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Reconfigurable and compact reversible channel multiplexers using Si_3N_4 based optical microring resonator

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Highlights

- This manuscript demonstrates a novel technique to implement an all optical channel multiplexer using an optical microring resonator.
- This silicon nitride-based MRR is modulated using an optical pumping signal which ultimately helps to achieve the optical switching through the constructed device using its nonlinear properties.

- The optical signal reversible multiplexer using a microring resonator is a unique method to implement optical network.
- This multiplexer can be further cascaded to design complex optical processor and routers.

Abstract

The paper presents the novel all-optical 2×1 and 4×1 reversible multiplexer using the optical microring resonator (OMRR). The numerical modeling of the Silicon Nitride (Si_3N_4)-based OMRR has been done and employed to design the reversible multiplexers. The proposed reversible multiplexers are validated through MATLAB results. The desired figure of merits like extinction ratio (ER) is 20.29 dB, amplitude modulation (AM) is 0.71 dB, and the contrast ratio (CR) is 19.54 dB of designs obtained through simulation prove the high performance and practical realization of the proposed models.

Introduction

Research has focused more on low-power dissipation circuits in the yesteryears. The conventional logic circuits are irreversible, and logic computations involved in these circuits dissipate energy when bits of information are lost. According to Landauer[1], the energy lost is kT^*ln_2 joules for losing single-bit information, T is the temperature (absolute) of the operation being executed, and k is the Boltzmann constant. Bennett[2] has shown that zero-energy dissipation is possible if reversible logic (RL) has been used for computation. The reversible logic circuits are more significant than the classical logic circuits. The reversible circuit performs one-to-one mapping of the input and output vector. The reversible circuit produces unique specific output for every specific input and vice versa. The researchers focus more on reversible logic because of their application in several enabling technologies, optical computing, and quantum computing.

The parameters like operational speed and bandwidth limit the working of conventional electronic circuits. The introduction of photonic circuits has overcome the limitation of the conventional electronic circuit[3]. To meet today's requirement of high signal processing in optical computing and optical communication all-optical processing is one of the key methods[3]. The photon is the carrier for optical communication and optical computing in the all-optical process. Photon has the property to store information in a signal and provide a high speed compared to the speed of light and zero-rest mass. Hence, in optical devices, there will be no delay whereas in an electronic system there will be a delay in the interconnection of the devices. In general, at the switching point, we required an electrical signal for switching the optical signal i.e.one optical signal can be controlled by an electrical signal but in all-optical switching, one optical signal can be controlled by another optical signal, so there is no need for any electrical signal. This all-optical switching can be implemented by changing the refractive index or by applying the pump signal. All-optical computing has many benefits such as size is reduced, heating from the devices reduces, speed increases, no electromagnetic interference, less power consumption, no crosstalk, and highly efficient.

In the optical system, there is more than one wavelength can travel simultaneously in the system. Long-distance digital communication can be accomplished by ultra-fast all-optical switching. The all-optical computing and processing can be implemented using all-optical switching. In the preceding years, many researchers have investigated all-optical switching using Mach Zehnder interferometer (MZI)[4], [5], [6], [7], [8], terahertz-optical asymmetric de-multiplexers (TOAD)[9], [10], [11], semiconductor-optical amplifier (SOA)[12], [13], [14], micro-ring resonator (MRR)[15], [16], [17], [18], [19], [20], [21], to design various non-reversible logic circuits like logic gates, different combinational logic circuits, different sequential logic circuits, memory units, etc. Some researchers also report the implementation of reversible gates, reversible multiplexers, and reversible decoders using SOA[22], [23], MZI[24], [25], [26], [27], and OMRR[28], [29], [30]. Recently some other photonic technologies like plasmonics[31], photonic crystal[32], [33], and mode rotation in OMRR[34]-based reversible gates are introduced.

