Design and Simulation of Optical Logic Gates Based on (MIM) Plasmonic Waveguides and slot cavity resonator for Optical Communications

Wissam Abed jasim¹, Faris Mohammed Ali², Ahmed Kareem Abdullah³, Mohammed Ahmed AbdulNabi⁴
¹Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 31001 Najaf, Iraq;
²Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 31001 Najaf, Iraq;
³Engineering Technical College-Najaf, Al-Furat Al-Awsat Technical University, 31001 Najaf, Iraq;
⁴Kufa University, College of Engineering, Department of Electronics and Communications Engineering, 54003: mohammeda.khaleel@uokufa.edu.iq
wissam.abed@student.atu.edu.iq
faris@atu.edu.iq
ahmedalbakri2012@atu.edu.iq

Abstract. In the field of optics the tinier devices are the better; therefore, the diffraction limit of light seems like an essential limitation in the way of that field. In return, new methods have appeared to resolve this issue. One of these methods is the plasmonic technology which allows light pressure into nanostructures. The current study proposes all-optical logic gates based on metal insulator metal structures (mim) waveguide. This waveguide has an important characteristic which is restricting the applied light strongly far from the diffraction limit. The proposed structure is small compared to the applied wavelength. The optical plasmonic gates proposed are (OR, NOR, AND, NAND, NOT). The comsol multiphysics 5.5 software was used for simulation by the 2-D FDTD method. Hence, these five gates will be obtained by optical interference between the propagating signals through the input ports and the control ports, whose positions can be altered according to the gate needed. The implementation and simulation of the proposed gates were all in the same structure, with the same dimensions, the same wavelength and the same transmission threshold, with applicable wavelength of (1550 nm). The performance of the proposed plasmonic gates was tested by two criteria; the optical transmission ratio and the contrast ratio, which is the ratio between the ON and OFF states of the proposed gate.

1. Introduction
Optical computing is a striking technology mainly because of its high speed in data processing and its low heat loss. These two features are the most significant obstacles that face modern electronic integrated circuits (ICs). There have been different devices performing different functions depending on optical computing, for instance, solving differential equations [1, 2], differentials [3-4], integrals [5], analogue computer [6], features [7], comparative [8], due to the enormous advances in nan-photons and nano-plasmonics.
Hence, compared to electronic integrated circuits (EIC), photonic integrated circuits (PIC) have drawn remarkable attention in last few years due to their low cost, high speed and super-speed range [9]. Moreover, PICs can be synthesized from a variety of nano-optical structures, including ring resonators [10], Bragg grating [11], waveguide grating [12], metal plane lens [13], optical coil [14], optical add-drop multiplexer (OADM) [15], where optical logic devices are expected to be the building blocks of a long-distance optoelectronic integrated circuit (OEIC) [16].

All surface plasmon polaritons (SPP)-based optical devices have been a topic of interest to researchers in recent years. These devices overcame the main boundaries of semiconductor electronic devices, which undergo delays in data transfer and overheat generation. SPPs are electromagnetic waves associated with electron oscillations that propagate along the insulating metal interface with an exponential field in the vertical direction of the interface [17]. In addition, SPPs are considered a promising energy that helped overcome the diffraction limit of the conventional optical devices and treat light on the sub-wavelength scale [18-19]. This feature opens the doors toward ultrafine light-guide structures, which allow for sub-wavelength confinement of optical patterns. Plasmonic waveguides have shown remarkable potentials of guiding sub-wavelength light patterns.

A variety of plasma waveguide structures have been proposed, such as metal pegs [20], grooves [21], nanowires [22], and metal insulator metal structures (MIM) [23-24]. Whereas, MIM waveguides are characterized by their high light trapping with satisfactory spread lengths (SPPs). The unique features of MIM plasma wave devices are to overcome the diffraction limit, hence, the use of the above devices enabled light processing at a sub-wavelength scale [25]. SPPs can be defined as the interaction of electromagnetic waves and free electrons of metals, which propagate on the MIM interfaces [26-27]. Different plasma devices, such as nanocavities [28], Bragg reflectors [28], dividers [29], resonators [30], couplers [31], modifiers [32], providers / multiplexers [33], stub waveguides [29], hybrid waveguides [34], switches [35-36], and logic gates [37-38], have been achieved to date.

In all-optical logic gates, many studies have been proposed, analyzed and examined. For example, mono-semiconductor optical amplifiers [39], cavities of a hybrid nano-crystalline beam [38], two-photon absorbers in silicon waveguides [40], nanoscale silicon ring resonators [41-42], phase modification [43], and nanoscale plasmonics [44]. Recently, many optical-plasmonics structures presented complete nanoscale logic gates [45-46], in which each nanoparticle had a different way for functions of gates, different number of logic gates, different types of logic gates, different values for resonant frequencies, different geometries, different structures of materials, and different transmission values.

