THE DESIGN OF A HIGH-SPEED HALF ADDER BASED ON GRAPHENE RESONATORS

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Abstract - In the field of optical technologies, modern optical scenarios such as integrated multi-operand optical gates are considered as very useful and effective substrates. In this paper, a new and unique design and three-dimensional simulation of a graphene based integrated half adder by the use of ring resonators and central waveguides has been presented. The proposed structure includes two separate AND and XOR gates, and the presence of graphene in this design allows to tune the wavelength and to turn on or off the structure at the desired wavelength without changing the design parameters and only by changing the Fermi voltage of graphene . The half adder logic is controlled based on the output power of the CARRY and SUM ports at a central wavelength of 1550 nm. This can be used to further enhance the speed of communication systems in many ways. Graphene based resonators overall enhances the switching speed of the circuit.

Keywords - Graphene , Wavelength , Intereference , Waveguides.

I. INTRODUCTION

Advances in technology cause the need for communications with wide bandwidth, high speed, low power consumption, and high rate of data transmission to be inevitable. To achieve this success, one of the suitable options that are very much considered by researchers today is integrated optical circuits [1]. The most basic step for the realization of integrated optical circuits is the design of all-optical logic gates. Logic gates are devices that perform logical operations on one or more inputs and generate eventually one or more logic outputs based on Boolean algebra [2]. To design optical logic gates, two key points must be considered, including the method of controlling the emission of light within the structure and the composition of the appropriate materials [2,3]. The methods of controlling the emission of light within the logic gates include self-aligning effects, multi-mode interferences, nonlinear effects, and interference effects . Since there are limited contrast ratio, high cost, and limited operating frequency range in the case of using self aligning , multi-mode, and nonlinear effects and the optical power of the first block must be very high when cascading these gates to allow the next logic gates to operate correctly, the interference effect has been used in the present paper to design the logic gate [7,9]. Using the interference effect, the structure operates inthis way that if the light waves have a fuzzy difference of about 2 nπ when interfering with each other, the interference is constructive and the output of the logic gate is 1. However, if the fuzzy difference between the waves during the interference is about (2n + 1) π, the interference is destructive and the output of the logic gate is 0. There are several ways to choose the appropriate materials for designing the logic gates. Today, a wide variety of materials are used to design optical devices, the most common of which are graphene-silicon composites , photonic crystals metamaterials, and metal–insulator-metal structures in two and three dimensions . The construction of one, two, and three-dimensional devices based on photonic crystals is very difficult because the output is extremely sensitive to the changes in the control parameters such as radius, refractive index, displacement of dielectric rods and it is difficult to control light in the third dimension when using the three-dimensional structures[4] .

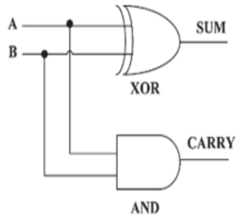
The construction of optical devices using metal–insulator-metal technology is not attractive due to the low transmit power at the output in the state ON and the lack of proper separation between the output powers of 0 and 1. As a result, one of the most important and practical composites used to design optical devices, especially optical logic gates, is the graphene silicon composites. .The excellent properties of graphene have made it one of the most promising options for various applications, such as high-speed integrated optical circuits, high-precision sensors, and optical logic gates [5,6]. The electronic properties of graphene composition depend largely on the number of graphene layers and their effects on the substrate. In this paper, we have used single-layer graphene . Graphene generally behaves like Drude-type metals, and due to this property, it can support the stimulation of surface plasmon. The plasmon is a quantum of surface electromagnetic waves that appears at the metaldielectric interface and dampens perpendicular to the interface. Plasmons are oscillations of the free-electron plasma in the opposite direction to fixed metal ions. The collisions of waves with different angles to the metal stimulate the plasmons [7]. Thus, the light reflected from the surface of the metal is significantly reduced at certain frequencies.

In optical structures, single-layer and multi-layer graphene are commonly used. In the proposed structure, single-layer graphene was used because the graphene plasmonic effect was considered. Single-layer graphene is defined as a two-dimensional sheet of carbon atoms arranged in a hexagonal lattice. Multilayer graphene is used in structures where enhanced adsorption is intended. To produce graphene, mechanical exfoliation, graphene oxide liquid suspension with chemical reduction, liquid-phase exfoliation, solvent thermal synthesis, and isolated carbon nanotubes are used. Due to the considerable properties of graphene, many studies have recently been conducted on it to investigate its application in photonics, optoelectronics, sensors logic gates multiplexers/ demultiplexers , power splitters, and plasmonics[7,8].

