Characteristics of All-Optical Gate Switch Employing Quasi-Phase-Matched Lithium Niobate Devices

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***Abstract*-We analyze characteristics of all-optical switches using the cascade of second harmonic generation and difference frequency mixing in quasi-phase-matched lithium niobate devices. Numerical calculations consider not only the pulse waveforms but also the optical noises.**

I. Introduction

Recently, there has appeared an attractive candidate for the all-optical gate switches, which employs the cascaded $\chi^{(2)}$ effect in quasi-phase-matched (QPM) $LiNbO_3$ (LN) devices [1]. The QPM-LN devices can arbitrarily control the QPM wavelength by changing the period of the $\chi^{(2)}$ grating, and also feature ultra-fast response, high conversion efficiency, low noise, low cost, compactness, integration compatibility, and high stability.

In the QPM-LN-based switches, when the center wavelength of the pump pulses is set to the QPM wavelength, its second harmonic (SH) is generated. Then, difference frequency mixing (DFM) between the SH pump and signal pulses produces the idler pulses, which is the wavelength-converted output from the switch. The potential of the QPM-LN-based switches has already been revealed in a number of experimental demonstrations and system experiments [2-5]. However, it is still an open question how the waveform of the idler pulses is affected by those of the input pump and signal pulses. Furthermore, it has not been elucidated yet how the optical noises on those inputs are transferred to the switched output.

In this paper, considering not only the pulse waveforms but also the optical noises, we numerically analyze characteristics of all-optical gate switches using the cascaded $\chi^{(2)}$ effect of second harmonic generation (SHG) and DFM in the QPM-LN devices.

II. Model and Method for Numerical Analyses

We consider a 1-cm-long QPM-LN waveguide device with a domain inversion period of 16.2 μm. This period is required for SHG using the maximum second-order nonlinear coefficient d_{33} (= 25.9 pm/V) of the LN crystal when the center wavelength of the pump pulses is 1.55 μm. The center wavelength of the signal pulses is set to 1.52 μm. The effective cross-section area of the waveguide is 8 μm^2. The group-velocity mismatch (GVM) between the fundamental and SH pump pulses is assumed to be 350 ps/m. Due to the large GVM, walk-off between the fundamental and SH pump pulses induces crosstalk between the neighboring bit durations. Thus, the pulse walk-off delay limits not only the switching efficiency (wavelength-conversion efficiency) but also the operational bit rate of the switch [4-6]. For compensating the pulse walk-off delay and also enhancing the switching efficiency, the pump pulses precede the signal pulses by 0.8 ps at the input port of the QPM-LN device. The device length of 1 cm is optimized for the switching operation at the bit rate of 200 Gbit/s.

The roles of the pump pulses and the signal pulses can be determined according to the switch applications. For the inputs to the switch, we assume 200-GHz clean gate pulses and 200-Gbit/s data pulses with an optical noise as shown in Figs. 1 (a) and (b), respectively. The data pulses are patterned by the 2^8–1

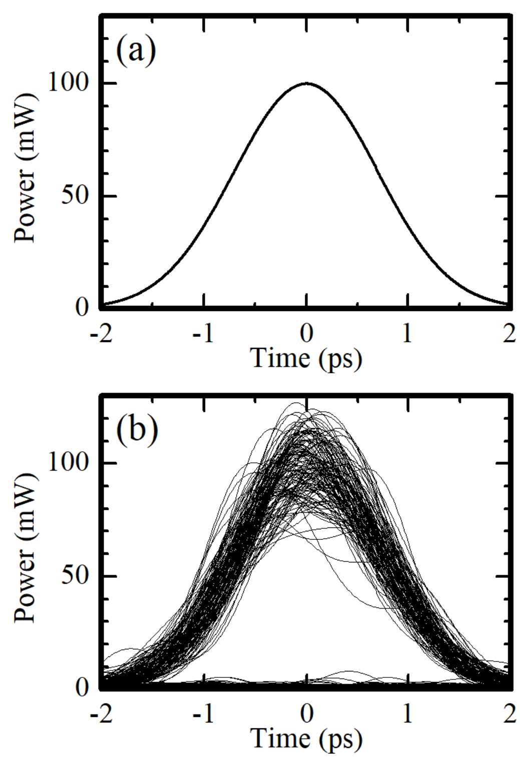

Fig. 1. Intensity waveforms of initial pulses.
(a): 200-GHz clean gate pulses.
(b): 200-Gbit/s PRBS data pulses with optical noise.

pseudo-random bit sequence (PRBS), and also have a Gaussian noise whose bandwidth is as same as that of the data pulses [7]. The Q factor, which can evaluate the optical noise quantitatively, is calculated to be 8.6 dB. The peak power of the gate pulses and the average peak power of the data pulses are set to 100 mW. All the pulse waveforms are assumed to be Gaussian having a same pulse width parameter T_0 of 1 ps. The duty cycle is 1/3.