In this study, the largest number of plasma logic gates (five) are presented with the same structure, same resonance frequency and same transmitter threshold. Simulation results are obtained by means of a comsol multiphysicsce (5.6). It is hoped that these devices will be a gateway to the integrated circuit applications with nanophytes.

2. Literature Review

In [45], a structure implementing four optical logic gates was proposed: NAND, NOT, EX-OR and EX-NOR based on the plasmonic waveguide and nanoscale ring resonator. The geometric dimension of the proposed structure is (1220 × 1120) nm. The maximum contrast ratio of 26 dB was obtained at a wavelength of 525 nm. These gates were simulated and studied using the FDTD digital method. These simple and micro devices can be used in phonotonic integrated circuits (PICs). Their behavior and performance can be modified by altering the structural parameters. The proposed XOR gate had the best performance in this structure.

In [47], new (MIM)-based optical logic gates of dielectric plasmonic waveguides were proposed. Hence, all the proposed optical logic gates were examined numerically using finite difference time domain (FDTD) method wherein the optical logic NOT gate was implemented. By changing the control port, the outbound field can be propagated or not in the waveguide. Therefore, the proposed device could serve as a major prospective component in applying the processing system of optical signals in the integrated circuits (a plasmonic (MIM) waveguide was used) as a structure to achieve the logic NOT gate in this study with structure as large as (2.4 μm). X 3 μm) and a maximum transmission of 65.35%.
In [48], two structures implementing three plasmonic optical logic gates were proposed. These plasmonic logic gates are based on the plasmonic waveguide structures and MIM square ring resonator. These gates were NOT, AND, and NOR, realized in the two dimension structures of the first (750 nm x 900 nm) to implement the NOT gate, and (1.5 μm x 1.8 μm) for AND and NOR gates. The maximum transmissions was 70% and 90% for both structures, operating at the wavelength 1535 nm.

In [49], the gates OR, NOT, AND, and EX-OR based on a single matrix waveguide were proposed. The structure has one input port and three output ports. The waveguide length (L) was changed to obtain each of the above gates, where L1 = 0.68 μm is to implement the NOT gate, L2 = 0.38 μm is to implement the AND gate, and L3 = 0.32 μm is to implement the XOR gate. A maximum contrast ratio of 13.98 dB was obtained (the logic functions OR, AND, NOT, and EX-OR can be achieved by selecting the appropriate length of the waveguide, the specified input ports, the output ports, and the appropriate threshold value. Thus, the lengths of the waveguides of the proposed gates differed).

In [50], a study proposed a structure to implement the three plasmonic optical logic gates, AND, XNOR, and NOR based on graphene-dielectric-metal structure. It contains one input port and three output ports. The geometric dimensions of the proposed structure are as follows; structure size = 4.5 μm, SiO₂ layer width = 120 nm, Au layer width = 30 nm, and graphene layer thickness= 1 atom. The maximum contrast ratio obtained was (29.41, 97.38 and 29.40 dB) for (AND, XNOR, NOR), respectively.

In [51], a study proposed a structure to implement the plasmonic logic gates OR, and NOR using the proposed linear waveguides and MIM Plasmonic structure based vertical linear cavities with high contrast ratio of the dimensions: linear waveguide length (l)= 500 nm, waveguide linear width (w= 50) nm, and the length of the linear vertical cavity (L)= 1000 nm. The maximum contrast ratio was (12.36 db) for NOR gate.

In [52], a NAND gate based on Mach-Zehnder plasmonic interferometers (P-MZI) supported by MIM waveguides. The proposed structures were designed with a minimum number of P-MZI operating at 1550 nm wavelengths. The geometric dimension of the proposed structures are (40 x 7.5 μm). The contrast ratio of 10.25 db was obtained as maximum.

In [53], researchers proposed a structure to implement simple basic logic gates for XOR, OR and NOT based on tape graphene nanoscale resonators attached with properly designed nano waveguides as input and output logic ports, and verified numerically using the time-difference-domain method FDTD. A typical extinction ratio of about (8 db) was achieved between the ON and OFF logic settings according to the remarkable advantage of the voltage-dependent chemical potential of graphene delivery, whereby the properties of structures can be effectively manipulated to control their behavior and performance.