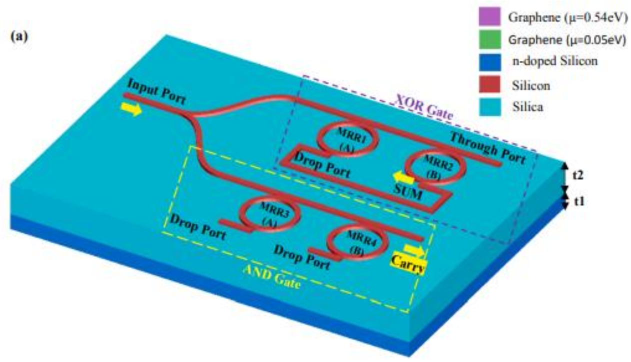
As the combination of AND and XOR gates at the operating wavelength of 1550 nm was intended, the transition curve and the time curve were investigated to analyze the transmission rate at the output ports and the speed of the logic gate, respectively. Using graphene-silicon composites, ring resonators, waveguides, and 3- dB power splitters and managing the combination of these structures, we have been able to achieve a turning point in the realization of half adder logic structures to reduce losses and prevent dispersion. In the present paper, the key parameters of logic gates including resolution, footprint, power consumption, frequency range, and operating wavelength have been analyzed and investigated. The proposed structure is very suitable for being used in integrated optical circuits due to the appropriate rate of footprint and transmit power. To optimize the output parameters of the proposed structure, the management of the interference effect between graphene and silicon and the control of the distance between the resonators and waveguides and the radius of the resonators were used [2].

II. STRUCTURE DESIGN AND THEORITICAL MODEL

One of the most important digital devices based on optics that is widely used in the design of integrated optical circuits is the half-adder. Half adder is a combinational digital circuit that adds two numbers and produces a sum (S) and carry (C) bits as the output. If A and B are the input bits, then sum bit is the XOR of A and B and carry bit will be the AND of A and B.

