

A compact Kerr effect based Plasmonic Logic Device for Nanotechnology Applications

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Abstract—This work utilizes the vital property of Kerr effect of altering the phase of optical signal to numerically investigate the plasmonic XOR/XNOR logic device for nanotechnology applications. Extinction ratio (ER) and insertion loss (IL) of basic switching element (Mach-Zehnder interferometer) is evaluated and plotted as a function of length of interferometric arms. The obtained result and compact footprints shows that the proposed logic circuit can be a potential candidate to be used in integrated circuits for nanotechnology applications.

Keywords: Kerr effect, Mach-Zehnder interferometer, nanotechnology.

I. INTRODUCTION

In recent years, surface plasmon polaritons (SPP) based optical logic devices are one of the comprehensive topic for research. Introduction of SPP based devices have accelerated the new arrivals to overcome the demerits of semiconductor devices, which faces the difficulties of heat generations and delay, and to alleviate the photonics technology limitations, that is, diffraction limit of light. Hence, the accommodation of aforementioned devices is able to confine the light beyond diffraction limit [1]. SPP are the resultant of interaction of electromagnetic (EM) waves and free electrons of the metallic layer, travelling at the interface of metal and dielectric [2]. Recently, number of active and passive device have been put forwarded such as nano-cavities [3], couplers [4], modulators [5], plasmonic waveguide [6], and logic devices [7]. The metal-insulator-metal (MIM) waveguides have been extensively used to develop the various plasmonic devices, because of their property of confining the SPP beyond the diffraction limit [8], and have also been used with nonlinear material [9]. The governing of SPP is efficiently done by MIM waveguide, where the dispersion of signal can be analyzed as;

$$\frac{k_m}{\varepsilon_m} = -\frac{k_d}{\varepsilon_d} \tanh\left(\frac{t}{2}k_d\right) \quad (1)$$

Where, k_m and k_d , and ε_m and ε_d are the transverse wave number and permittivity of metal and dielectric, respectively, and 't' is the width of dielectric layer. Therefore, in proposed work, we have utilized the confining property of MIM waveguides to cascade the structure of basic switching element such as Mach-Zehnder interferometer (MZI), as shown in Fig. 1. The MZI is designed within the footprints of $15 \times 3 \mu\text{m}$, and working on the principle of nonlinear switching. When the phases of signal vary by factor ' π ' at output port, the first order modes come into the picture and results to the leakage of optical signal into substrate as radiating mode, and no signal at

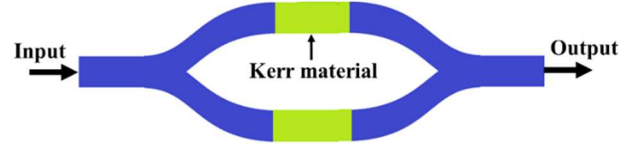


Fig.1. Schematic of switching element-MZI.

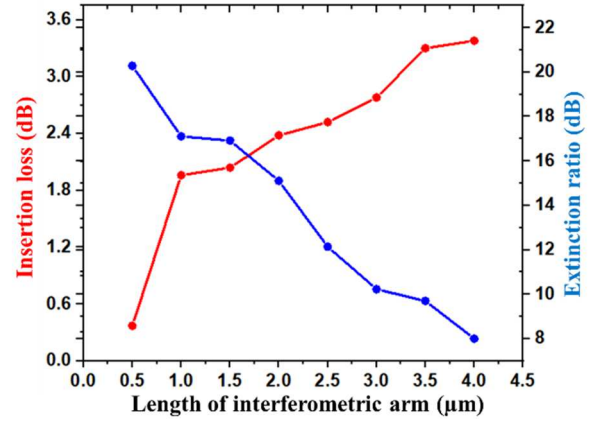


Fig.2. Extinction ratio and insertion loss versus interferometric arm of MZI.

output. However, on fundamental modes excitation, the optical beams reach to output with zero phase variation. Thus, the maximum power at output can be written as [10];

$$\frac{P_{Out}(\varphi)}{P_{Out}(0)} = \cos^2(\varphi) \quad (2)$$

The optical signal transmission at output of MZI is depends on its interferometric arms. Therefore, the extinction ratio (ER) and insertion loss (IL) is evaluated for MZI, by varying the length of interferometric arms. The trend in Fig. 2, shows that for the interferometric arm length of $0.5 \mu\text{m}$, the ER and IL of MZI are 20.1 dB and 0.37 dB, respectively. Furthermore, two waveguides have been incorporated with the MZI to control the phases of optical signal propagating in interferometric arms, to attain the functioning of XOR/XNOR logic gates. Added to this, the output terminal of MZI is branched into three, among two of which are merged together to attain the output of XOR gate, and another is used for XNOR logic function. The investigation of device is done by employing two dimensional finite difference time domain (FDTD) based Opti-FDTD tool. However, number of approaches have been utilized to realize the functioning of XOR/XNOR logic functions, but the novelty of proposed structure is its compactness, high extinction ratio

(ER) and transmission efficiency, low insertion loss, and easy fabrication [11] – [12].