In [54], study, a structure was proposed to implement two gates: AND and NOR, based on plasmonic waveguides and a MIM- ring resonator. The multi-input structure was 2 and 3 bits. The size was more than (3 μm x 2 μm). The maximum transmission was up to 84.06% in the AND.

All these studies aimed to minimize the size of optical devices used in the communication systems. Therefore, most of them implemented small number of gates in the one structure or more. Some studies alter some dimensions of the same structure to implement another gate. Moreover, most of these studies used a wavelength less than 1550 nm, which is the applicable wavelength in most optical communication systems. In the current study, the researchers aim to implement the largest number of gates in the same structure, with the same dimensions, the same wavelength of 1550 nm, and the same transmission threshold. It is hoped that this study will be a gateway to building integrated optical-plasmonic circuits.

3. Theoretical Calculations

The current proposed structure implementing (five) plasmonic optical gates, consists of a waveguide of three layers (metal - insulator - metal) (MIM) and a rectangular nano aperture, figure (1). Silver and air are used in this structure as conductive insulating material, respectively. The waveguide width is very small compared to the applied wavelength and the small size of the waveguide width will give a singlet propagation pattern for TM+ in the waveguide (MIM), and the complex propagation constant β can be calculated by solving the following dispersion relation:

$$\epsilon_d k_m + \epsilon_m k_d \tanh \left( \frac{k_d}{2} w \right) = 0$$  \hspace{1cm} (1)
Where \( k_d \) and \( k_m \) are obtained by:

\[
\begin{align*}
\frac{k_d}{k_o} &= \left( \frac{\beta^2 - \varepsilon_d k_o^2}{\lambda} \right)^{1/2} \quad \text{Dielectric wave number} \\
\frac{k_m}{k_o} &= \left( \frac{\beta^2 - \varepsilon_m k_o^2}{\lambda} \right)^{1/2} \quad \text{Metal wave number}
\end{align*}
\]

(2) Dielectric wave number

(3) Metal wave number

Where \( \varepsilon_d \) and \( \varepsilon_m \) are dielectric constants of the insulator and metal.

\( k_o = \frac{2\pi}{\lambda} \) \quad \text{Free space wavenumber} \quad (4)

The effective refractive index of the waveguide, MIM, can be obtained from the following relationship:

\[
\frac{n_{\text{eff}}}{\beta} = \frac{k}{k_o}
\]

(5)

Figure 1. The structure of the proposed optical plasmonic gates where \( w_c \) and \( l_c \) are the length and width of the slot cavity and \( d \) and \( w \) are the coupling distance between the ports and the slot cavity and the width of the waveguide port, respectively. And \( \Delta l \) is the distance between the ports and the center of the slot cavity.

Stationary waves in the slot cavity can occur when the following condition is met

\[
\Delta \phi = \beta_m 2l_c + \phi_r = 2m\pi
\]

When this condition is met where \( \Delta \phi \) is the total phase displacement of the light for each transport round occurring in the slot cavity and \( \phi_r \) is the phase displacement on both sides of the cavity boundary when the wave propagates [55]. The slot cavity length is \( l_c \) and \( m \) is an integer that decides the order of the resonance mode in the slot cavity and \( \beta_m \) is the rank propagation constant of \( \beta_m \) where \( \phi_r \) is very small. It can be neglected without affecting the results. Hence, the resonance wavelength can be calculated by the following relation:

\[
\lambda_m = \frac{2n_{\text{eff}}l_c}{m} \quad (6)
\]

where \( n_{\text{eff}} \) is the refractive index of the slot cavity, when the input pulse is assumingly executed from one of the three ports 1, 2, 3 placed in the random location \( \Delta l_i \) (i = 1, 2, 3) from the midpoint of the slot cavity. The magnetic field can be calculated, with \( m \) being the pattern rank, and the magnetic field in the slot cavity can be calculated by the following relation [55]

\[
H_m(x, t) = \frac{2H_o \cos(\beta_m x - \frac{\beta_m l_c}{2})}{\sigma} \left[ e^{i\left(\frac{3}{2} \beta_m l_c - \beta_m \Delta l\right)} + e^{i(\beta_m \Delta l - \beta_m l c/2)} \right] e^{-i\omega_m t}
\]

(7)

where \( \sigma \) is the total dissipation that takes place when the light propagates into the rectangular nano slot cavity, including the loss of both the losses that occur from the absorption of the metal and the coupling losses that occur between the waveguide and the slot cavity.

