronics

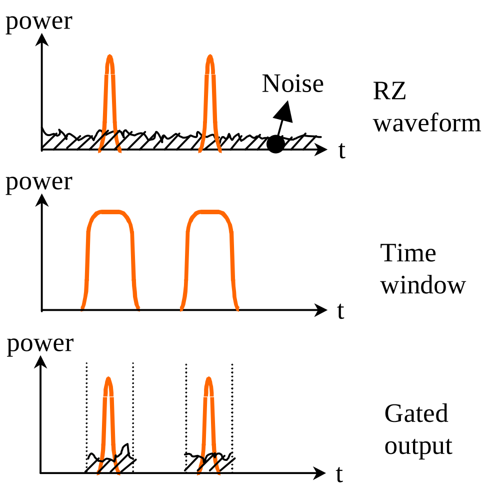


Fig.6 The time domain noise suppression

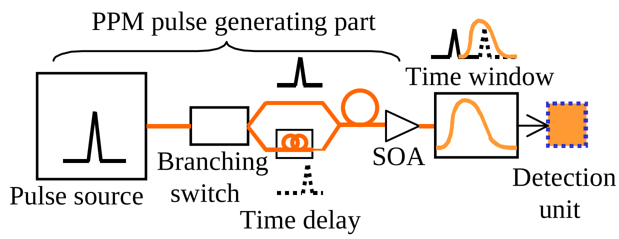


Fig.7 Schematic view of the detection system

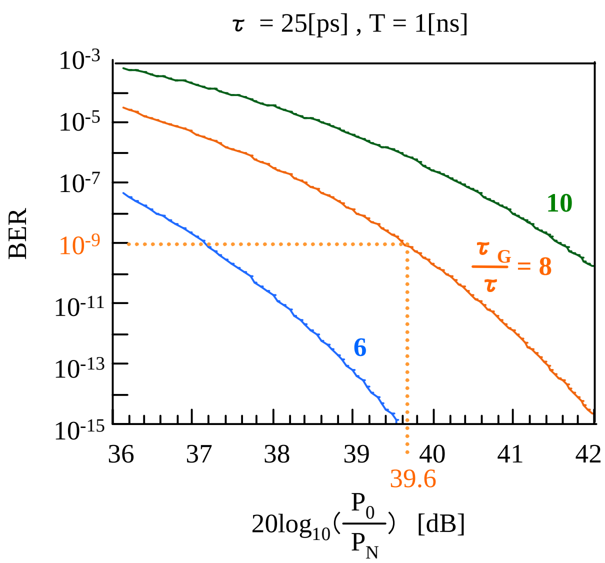


Fig.8 Relationship between SN ratio and BER

Table1 Relationship between time window width and BER

τ_G / τ	τ_G	BER
40	1 ns	1.0×10^{-1}
8	200 ps	1.1×10^{-9}
4	100 ps	9.9×10^{-30}

acts as an integrator. With the signal power of P_0 and the noise power of P_N, the bit error rate is expressed as the error function of Z, defined as:

$$BER = erfc(Z) = \frac{2}{\sqrt{\pi}} \int_{Z}^{\infty} e^{-t^2} dt \qquad (1)$$

$$Z = \frac{1}{\sqrt{\pi}} \cdot \frac{P_0}{P_N} \cdot \frac{\tau}{\tau_G} \qquad (2)$$

Numerical examples are shown in Fig. 7 and Table 1. They show the fact that with smaller values of τ_G, the bit error rate (BER) is improved. The bit error rates are plotted as the signal power to averaged noise power ratio for different values of the ratio between the gate width and the signal pulse width. As a numerical example we assume τ is 25 ps, and bit-rate is 1 Gbit/s, or bit interval T is 1 ns. We also assume that the integration time constant is 1 ns. Without using the time windowing gate, all the noise power for 1ns is integrated. If the time window of 200 ps is applied, BER is around 10^{-9} for SNR of 39.6 dB as shown in Fig. 8. The noise suppression is enhanced when the time window becomes close to the signal pulse width.

When the time window width becomes close to the signal pulse width, the bit-error rate is sensitive to the jitter noise. To relax the requirement of timing jitter, a choice of time window width τ_G somewhat larger than τ is practical. Another point to be noticed is the insertion loss of the time windowing gate. The insertion loss of time windowing gate may deteriorate BER when the electrical noise of the detection electronics becomes significant. Therefore to reach the ideal performance of time window gates, both the timing jitter and the insertion loss should be minimized. The key issue for the realization of this scheme is the implementation of a time-windowing module with modest production cost. We believe our approach of time gating module is appropriate for such application as LAN or access networks.

5. Conclusions

In order to achieve fast and robust all-optical switching modules, we tried to combine the technologies of all-optical MQW saturable absorber switches and free-space optical platforms containing binary optical elements. An optical platform for all-optical switching was designed with non-collinear pumping configuration, and was fabricated with 2 μm minimum feature technology, resulting in a good spatial overlap between pump and signal beams of ～10 μm diameter at 1.55 μm. Preliminary switching experiment for TDM-demultiplexing was performed using 25 ps gain-switched LDs and switching time constant around 200 ps was confirmed. As a novel application of the fast time gate, we discussed on a scheme of noise suppression in time domain. The scheme is expected to be very effective for low-duty-ratio-codes.

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