In the analyses, we numerically calculate evolution of waveforms of the fundamental pump, SH pump, signal, and idler pulses along the device length by using the nonlinear coupled-mode equations [4], [6].

III. Numerical Results and Discussions

Figure 2 (a) presents an intensity waveform of the idler pulses when the gate pulses and the data pulses shown in Figs. 1 (a) and (b) act as the pump pulses and the signal pulses, respectively. In this case, the Q factor is calculated to be 9.1 dB. Compared with the initial waveform shown in Fig. 1 (b), no output deterioration is confirmed, and thus a proper switching operation is successfully achieved.

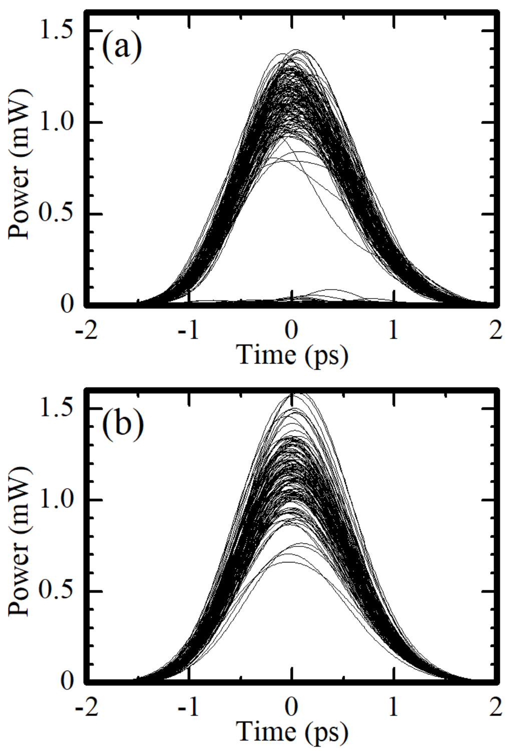

Fig. 2. Intensity waveforms of switched output.
(a): Gate and data pulses are used for pump and signal pulses, respectively.
(b): Gate pulses and data pulses contrary act as signal pulses and pump pulses.

On the other hand, Fig. 2 (b) represents an intensity waveform of the idler pulses when the gate pulses and the data pulses are contrary used for the signal pulses and the pump pulses. The Q factor is calculated to be 8.1 dB. In this case, the idler pulses have an excessive amplitude fluctuation at the mark state (‘1’). In contrast, the amplitude fluctuation decreases at the space state (‘0’). Those mechanism can be explained as follows. Theoretically, the idler power P_i at the output port of the QPM-LN devices is almost proportional to $P_p^2 \times P_s \times L^4$, where P_p and P_s are the pump power and the signal power at the input port, respectively, and L is the device length (propagation distance of the light). On account of such parabolic dependence of P_i on P_p, the amplitude fluctuation of the idler pulses is increased at the mark state (‘1’). In contrast, its amplitude fluctuation is reduced at the space state (‘0’) owing to the same nonlinearity (parabolic transmittance) between them. Meanwhile, additional amplitude fluctuations are not generated in Fig. 2 (a) because of the linear transmittance (proportional relation) between P_i and P_s.

Above numerical results imply that the roles of the pump pulses and the signal pulses are very important for avoiding the output degradation induced in the QPM-LN-based switches. Thus, the data pulses with the optical noise should be used for the signal pulses, and also the gate pulses act as the pump pulses must be clean.

IV. Conclusions

We have analyzed characteristics of the QPM-LN-based switches. Through numerical calculations, we have investigated how the waveforms of the pump and signal pulses and those optical noises affect the idler pules, and have revealed that the roles of those pulses are very important to avoid the output deterioration of the switch.

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