In the current study, the first resonance of the slot cavity is considered through the resonance condition of the first mode of the wave input ports, 1, 2, 3, 4, as shown in figure (1). Hence, the magnetic field of the first mode can be calculated as follows:

\[
H_{1,2,3,4}^i(x, t) = \frac{2H_o \sin(\beta_i x)}{\sigma} \left[ -\sin(\beta_i \Delta l) \right] e^{-i\omega_i t}
\]

(8)

And since \( \Delta l \) is considered equal for all ports in the current study, the equation becomes:

\[
H_i = H_{1,2,3,4}^i(x, t) = \frac{2H_o \sin(\beta_i x)}{\sigma} \left[ -\sin(\beta_i \Delta l) \right] e^{-i\omega_i t}
\]

(9)

By selecting the appropriate distance for \( \Delta l \), we can achieve constructive and destructive interference to implement the required five gates.
4. Experimental Work

4.1. PLASMONIC OR LOGIC GATE

Drawing on the discussion over the theoretical part of the structure illustrated in Fig. (1), \( \Delta L \) is considered equal for all ports of all five gates proposed. In this gate, ports (2 and 4) were considered input ports, and port (1) an output port. Port (3) is neglected and is not used in the implementation of this gate. As shown in the structure illustrated in Fig. (2.3), by examining the fact table of the OR gate in figure (2.4) and its form in figure (2.1), it can work as an OR gate and figure (2.5) shows the transmission to the proposed gate OR, the highest transmission ratio obtained is 0.91 and a transmission threshold is 0.35. When one input port is ON, the output in port (1) is ON, and when the two inputs are ON, the output in port (1) is ON as well. Likewise, when the two inputs are OFF, the output in port (1) is OFF, as shown in the figure (2.8).

| Input 1i | Input 2i | Output |
|----------|----------|--------|
| 0        | 0        | 0      |
| 0        | 1        | 1      |
| 1        | 0        | 1      |
| 1        | 1        | 1      |

Figure 2.1. The traditional symbol of OR logic gate

Figure 2.2. The fact table of OR logic gate

Figure 2.3. The proposed structure of Plasmonic OR logic gate

Figure 2.4. The spectrum of the transmitter showing the correlation between the transmission and the wavelength for all states of the optical-plasmonic logic OR gate
4.2. PLASMONIC NOR LOGIC GATE

According to equation (5) of the theoretical part, ports (2 and 4) were considered as input ports, and port (1) as control port. This port is always ON as shown in figure (3.3). As shown in the fact table of the NOR gate in figure (3.2) and its form illustrated in figure (3.1) it can work as an NOR gate. Figure (3.4) shows the transmission of the proposed NOR gate, as highest transmission ratio at 0.78, as shown in the figure (3.4). When one input port is ON, the output in port (3) is OFF, and when the two inputs are ON, the output in port (3) is OFF as well. Likewise, when the two inputs are OFF, the output in port (3) is ON, as shown in the figure (3.5).

![Figure 2.5](image)

Figure 2.5. The magnetic field of state of OR gate in the structure (2.5.a) when the input in the first port is ON, (2.5.b) when the input in the second port is ON, and (2.5.c) when the two inputs are ON

![Figure 3.1](image)

Figure 3.1. The traditional symbol of NOR logic gate

![Figure 3.2](image)

Figure 3.2. The fact table of NOR logic gate

![Figure 3.3](image)

Figure 3.3. The proposed structure of NOR logic gate

![Figure 3.4](image)

Figure 3.4. The spectrum of the transmitter showing the correlation between the transmission and the wavelength for all states of the optical-plasmonic logic NOR gate
4.3. PLASMONIC AND LOGIC GATE

In this gate; however, the ports (2 and 3) are considered as input ports, port (4) as a control port always on ON in all cases, and port (1) as an output port as shown in figure (4.3). As in the fact table of the AND gate in figure (4.2) and its shape in figure (4.1), it can operate as an AND gate. Figure (4.4) shows the transmission of the proposed AND gate, with the highest transmission ratio obtained as 0.85, as shown in the figure (4.4). When the input port (1) is ON in port (2) and the phase angle of the signal applied is 180 degrees, the output in port (1) will be OFF. On the other hand, when the second input is ON in port (3) and the phase angle of the applied signal is 0 degrees, the output in port (1) will be OFF. Likewise, when the two inputs are ON, the output in port (1) will be ON and when the two inputs are OFF, the output in port (1) will be OFF, as shown in the figure (4.5).

4.3. The magnetic field of states of NOR gate in the structure (3.5.a) when the input in the first port is ON, (3.5.b) when the input in the second port is ON, (3.5.c) when the two inputs are ON, and (3.5.d) when the two inputs are OFF.

