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Proposal of All-Optical Active Microring Logic Gate

Hideki Yajima, Masaki Nishimura, Taro Arakawa, and Yasuo Kokubun

Graduate School of Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama, Kanagawa 240-8501, Japan
Phone: +81-45-339-4143 E-mail: {arakawa, ykokubun}@ynu.ac.jp

Abstract We have proposed and theoretically demonstrated all-optical active microring logic gates. The simulation results reveal that the proposed active microring can be operated with very low energy

1. Introduction

All-optical logic gates based on semiconductor optical amplifiers (SOAs) are quite promising devices to realize higher-speed and lower-power photonic routing in the near future [1-3]. In this paper, we have proposed all-optical logic gate based on active microring resonator and simulated their high-speed operations by a transfer matrix method (TMM). The proposed microring logic gate has advantages compared to conventional semiconductor optical amplifiers (SOAs) such as compactness, single configuration, low power consumption due to nonlinear enhancement effect, and high cascadability. The high-speed gate operations including OR were theoretically demonstrated.

2. Principle of All-Optical Logic Gate Operation in Active Microring Resonator

Figure 1 shows the schematic calculation model of the proposed active microring resonator with buslines. The microring resonator itself is an SOA with a multiple quantum well active layer.

In the proposed device, cross-phase modulation (XPM) and cross-gain modulation (XGM) are utilized for logic gate operations. Figure 2 shows the schematic gain spectra at the drop port with and without input lights. The periodic gain peaks are obtained at the resonant wavelengths. When the light with the wavelength close to a resonant wavelength of the microring is incident on the input port, the carrier density decreases by stimulated recombination in the microring SOA, leading to the increase of the refractive index of the microring resonator. As a result, the resonant wavelength is shifted to a longer wavelength, as the dotted line in Fig. 2. The intensity of the gain peaks also decreases with the decrease of the carrier density.

Using the above-mentioned red-shift of the gain peaks

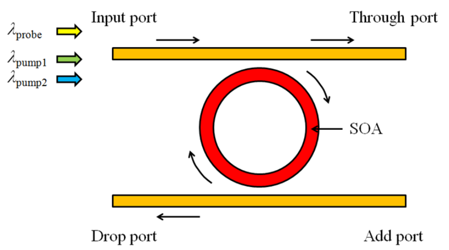

Fig. 1. Schematic illustration of the proposed active microring resonator with buslines.

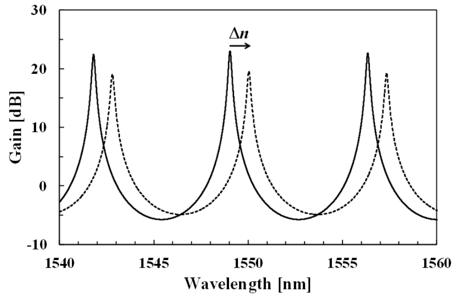

Fig.2. Schematic gain spectra at a drop port of the active microring resonator with and without input lights.

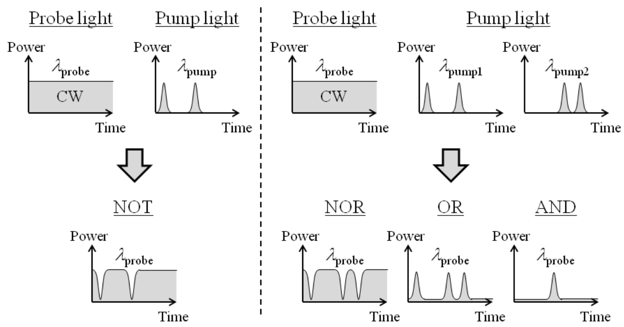

Fig.3. All-optical gate operations using the active microring resonator.

controlled by input lights, NOT, NOR, OR, and AND gate operations can be realized. For the following discussion, a probe light with λ_{probe} and pump lights with λ_{pump1} and λ_{pump2} are defined in Fig. 1. The probe light is a continuous-wave light, and the pump lights are intensity modulated input signals. The intensity of the probe light at the drop port is controlled by the pump lights, as shown in Fig. 3.

3. Wavelength Conversion and All-Optical Logic Gate Operations

All-optical logic gate operations using the active microring with the device parameters in Table 1 were analyzed by the TMM [4,5].

The pump light (input signal) is assumed to be return-to-zero (RZ) signal. The power of the probe light is fixed at 0.01 mW. The coupling efficiency K between the busline and the microring resonator is 0.7. The FWHM bandwidth of the microring resonator is calculated to be approximately 3.0 nm, which is sufficiently wide for signals at the speed of over 10 Gbps.