II. PROPOSED PLASMONIC LOGIC DEVICE AND ITS ANALYSIS

The output port of MZI is modified into three branches, to realize the functioning of XOR/XNOR logics through proposed plasmonic device, as shown in Fig. 3. The device is obeying the angular deflection scheme of spatial solitons, which is guided by phase modulation occurs in MZI. The evanescent tails propagating in linear control waveguides introduces the variation in phase in interferometric arms of MZI. However, to obtain the optical signals at each output waveguides, the angle between them is very low. The signal is useless at the end of control waveguides, and hence, a lossless material is introduced to minimize the interference on output. The realization of XOR is obtained by combing first and third output ports of device. The output for XNOR gate is attained from second output port. Optical signal approaches to first output port, when the magnitude of Input1 (In_1) is less than that of Input2 (In_2). The optical signal reaches to second output port when the magnitude of In_1 and In_2 is equal, and hence designated as XNOR gate. The optical signal is attained at third output port due to the presence of In_1 only.

A continuous wave (CW) is used to excite all the inputs with magnetic polarization state in transverse direction. The light source is centralized at the wavelength of 1550 nm with central line width of 0.35 μm . To avoid the reflections at the interfaces of metal and dielectric, the geometry is bounded with perfect matched layer (PML) conditions. The analysis of device is done by using FDTD method, and partial differential equation (PDE) are evaluated by Opti-FDTD tool. The simulation results of device are presented in Fig. 4. The study of device is done under four different combinations of input signals, which are individually discussed as follows:

Case I: $In_1 In_2 = 0 0$

Here, only pump signal is present, which propagated through the interferometric arms of MZI and gets recombined at power combiner. The optical signals recombined with zero phase shift due to the presence of Kerr material, and propagated towards second output port which is assigned for XNOR logic function.

Case II: $In_1 In_2 = 0 1$

In this case, optical signal is given at In_2 with the pump signal. The evanescent tails of optical signal propagating in In_2 gets coupled with the field of lower interferometric arm. Therefore, phase of signal in lower interferometric arms is lag by a factor of ' π ', and hence, arrived at first output port as shown in Fig. 4.

Case III: $In_1 In_2 = 1 0$

Here, the signal is given at In_1 with pump signal, which gets coupled with the signal in upper interferometric arm. Hence, due to the phase lagging state, signal reaches to third output which is assigned for XOR gate.

Case IV: $In_1 In_2 = 1 1$

Here, signals are given on both the inputs with pump signal. The signal gets recombined at power combiner with '0' phase shift and propagated towards the second output port, which is designated for XNOR gate.

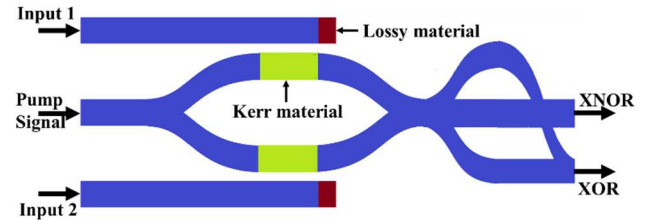


Fig.3. Schematic of proposed plasmonic logic device.

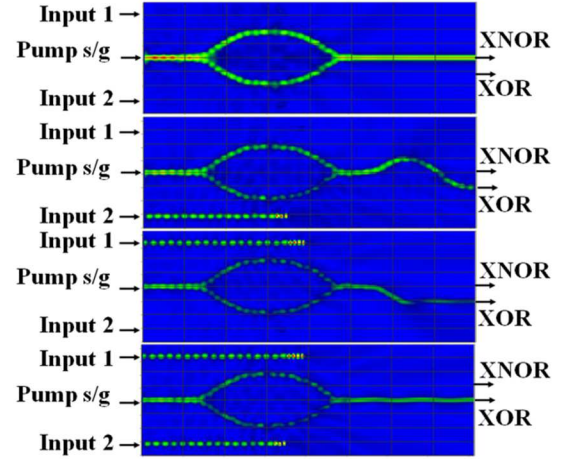


Fig.4. Signal propagation through plasmonic logic circuit.

CONCLUSION

This work, presents a plasmonic device to realize the XOR/XNOR logic functions. The device is compact in nature and efficient than existing works in terms of ER and IL. The basic switching element works with the transmission efficiency of 79 %, and can be used to realize other logic functions.

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