4.3. PLASMONIC AND LOGIC GATE

Figure 4.1. The traditional symbol of AND logic gate

| Input 1 | Input 2 | Output |
|---------|---------|--------|
| 0       | 0       | 0      |
| 0       | 1       | 0      |
| 1       | 0       | 0      |
| 1       | 1       | 1      |

Figure 4.2. The fact table of AND logic gate
4.4. PLASMONIC NAND LOGIC GATE

To implement the NAND gate, the ports (2 and 4) will be considered as an input port, port (1) as a control port, always ON in all cases, and port (3) as an output port. As indicated in the fact table of NAND gate in the figure (5.2) and its shape shown in figure (5.1), it can work as a NAND gate. Figure (5.4) shows the transmission of the proposed NAND gate, with the highest transmission ratio as 1.91, as shown in the figure (5.4). When the first input port is ON in port (2), with the phase angle of the signal 180, the output in port (3) will be ON and when the second input is ON in port (4) with the phase angle of the applied signal as 180 degrees, the output in port (3) will be ON. On the other hand, when the two inputs are OFF, the output in port (3) will be ON, and when the two inputs are ON, the output in port (3) will be OFF, as shown in the figure (5.5).

| Input 1 | Input 2 | Output |
|---------|---------|--------|
| 0       | 0       | 1      |
| 0       | 1       | 1      |
| 1       | 0       | 1      |
| 1       | 1       | 0      |

Figure 4.3. The proposed structure of AND logic Plasmonic gate

Figure 4.4. The spectrum of the transmitter showing the correlation between the transmission and the wavelength for all states of the optical-plasmonic logic AND gate

Figure 4.5. The magnetic field of states of AND gate in the structure (4.5.a) when the input in the first port is ON, (4.5.b) when the input in the second port is ON, and (4.5.c) when the two inputs are ON.

Figure 5.1. The traditional symbol of NAND logic gate

Figure 5.2. The fact table of NAND logic gate
4.5. PLASMONIC NOT LOGIC GATE

To execute this gate, port (1) was considered as the input port, port (2) was a control port always in the ON state in all cases, port (4) as an output and port (3) is neglected as shown in the figure (6.3). As in the fact table of the NOT gate in the figure (6.2) and its illustration in figure (6.1), it can operate as a NOT gate. Figure (6.4) shows the transmission of the proposed NOT gate, with the highest transmission ratio obtained 0.38 as in the figure (6.4). Hence, when port (1) is ON, the output in port (4) is OFF and when the input in port (1) is OFF, the output in port (4) is ON, as shown in the figure (6.5).
Figure 6.1. The traditional symbol of NOT logic gate

| Input | Output |
|-------|--------|
| 0     | 1      |
| 1     | 0      |

Figure 6.2. The fact table of NOT logic gate

Figure 6.3. The proposed structure of NOT logic Plasmonic gate

Figure 6.4. The spectrum of the transmitter showing the correlation between the transmission and the wavelength for all states of the optical-plasmonic logic NOT gate
5. Results and Simulation

The two-dimensional finite-difference time-domain (FDTD) method was used to numerically solve Maxwell’s equations using comsol multiphysics package software (5.6) with nm (5x5) network size and convolutional perfectly matched layer (CPML) to absorb the boundary conditions of the region being simulated. All input optical TM are polarized.

The proposed structure in the current study has four ports, two of which are input ports, the third is a control port, and the last is an output port. The basic operations of logic gates are realized on the principle of constructive and destructive interferences between optical signals that propagate in the waveguide. Consequently, the interaction between the waveguides and the slot cavity the surface resonance plasmon (ssp) will occur as the interference between the incident light signals depends on the phase of the applied light field as well as the positions of stimulating ports (input or control), in which the structure dimensions of the waveguides are as follows.

where \( w = \omega_c = 100 \text{ nm} \) is waveguide width and the slot cavity, \( l_c = 560 \text{ nm} \) is the slot cavity length, and \( d = 15 \text{ nm} \) is the distance between the waveguide and the slot cavity. The materials used in this proposed structure are silver and air. The waveguides and the slot cavity are of air substance and the rest of the structure is of silver, figure (1).

The proposed structure will simulate plasmonic optical logic gates (OR, NOR, AND, NAND, NOT) MIM based on plasmonic waveguide. All five proposed plasmonic optical gates have the same dimensions, the same materials and the same structure. The Jonson and Christy data are used in simulations to describe the permittivity of silver, while the refractive index of air is \( (\varepsilon_d = 1) \) for the insulator, as the wavelength of resonance can be calculated by equation (2).