Here, we define "wavelength detuning" as $(\lambda_{input}-\lambda_0)/\Delta\lambda\times100$ (%) where λ_{input} is the wavelength of the input light (the probe or pump lights), λ_0 is the resonant

Table 1 Device parameters of active microring resonator

Coupling efficiency	K	0.70
Total length of the SOA	L [μm]	100.0
Width of the active region	W [μm]	1.2
Thickness of the active region	d [μm]	0.24
Refractive index in the active region at transparency	n_{g0}	3.46
Refractive index in the cladding layer	n_c	3.17
Wavelength at the maximam gain	λ_p [nm]	1550.0
Injection current density	J [kA/cm^2]	43.0
Internal loss	α_{int} [Neper/m]	2000
Optical confinement factor	Γ	0.134

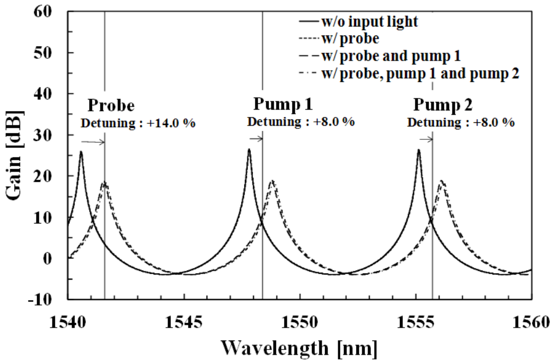

Fig.4. Calculated gain spectra at the drop port of the active microring resonator for the OR gate operation.

wavelength closest to λ_{input} without input lights, and $\Delta\lambda$ is the FSR of the microring resonator, respectively.

Using the proposed active microring, the high-speed wavelength conversion and gate operations of NOT, NOR, OR and AND can be realized. Here, we show the OR gate operation as an example.

Figure 4 shows the calculated gain spectra at the drop port of the active microring resonator for the OR gate. The wavelength of the probe light λ_{probe} is set at 1541.58 nm that corresponds to the wavelength detuning of +14.0%. The wavelengths of the two pump lights λ_{pump1} and λ_{pump2} are set at 1548.39 and 1555.72 nm that correspond to the wavelength detuning of +8.0 %, respectively. The average power of the pump lights is set at 0.05 mW. The shift of the resonant wavelength caused by self-phase modulation (SPM) due to the probe light is very small, and λ_{probe} is still far from the resonant wavelength, therefore, the probe light at the drop port is very small. This is the “0” or “null” state for the output. Next, when one of the pump lights are incident (input signal “01” or “10”) in addition to the probe light, the resonant wavelength shifts to a longer wavelength due to the XPM and almost coincides with the wavelength of the probe light, then the power of the probe light at the drop port increases. This state corresponds to the “1” state for the output. When the two pump lights are incident simultaneously on the input port (input signal “11”), the resonant wavelength λ_0 hardly move and the power of the probe light at the drop port is almost comparable with that for the case of the input signal “10”. This is because when the second pump light is incident, its wavelength is shorter than the resonant wavelength and the gain for the pump lights is small as the dashed line for “w/ probe and pump1” in Fig. 4, leading to small XPM. Therefore the resonant wavelength hardly moves even when the second pump light is input.

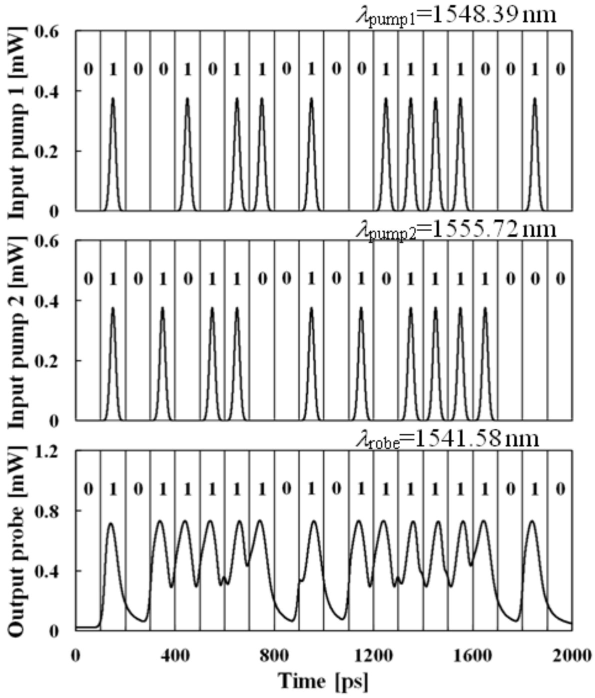

Fig.5. Simulated 10 Gbps operation of the OR gate.

The simulated 10 Gbps operation of the OR gate is shown in Fig. 5. The extinction ratio was approximately 15.0 dB and the eye opening is 79.6%.

It has also been confirmed by the simulations that the other 10-Gbps operations of NOT, NOR and 5-Gbps AND operation can be realized in the proposed active microring with very low energy as low as 1.0-20.0 fJ/pulse.

4. Conclusion

We have proposed all-optical active microring logic gates. The all-optical active microring logic gates are operated on the basis of XGM and XPM. The XGM and XPM are enhanced in the active microring, leading to low operation power. We have successfully demonstrated 10-Gbps OR gate operations by the transfer matrix method. The simulation results show that the proposed active microring can be operated with very low energy.

Acknowledgements

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