

# Design and characteristic analysis of an all-optical AND, XOR, and XNOR Y-shaped MIM waveguide for high-speed information processing

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Received 23 December 2021; accepted 9 January 2022; posted 12 January 2022; published 4 February 2022

All-optical logic gates are exceptionally suited for Boolean ultrahigh-speed operation and logical computing. This study presents a plasmonic model that uses a Y-shaped metal-insulator-metal waveguide structure that realizes the ultrafast all-optical AND, XOR, and XNOR gate operation that is developed at a footprint of  $6.6 \mu\text{m} \times 3.4 \mu\text{m}$  with a wavelength of  $1.55 \mu\text{m}$ . This construction relies on the notion of linear interference. The insertion loss and extinction ratio of the model are observed as 1.49 dB and 21.49 dB for AND, 1.03 dB and 18.97 dB for XOR, and 2.06 dB, and 10.92 dB for XNOR, respectively. The transmission efficiency, response time, and speed of the structure also are calculated and are used to improve the performance of any complex circuit in the future. The theoretical analysis of the proposed structure is carried out using the finite-difference time-domain method. © 2022 Optica Publishing Group

<https://doi.org/10.1364/AO.451871>

## 1. INTRODUCTION

The semiconductor industry has made enormous progress during the last few decades creating smaller, quicker, and more potent electronic devices, despite limits in low switching time, high input power, high power dissipation, limited bandwidth, and connectivity delays [1,2]. To overcome these limits, optical communications emerged and rapidly gained popularity because it replaced electrons with photons to transmit information [3]. Because of its enormous operational bandwidth, minimal electromagnetic interference (EMI), rapid speed, and massive data transmission capability, optics outperforms electronic systems [4,5]. As a result, optical circuits are seen as very bright prospects for signal transmission and processing, which can provide promising solutions [6].

Electronics or photonics are the most commonly used technologies in communications systems [7]. However, both face limitations in terms of speed and miniaturization [8,9]. As a result, researchers are developing a new technology called plasmonics [10]. The term plasmonics comes from plasmons, which are quanta linked with collective excitation of unpaired electrons in metals. Plasmonics is a technique used to compress

electromagnetic waves into tiny structures, which could lead to a new generation of ultrafast computer circuits and ultrasensitive detectors [11]. Surface plasmon polaritons (SPPs) are generated, manipulated, and detected through the science of plasmonics, which avoids the diffraction limit found in photonics [12]. Plasmonics allow light to be manipulated at subwavelength scales, potentially bridging the gap between traditional optics and nanoelectronics. Plasmon waves operate at optical frequencies that are a million times greater than the frequency of an electronic microprocessor. The higher the frequency of the wave, the more information we can transport [10–12]. Loss inside SPs has inhibited the use of plasmonics; however, this has been addressed by employing multiple waveguides serving as a metal-insulator-metal (MIM) structure [13–16], or a metal-dielectric and insulator-metal-insulator (IMI) structure [17]. Only MIMs have the strength to confine light to deep subwavelengths and route light at the nanoscale. MIM is combined with a variety of nanocavities to create all-optical tiny switching devices.

Logic gates are the crucial tenets in all digital devices. A Mach-Zehnder interferometer (MZI) based on a semiconductor optical amplifier (SOA) and a MZI based on lithium-niobate  $\text{LiNbO}_3$  were used to build logic gates. Electrical signals are

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