According to the above equation, the structure parameters and the type of material used in the simulations are considered a rule in selecting the wavelength, for which 1550 nm was selected as it is the best option in optical communication applications. These five gates can be measured by two criteria, the first is the transmission ratio which is the ratio between the optical power output to the optical power of the signal entering the port (input or control). The second criterion is the contrast ratio, which is the ratio between the lowest optical power in the ON state and the highest optical power in the OFF state in the output port, and the higher this ratio the better the performance of the gate, as follows.

\[
T = \frac{P_{out}}{P_{in}} \quad \text{(for the ON and OFF states in the output)} \tag{10}
\]

where \( T \) represents the transmission and \( P_{out} \) is the optical output power in the output port in the ON and OFF states., whereas \( P_{in} \) is the optical input power in the input port or control port.

\[
\text{ON/OFF contrast ratio (db)} = 10 \log_{10} \left( \frac{(P_{out}|on)_{\min}}{(P_{out}|off)_{\max}} \right) \tag{11}
\]
where the $P_{\text{out}|\text{on}}$ is the lowest optical power exiting from the output port in the ON state, i.e. logic (1), whereas the $P_{\text{out}|\text{off}}$ is the highest optical power exiting from the output port in the OFF state i.e. logic (0).

6. Conclusion

This study proves that the plasmonic technology is one of the best techniques used to minimize the dimensions of optical devices used in communications to less than the wavelength dimensions applied to them. Five gates were designed: OR, NOR, AND, NAND and NOT gates in one structure with the same dimensions, the same wavelength and the same transmission threshold. The results were analyzed numerically using 2-D FDTD where these gates were implemented depending on the optical interference feature between the propagated signals in the input or control ports and the coupling process between the waveguides and the slot cavity. The results of simulations revealed that the highest transmission ratio exceeded 100% in the NAND gate, reaching 190%, and the highest contrast ratio was in the OR gate, of more than (26 db).

7. References

[1] Yang, P., Gu, H., Zhao, Z., Wang, W., Cao, B., Lai, C., ... & Wang, X. (2014). Angiotensin-converting enzyme 2 (ACE2) mediates influenza H7N9 virus-induced acute lung injury. Scientific reports, 4(1), 1-6.

[2] Tan, S., Xiang, L., Zou, J., Zhang, Q., Wu, Z., Yu, Y., ... & Zhang, X. (2013). High-order all-optical differential equation solver based on microring resonators. Optics letters, 38(19), 3735-3738.

[3] Pors, A., Nielsen, M. G., & Bozhevolnyi, S. I. (2015). Analog computing using reflective plasmonic metasurfaces. Nano letters, 15(1), 791-797.

[4] Xu, Jing, et al. "High-speed all-optical differentiator based on a semiconductor optical amplifier and an optical filter." Optics letters 32.13 (2007): 1872-1874

[5] Azaña, José. "Ultrafast analog all-optical signal processors based on fiber-grating devices." IEEE Photonics Journal 2.3 (2010): 359-386.

[6] Ferrera, M., Park, Y., Razzari, L., Little, B. E., Chu, S. T., Morandotti, R., ... & Azaña, J. (2010). On-chip CMOS-compatible all-optical integrator. Nature communications, 1(1), 1-5

[7] Lu, Cuicui, et al. "Integrated all-optical logic discriminators based on plasmonic bandgap engineering." Scientific reports 3.1 (2013): 1-8.

[8] Lu, C., Hu, X., Yang, H., & Gong, Q. (2014). Chip-integrated ultrawide-band all-optical logic comparator in plasmonic circuits. Scientific reports, 4(1), 1-8.

[9] Vlasov, Y. A., & McNab, S. J. (2004). Losses in single-mode silicon-on-insulator strip waveguides and bends. Optics express, 12(8), 1622-1631.

[10] Bozhevolnyi, S. I., Volkov, V. S., Devaux, E., Laluet, J. Y., & Ebbesen, T. W. (2006). Channel plasmon subwavelength waveguide components including interferometers and ring resonators. Nature, 440(7083), 508-511.

[11] Meltz, G., Morey, W., & Glenn, W. H. (1989). Formation of Bragg gratings in optical fibers by a transverse holographic method. Optics letters, 14(15), 823-825.

[12] Rosenblatt, D., Sharon, A., & Friesem, A. A. (1997). Resonant grating waveguide structures. IEEE Journal of Quantum electronics, 33(11), 2038-2059.

[13] Wellems, L. D., Huang, D., Leskova, T. A., & Maradudin, A. A. (2012). Nanogroove array on thin metallic film as planar lens with tunable focusing. Physics Letters A, 376(3), 216-220.

