All-Optical Decision Gate Circuits Using Cascaded Periodically Poled Lithium Niobate Devices

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***Abstract*-We propose a cascaded periodically poled lithium niobate device. In the device, two lithium niobate crystals with different quasi-phase matching wavelengths are cascaded. We numerically show that the cascaded periodically poled lithium niobate device has an all-optical level discriminating characteristic, thus enabling a compact and stable ultra-fast 3R circuit.**

I. INTRODUCTION

All-optical 2R/3R (reamplification, reshaping, and retiming) circuits are key devices in future optical time-division multiplexed (OTDM) systems. The 2R/3R circuits that have been demonstrated so far fall into three categories: saturable absorbers [1], parametric amplifiers [2]–[4], and nonlinear interferometers [5]–[9].

On the other hand, an all-optical gate switch using a periodically poled lithium niobate (PPLN) has been reported recently [10]. In the PPLN switch, when the center wavelength of the signal pulses is set to the quasi-phase matching (QPM) wavelength, the signal pulses can switch a clock pulse train through the cascaded second-order nonlinear effect.

In this paper, we propose a cascaded PPLN device. In the device, two PPLN crystals with different QPM wavelengths are cascaded. We numerically show that such device has an all-optical level discriminating function, thus enabling a compact and stable 3R circuit. We should note that the operation principle differs from other all-optical 2R/3R circuits that have been proposed so far.

II. STRUCTURE AND PRINCIPLE

The structure of an all-optical 3R circuit using the cascaded PPLN device is illustrated in Fig. 1. In the device, the domain inversion periods of each PPLN crystal are $\Lambda_{1\mathrm{QPM}}$ and $\Lambda_{2\mathrm{QPM}}$, respectively. The transmitted OTDM signal pulses in the return-to-zero (RZ) format, which have the amplitude fluctuation and the timing jitter, are pre-amplified by an optical amplifier (OA). The pre-amplified signal pulses are then launched on the cascaded PPLN device together with a clean clock pulse train with a fixed repetition rate.

In the former PPLN crystal with the length L_1, when the center wavelength of the input signal pulses is set around the QPM wavelength determined from $\Lambda_{1\mathrm{QPM}}$, its SH is first generated. Then, DFM between the SH signal pulses and the clock pulses generates the wavelength-converted signal pulses. On the other hand, in the latter PPLN crystal with the length L_2, the center wavelength of the incoming wavelength-converted signal pulses is set around the QPM wavelength determined from $\Lambda_{2\mathrm{QPM}}$, and its SH is generated. In the output port of the device, the wavelength-converted signal pulses are filtered out by an optical bandpass filter (BPF) with an appropriate bandwidth. The timing jitter of the output wavelength-converted signal pulses can be suppressed because the input signal pulses switch the clean clock pulse train.

The amplitude fluctuation of the output wavelength-converted signal pulses can also be suppressed in the following way. In the region where the peak power P_{in} of the input signal pulses is low, the SH of the wavelength-converted signal pulses generated in the latter PPLN crystal is negligibly small. In this case, the peak power P_{out} of the output wavelength-converted signal pulses is proportional to P_{in}^2. Owing to the parabolic dependence of P_{out} on P_{in}, the amplitude fluctuation of the output wavelength-converted signal pulses can be suppressed in the space (“0”) level. On the other hand, in the high power region, P_{out} is saturated as the increase in P_{in} because the effect of the SHG in the latter PPLN crystal can no longer be ignored. By using the limiting characteristic, the amplitude fluctuation of the output wavelength-converted signal pulses can also be suppressed in the mark (“1”) level. These consequences result in a decision gate function, and all-optical 3R operation can be achieved.

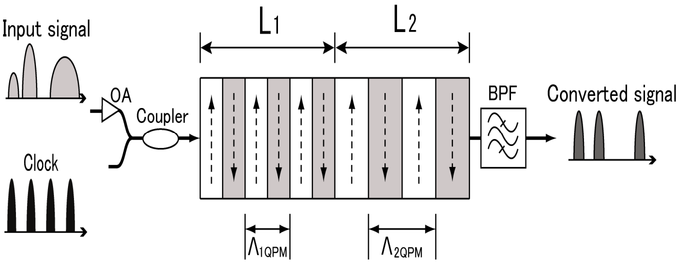

Fig. 1. Structure of an all-optical 3R circuit using the cascaded PPLN device.

III. RESULTS AND DISCUSSIONS

We consider a cascaded PPLN waveguide device. The effective cross-section of the waveguide is set to 8 $\mu\mathrm{m}^2$. We set L_1 and $\Lambda_{1\mathrm{QPM}}$ to 10 mm and 16.2 μm, respectively. This period is required for SHG using d_{33} (= 25.9 pm/V) when the center wavelength of the input signal pulse is 1550 nm. On the other hand, $\Lambda_{2\mathrm{QPM}}$ is set to 16.9 μm, which is required for SHG of the wavelength-converted signal pulse with a center wavelength of 1580 nm. The GVM between the fundamental pulse and the SH is assumed to be 350 ps/m. The center wavelength and the peak power of the input clock pulse are 1520 nm and 0.8 W, respectively. The input signal and clock pulses are assumed to be chirp-free Gaussian pulses having the same pulse width parameter T_0 of 1 ps. The input signal pulse precedes the input clock pulse by 2 ps for improving the wavelength conversion efficiency [10]. We numerically calculate the coupled-mode equations for all frequency components contained in each optical pulse [10].

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The P_{out} calculated as a function of P_{in} for various L_2 values is shown in Fig. 2. We find that the cascaded PPLN device has the parabolic transmittance for the low power region. On the other hand, we also find that the limiting characteristic for the high power region is improved as L_2 is increased. For example, when L_2 = 4 mm, P_{out} saturates above P_{in} = 4 W. When L_2 is increased to 10 mm, P_{out} saturates above P_{in} = 2 W. These consequences result in the all-optical level discriminating characteristic.

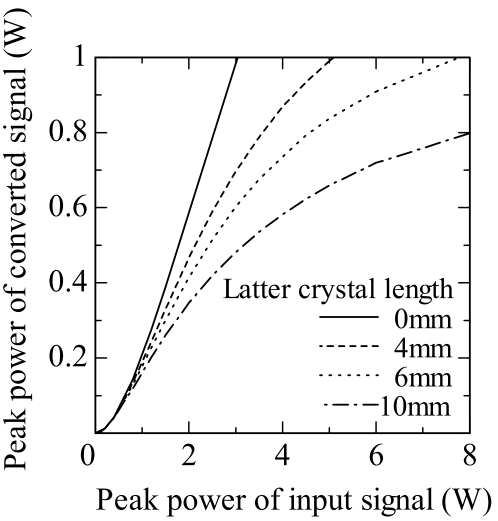

Fig. 2. Peak power of the output wavelength-converted signal pulse calculated as a function of the peak power of the input signal pulse for various values of the latter crystal length.

IV. CONCLUSIONS

We have numerically shown that the cascaded PPLN device has an all-optical decision gate function. In the device, two PPLN crystals with different domain inversion periods are cascaded. The parabolic transmittance for the low power region is induced by the SHG-DFM process in the former PPLN crystal. On the other hand, the limiting characteristic for the high power region is induced by the SHG process in the latter PPLN crystal. Thus, all-optical ultra-fast 3R operation with the low input power can be expected by using the nonlinear transfer function of the cascaded PPLN device.

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