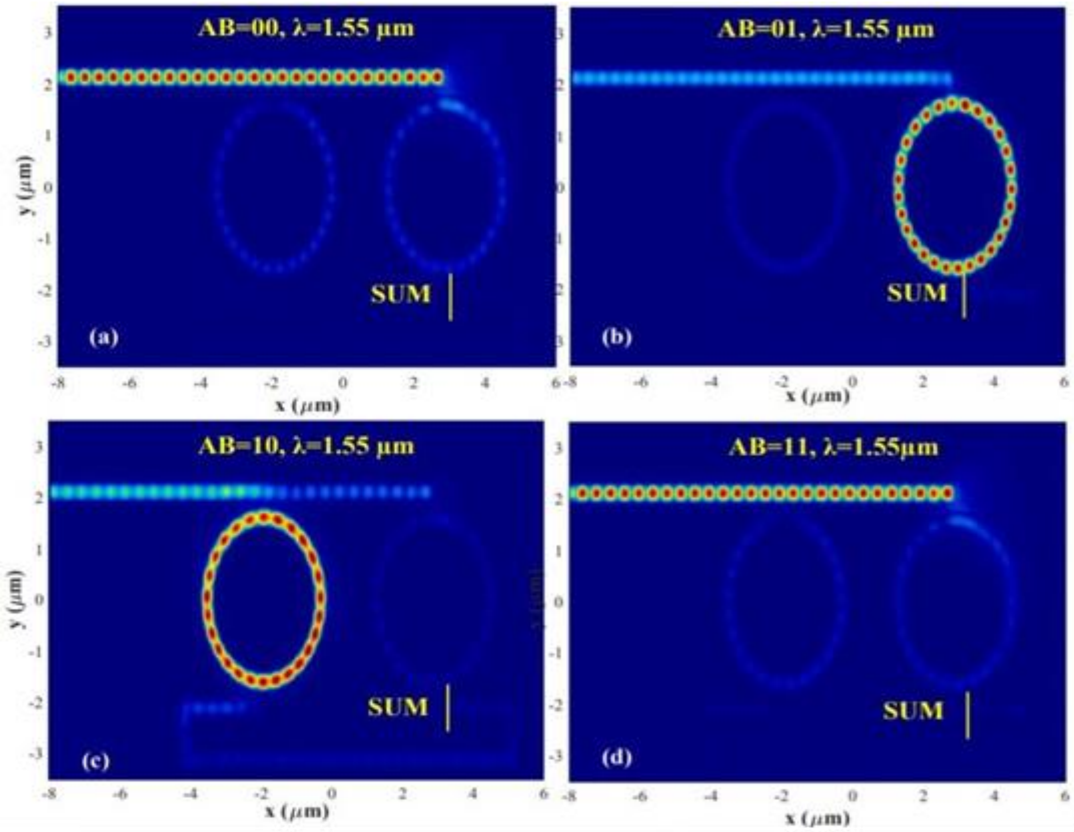


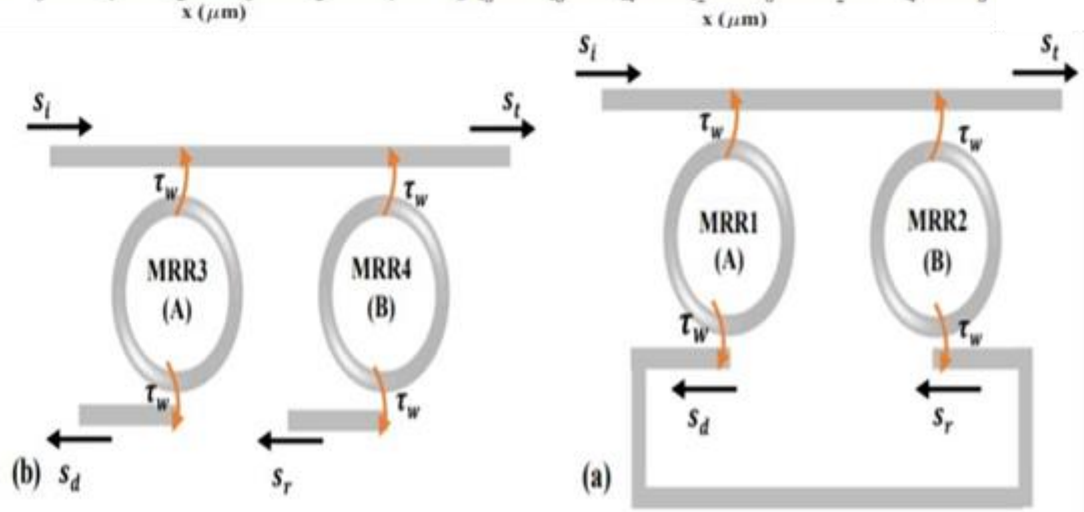
Input		Output	
A	B	Sum (S)	Carry (C)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1



The realization of integrated optical devices as a half adder gate operation using graphene/ silicon ring resonators are investigated. A three-dimensional view of the proposed structure, which is considered as the basic block diagram .The proposed structure consists of two separate sections to provide the functions of XOR and AND gates[1]. When the fundamental TM mode is injected to the structure from the input port, through a 50:50 power splitter enters the other two waveguides. The light entering the upper waveguide exits the SUM port through the lower U-shaped waveguide after causing interference in the two ring resonators A and B[3]. This part of the structure acts as an XOR gate. The light entering the lower waveguide exits the structure through the CARRY port after causing interference in the two ring resonators A and B, and this part of the structure acts as an AND gate[5,6].

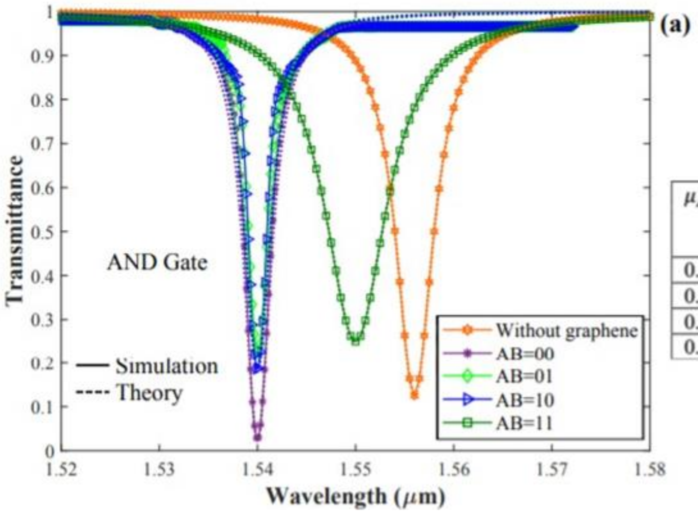
Using random phase approximation relation using Kubo formula as Eq. (1). This relation includes both interband and intraband transitions for graphene. μc is the chemical potential of graphene which here changes with the electric field tuning, Γ represents the scattering rate of particles which is equal to 5 meV, and $fd(\varepsilon) = 1/(\varepsilon - \mu c/kBT + 1)$QUOTE$fd(\varepsilon) = 1/ (\varepsilon - \mu\ kBT +1)$ shows the FermiDirac distribution. kB, ℏ, and T respectively indicate the Boltzmann constant, reduced Planck constant and temperature.