[14] Kind, H., Yan, H., Messer, B., Law, M., & Yang, P. (2002). Nanowire ultraviolet photodetectors and optical switches. Advanced materials, 14(2), 158-160.

[15] Geng, M., Jia, L., Zhang, L., Yang, L., Chen, P., Wang, T., & Liu, Y. (2009). Four-channel reconfigurable optical add-drop multiplexer based on photonic wire waveguide. Optics express, 17(7), 5502-5516.

[16] Liu, Z., Ding, L., Yi, J., Wei, Z., & Guo, J. (2019). Design of a multi-bits input optical logic device with high intensity contrast based on plasmonic waveguides structure. Optics Communications, 430, 112-118.
[17] Krenn, J. R., & Weeber, J. C. (2004). Surface plasmon polaritons in metal stripes and wires. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 362(1817), 739-756.

[18] Kotsifaki, D. G., & Chormaic, S. N. (2019). Plasmonic optical tweezers based on nanostructures: fundamentals, advances and prospects. Nanophotonics, 8(7), 1227-1245.

[19] Li, C., Liu, Z., Chen, J., Gao, Y., Li, M., & Zhang, Q. (2019). Semiconductor nanowire plasmonic lasers. Nanophotonics, 8(12), 2091-2110.

[20] Kenausis, G. L., Vörös, J., Elbert, D. L., Huang, N., Hofer, R., Ruiz-Taylor, L., ... & Spencer, N. D. (2000). Poly (L-lysine)-g-poly (ethylene glycol) layers on metal oxide surfaces: Attachment mechanism and effects of polymer architecture on resistance to protein adsorption. The Journal of Physical Chemistry B, 104(14), 3298-3309.

[21] Bozhevolnyi, S. I., Volkov, V. S., Devaux, E., Laluet, J. Y., & Ebbesen, T. W. (2006). Channel plasmon subwavelength waveguide components including interferometers and ring resonators. Nature, 440(7083), 508-511.

[22] Fang, Y., Li, Z., Huang, Y., Zhang, S., Nordlander, P., Halas, N. J., & Xu, H. (2010). Branched silver nanowires as controllable plasmon routers. Nano letters, 10(5), 1950-1954.

[23] Wang, B., & Wang, G. P. (2004). Surface plasmon polariton propagation in nanoscale metal gap waveguides. Optics letters, 29(17), 1992-1994.

[24] Fu, Y., Hu, X., Lu, C., Yue, S., Yang, H., & Gong, Q. (2012). All-optical logic gates based on nanoscale plasmonic slot waveguides. Nano letters, 12(11), 5784-5790.

[25] Hill, M. T. (2010). Status and prospects for metallic and plasmonic nano-lasers. JOSA B, 27(11), B36-B44.

[26] Mei, X., Huang, X. G., & Jin, T. (2011). A sub-wavelength electro-optic switch based on plasmonic T-shaped waveguide. Plasmonics, 6(4), 613-618.

[27] Peng, X., Li, H., Wu, C., Cao, G., & Liu, Z. (2013). Research on transmission characteristics of aperture-coupled square-ring resonator based filter. Optics Communications, 294, 368-371.

[28] Wang, B., & Wang, G. P. (2005). Plasmon Bragg reflectors and nanocavities on flat metallic surfaces. Applied Physics Letters, 87(1), 013107.

[29] Chen, J., Li, Z., Lei, M., Fu, X., Xiao, J., & Gong, Q. (2012). Plasmonic Y-splitters of high wavelength resolution based on strongly coupled-resonator effects. Plasmonics, 7(3), 441-445.

[30] Guo, Y., Yan, L., Pan, W., Luo, B., Wen, K., Guo, Z., & Luo, X. (2013). Transmission characteristics of the aperture-coupled rectangular resonators based on metal–insulator–metal waveguides. Optics Communications, 300, 277-281.

[31] Nozhat, N., & Granpayeh, N. (2012). Switching power reduction in the ultra-compact Kerr nonlinear plasmonic directional coupler. Optics Communications, 285(6), 1555-1559.

[32] Lu, Z., & Zhao, W. (2012). Nanoscale electro-optic modulators based on graphene-slot waveguides. JOSA B, 29(6), 1490-1496.

[33] Nozhat, N., & Granpayeh, N. (2011). Analysis of the plasmonic power splitter and MUX/DEMUX suitable for photonic integrated circuits. Optics Communications, 284(13), 3449-3455.

[34] Nozhat, N., & Granpayeh, N. (2011). Analysis of the plasmonic power splitter and MUX/DEMUX suitable for photonic integrated circuits. Optics Communications, 284(13), 3449-3455.