Compared to other photonic components, silicon OMRR-based all-optical switching proved to be more significant in providing less design complexity, reducing size, low operating power, high bandwidth, high speed, stability, and ease of fabrication. Due to these advantages, the OMRR is an efficient AOS and greatly challenges other technologies. Simple OMRR can design an “add-drop” filter, and this can be used in different high-speed applications like signal processing, laser system, sensing applications, and switching. Therefore, seeing the advantage of OMRR, in this report, we have designed the novel 2×1 and 4×1 reversible multiplexers using the OMRR.

Section snippets

Mathematical modeling of OMRR

In advanced optical engineering, a perception of all-optical switching is a very advantageous phenomenon. OMRR is an optical device based on the perception of all-optical switching and has a very efficient all-optical switching capability. OMRR has been widely used to realize all-optical logic functions for the last decade.

Si_3N_4 has non-linear behavior, so it is being used to fabricate an OMRR. The Optical Kerr effect is dominant over third-order nonlinearity like two-photon absorption (TPA) in …

Model of 2×1 reversible multiplexer

The model of the 2×1 reversible multiplexer is implemented using 7 OMRR, as depicted in Fig.4. OMRR 1 is provided with pump signal “S” so that at resonant conditions, “S” will be received at throughput and “S‘” at the drop port. OMRR 2 and OMRR 3 are modulated with pump signal “A‘” and “Respectively and output are obtained at through port of OMRR 2 as “X=A” and at through port of OMRR 3 as “Y=B”. The main purpose of OMRR 2 and OMRR 3 is to provide the one-to-one mapping of bits to satisfy the …

Simulation result analysis of 2×1 reversible multiplexer

The MATLAB simulation result of the 2×1 reversible multiplexer is shown in Fig. 5. The obtained MATLAB simulation result satisfies the truth Table 2 of the 2×1 reversible multiplexer. The first two columns A and B are the inputs for the reversible multiplexer, and the third column represents the selection line S. The output Z is given in the fourth column. The fifth and the sixth column are one-to-one mappings for output X and Y.

Case 1: In the first case, both the input A and B and selection …

Model of 4×1 reversible multiplexer

The design layout of the 4×1 reversible multiplexer is shown in Fig. 6. The 4×1 reversible multiplexer is implemented using 23 OMRR modulated by the specific pump signals. We have considered one case to explain the process among the different combinations of inputs and selection lines for the 4×1 reversible multiplexer. The below-given equation governs the output of the 4×1 reversible multiplexer. $\mathrm{Z} = \mathrm{S}_0'\mathrm{S}_1'\mathrm{A} + \mathrm{S}_0'\mathrm{S}_1\mathrm{B} + \mathrm{S}_0\mathrm{S}_1'\mathrm{C} + \mathrm{S}_1\mathrm{S}_0\mathrm{D}$

…

Simulation result analysis of 4×1 reversible multiplexer

For the specific case of the 4×1 reversible multiplexer, the MATLAB simulation result is shown in Fig. 7. The truth Table 3 of the 4×1 reversible multiplexer and obtained MATLAB result justifies the working of the proposed design. To achieve the one-to-one mapping condition OMRR 19, OMRR 20, OMRR 21, and OMRR 22 are used.

The OMRR 1 and OMRR 2 give output for the selection lines. The final output is obtained from OMRR 23.

Case 1: In the first case, input A is logic 1 while input B, input C, input …

Discussion and performance parameters of OMRR

The performance of the proposed designs of the reversible multiplexers is evaluated by the performance parameters, such as on–off ratio, full-width at half maximum (FWHM), free spectral range (FSR), finesse, quality factor, extinction ratio, and contrast ratio. The calculated value of quality factor, finesse, FSR, and FWHM are 7700,40,8 nm, and 0.2 nm respectively.

The other performance parameters are given below

(a) On–off ratio — It gives the ratio of output intensity at the through port, and …

…

Conclusion

This paper proposes silicon-nitride-based OMRR to obtain appropriate optical switching. Further, the combination of the proposed OMRR is employed to implement the novel 2×1 and 4×1 reversible multiplexers. The MATLAB simulation results obtained for novel proposed reversible multiplexers are promising and validate the proposed design. The performance parameters like ER, CR, AM and on-off time for the proposed reversible multiplexers are calculated. The calculated value of performance parameters ...

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. ...

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