AB=00, λ=1.55 μm
AB=01, λ=1.55 μm
AB=10, λ=1.55 μm
AB=11, λ=1.55μm
SUM
(a)
(b)
(c)
(d)
x (μm)
y (μm)


s_i
s_t
τ_w
MRR3 (A)
MRR4 (B)
MRR1 (A)
MRR2 (B)
s_d
s_r
(b)
(a)

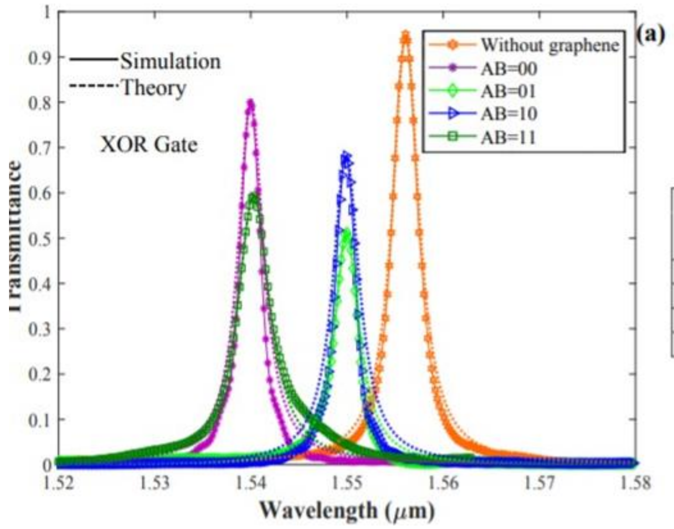
The profile of field distribution for the proposed XOR gate in different states of (a) AB = 00, (b) AB = 01, (c) AB = 10, and (d) AB = 11 at 1.55 µm wavelength[6,8].

The curve of transmission versus wavelength in both numerical and theoretical simulationsfor the XOR gate and its Truth table.



(b)

μ_A(eV)	μ_B(eV)	Carry	
		Wavelength (nm)	Digital output
0.54	0.54	1.54	0
0.54	0.05	1.54	0
0.05	0.54	1.54	0
0.05	0.05	1.55	1



(b)

μ_A(eV)	μ_B(eV)	Sum	
		Wavelength (nm)	Digital output
0.54	0.54	1.54	0
0.54	0.05	1.55	1
0.05	0.54	1.55	1
0.05	0.05	1.54	1

The curve of transmission versus wavelength in both numerical and theoretical simulationsfor the XOR gate and its Truth table.

III. RESULT

The structure proposed to design the XOR gate . A central waveguide, two identical ring resonators with inner radius R1 and outer radius R2, and a U-shaped waveguide have been used to design the structure. To tune the wavelength to be 1.55 µm and the ring circumference to be 2π/3, graphene has been placed on each of them. The chemical potential of each waveguide arm in phase has been in opposition to the chemical potential of the ring. In addition, graphene has been placed on the horizontal arm of each gate with the length LLto achieve the function of the gate. Light enters MRR1 and MRR2 through the central waveguide. On the other hand, due to the indirect coupling between the waveguides, a part of the light is coupled to the U-shaped waveguide and creates a phase shift between the resonance modes inthe rings. Changes in the level of the Fermi voltage in graphene-based plasmonic structures lead to intensified wavelength shifts .Therefore, due to the different levels of Fermi voltage in different parts of graphene, it is possible to tune the output wavelength in the SUM output.

IV. CONCLUSION

In this paper employing highly efficient techniques, the design of a three-dimensional graphene-based integrated half adder by the use of the ring resonators and central waveguides has been presented. In the proposed design, ring resonators have been made of a combination of silicon and graphene and act as a very powerful optical switch. According to the results obtained from the design, simulation, and optimization of the proposed structure, the use of both simulation and theoretical methods can be considered a basis for the analysis of optical integrated circuits and fast switching systems. By changing the Fermi voltage of graphene and tuning the desired wavelength , the state of the structure can be controlled externally. Communication systems become more fast by applications of optics into it. Half adder upon integrating graphene becomes faster as well as more efficient.

V. REFERENCES

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