[35] Tao, J., Wang, Q. J., & Huang, X. G. (2011). All-optical plasmonic switches based on coupled nano-disk cavity structures containing nonlinear material. Plasmonics, 6(4), 753-759.

[36] Nozhat, N., & Granpayeh, N. (2014). All-optical nonlinear plasmonic ring resonator switches. Journal of Modern Optics, 61(20), 1690-1695.

[37] Liu, Y., Qin, F., Meng, Z. M., Zhou, F., Mao, Q. H., & Li, Z. Y. (2011). All-optical logic gates based on two-dimensional low-refractive-index nonlinear photonic crystal slabs. Optics express, 19(3), 1945-1953.

[38] Maksymov, I. S. (2011). Optical switching and logic gates with hybrid plasmonic–photonic crystal nanobeam cavities. Physics Letters A, 375(5), 918-921.
[39] Kaur, S., & Kaler, R. S. (2012). Ultrahigh speed reconfigurable logic operations based on single semiconductor optical amplifier. Journal of the Optical Society of Korea, 16(1), 13-16.

[40] Oh, G. Y., Kim, D. G., & Choi, Y. W. (2010, July). All-optical logic gate using waveguide-type SPR with Au/ZnO plasmon stack. In OECC 2010 Technical Digest (pp. 374-375). IEEE.

[41] Xu, Q., & Lipson, M. (2007). All-optical logic based on silicon micro-ring resonators. Optics express, 15(3), 924-929.

[42] Liang, T. K., Nunes, L. R., Tsuchiya, M., Abedin, K. S., Miyazaki, T., Van Thourhout, D., ... & Tsang, H. K. (2006). High speed logic gate using two-photon absorption in silicon waveguides. Optics Communications, 265(1), 171-174.

[43] Kim, J. H., Kang, B. K., Park, Y. H., Byun, Y. T., Lee, S., Woo, D. H., & Kim, S. H. (2001). All-optical AND gate using XPM wavelength converter. Journal of the Optical Society of Korea, 5(1), 25-28.

[44] Wei, H., Wang, Z., Tian, X., Käll, M., & Xu, H. (2011). Cascaded logic gates in nanophotonic plasmon networks. Nature communications, 2(1), 1-5.

[45] Dolatabady, A., & Granpayeh, N. (2012). All optical logic gates based on two dimensional plasmonic waveguides with nanodisk resonators. Journal of the Optical Society of Korea, 16(4), 432-442.

[46] Liu, Z., Ding, L., Yi, J., Wei, Z., & Guo, J. (2019). Design of a multi-bits input optical logic device with high intensity contrast based on plasmonic waveguides structure. Optics Communications, 430, 112-118.

[47] Wu, Y. D., Hsueh, Y. T., & Shih, T. T. (2013, August). Novel All-optical Logic Gates Based on Microring Metal-insulator-metal Plasmonic Waveguides. In PIERS Proceedings.

[48] Nozhat, N., & Granpayeh, N. (2015). All-optical logic gates based on nonlinear plasmonic ring resonators. Applied optics, 54(26), 7944-7948.

[49] Yang, W., Shi, X., Xing, H., & Chen, X. (2018). All-optical logic gates based on metallic waveguide arrays. Results in Physics, 11, 837-841.

[50] Rezaei, M. H., Zarifikar, A., & Miri, M. (2018). Ultra-compact electro-optical graphene-based plasmonic multi-logic gate with high extinction ratio. Optical Materials, 84, 572-578.

[51] Sharma, S., Zafar, R., Mahdieh, M. H., Singh, G., & Salim, M. (2020). High Contrast Ratio Based All-Optical OR and NOR Plasmonic Logic Gate Operating at E Band. In Optical and Wireless Technologies (pp. 325-332). Springer, Singapore.

[52] Singh, A., Pal, A., Singh, Y., & Sharma, S. (2019). Design of optimized all-optical NAND gate using metal-insulator-metal waveguide. Optik, 182, 524-528.

[53] Dolatabady, A., Granpayeh, N., & Abedini, M. (2020). Frequency-tunable logic gates in graphene nano-waveguides. Photonic Network Communications, 1-8.

[54] Liu, Z., Ding, L., Yi, J., Wei, Z., & Guo, J. (2019). Design of a multi-bits input optical logic device with high intensity contrast based on plasmonic waveguides structure. Optics Communications, 430, 112-118.

[55] Hu, F., Yi, H., & Zhou, Z. (2011). Band-pass plasmonic slot filter with band selection and spectrally splitting capabilities. Optics express, 19(6), 4848-4855.